A Meta Analysis of Simulation Based Learning and Instructional Support in Higher Education

Mohd Shahid Ali
School of Management, IILM University, Gurugram, Haryana, 122003.
mohmd.shahidali@gmail.com

Correspondence should be addressed to Mohd Shahid Ali : mohmd.shahidali@gmail.com

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Abstract – This meta-analysis aims to assess the impact of Simulation-Based Learning (SBL) on complex cognitive skills in higher learning institutions with data from 145 studies involving 10,532 students and published between December 1903 and March 2024. This rationale is based on research evidence collected using a problem-solving learning approach and simulation to mimic real life situations. We quantify the extent of SBL's effectiveness in developing skills across different areas of practice and to determine the moderating variables, which include the type of simulation, simulation length, instructional support, and learner attributes. The findings from the meta-study using a random-impacts model showed a positive Effect Size (ES) for overall SBL, but with significant heterogeneity. The most represented field was medical education with 126 articles, which positively influenced technical skills, overall problem-solving abilities, and diagnostic competencies. As for the interpersonal skills, there were only moderate gains in communication and teamwork skills. Instructional supports, such as knowledge conveyance and scaffolding, significantly enhanced learning outcomes, particularly when combined (e.g., knowledge conveyance with samples identified in 82 articles). We provided assurance that there was no publication bias, thus affirming the credibility of the findings. However, future research should investigate the effects of SBL over an extended period, include new technologies, and focus on the areas that are not well-represented to enhance SBL's effectiveness and achieve the greatest gains in education.

Keywords – Simulation-Based Learning, Complex Cognitive Skills, Knowledge Conveyance, Scaffolding, Problem-Solving Learning Approach, Problem-Solving Abilities, Interprofessional Teamwork Assessment Tool.

I. INTRODUCTION

Simulation-based learning (SBL) [1] provides a learning experience that closely resembles real-life practice, enabling learners to overcome the constraints of learning in actual scenarios. According to Winsberg [2], a simulation is a technology that replicates the authentic features of an event or circumstance. Asad et al. [3] proposed a more precise definition of simulation as an instructional tool or gadget that allows learners to physically engage with and imitate real-life situations. They emphasize the importance of interacting with realistic objects in this process. Simulations are considered educational tools because they allow for the modification and adjustment of certain elements of reality, which in turn enhances the process of learning and practice. For example, simulations can focus on less common events, reduce response time, and offer quick feedback to the learner. While feedback is crucial in building simulations as it provides information about the discrepancy between the present state or action and the anticipated goal state [4], there are numerous additional possibilities for instructional support. The current study is to investigate possibilities for offering supplementary information and support to the student in a comprehensive manner.

Simulation-Based Experiences (SBEs) [5] typically take place in a simulation laboratory, where undergraduate students participate in activities that are particularly designed to achieve certain learning objectives. These actions are transformed into simulation scenarios. The scenario includes the learning goal, patient details (such as background, current state, medications, and other pertinent information), actor scripts, if necessary, instructions for the high-fidelity simulator, a timeline for the scenario's progression, cues for the facilitator to guide the action, and other crucial information to ensure the success of the SBL experience. Various educational learning theories and conceptual frameworks are used to direct the creation of SBEs. SBL is an educational method that focuses on the student and is based on learning theories rooted in constructivism. Learners have the ability to construct their own perception of reality and establish their own understanding of truth. In order to facilitate this form of learning, the activities encompass dialogue, introspection, and inquiry, enabling learners to actively engage in the process of acquiring knowledge.

Complex issues, such as microworlds [6], appear to possess more ecological validity compared to other cognitive tasks, such as those utilized in traditional IQ tests [7]. Within intricate microworlds, individuals can adjust certain input factors and witness the corresponding alterations in a defined set of outcome variables. During problem-solving, individuals must acquire and apply knowledge about the intricate structure of the scenario in order to achieve their objectives. This includes constructing a representation of the problem and searching for a solution. This process involves various techniques such as reducing information, learning causality through interaction, testing hypotheses, making decisions in dynamic situations, and monitoring oneself and the task at hand. The complexity level of a task, according to cognitive load theory, mostly depends on the extent to which its components interact with each other [8]. Controlling the quantity of information items and their interactions for a learner is necessary to regulate task complexity and accommodate the restricted working memory capacity [9]. The cognitive load experienced by a student can originate from either inherent factors or external factors related to the learning process. Intrinsic cognitive load pertains to the mental effort required for processing and assimilating new knowledge, as well as the building of cognitive frameworks.

While complex tasks in SBEs may require more cognitive effort and take longer to complete, students are likely to gain a greater amount of knowledge and learning from these assignments compared to simpler ones. Complex activities present a greater difficulty in terms of reasoning and so offer a more valuable learning experience from the student's point of view. Simulations present a viable solution to address this difficulty. Internships and other field involvements are the optimal means of acquainting students with the intricate and diverse realities of engineering practice. However, these are not feasible for shorter educational programs. Even if an internship experience is accessible, it is improbable that students would have the opportunity to modify engineering procedures and directly witness the outcomes.

According to Rutten, Van Joolingen, and Van Der Veen [10] simulations can serve multiple purposes: 1) They can create a realistic setting for students and practicing engineers, giving them a credible representation of their work ecosystem. 2) Simulations can teach implicit, experimental lessons about the interconnected nature of present practices and the impact of changes. 3) They can facilitate experiential learning of transformation tools and process analysis by providing a practice field for students. 4) Simulations can also enhance student engagement and enthusiasm for the subject matter. The assumption was made that simulations would yield supplementary advantages, such as engaging non-traditional learning styles and fostering collaboration and collaborative learning. However, these benefits were not actively pursued as intentional objectives.

The aim of this paper is to present a synthesis of the literature regarding SBL in the context of higher education. It examines SBL's efficiency in fostering intricate cognitive skills, relying on research-backed problem-solving techniques and the practical usability of simulation. It measures SBL's effectiveness in terms of learning domains and establishes where simulation type, study duration, instructional support, and learner characteristics can act as a benchmark. There is substantial empirical evidence that strongly supports the efficiency of problem-solving as a learning method in higher education. Simulation can be seen as a method for applying problem-solving techniques in settings that closely resemble real-life situations. Empirical data supports the use of simulation in medical and nursing education to enhance learning. Consistent with other studies, we anticipate significant impacts of SBL on the acquisition of intricate abilities.

RQ 1: How effective are SBL environments in fostering the acquisition of advanced cognitive abilities in higher education?

RQ 2: Can the impacts of SBL and scaffolding be applied to many complex skills?

The rest of the article has been organized as follows: Section II provides a literature review of SBL, which includes its definition, and effective implementation. Section III presents the methodology employed in literature search and selection of articles. In addition, the section highlights the methodology for data extraction, as well as meta-analysis procedures. The findings of the literature search have been discussed in Section IV and V providing a detailed understanding of preliminary analysis, quantitative assessment, and the general impact of SBL on complex skills. Lastly, Section VI summarizes the findings obtained in the results sections.

II. RELATED WORKS

According to Hallinger et al. [11], Husebø et al. [12], Walton et al. [13], and Rajaguru et al. [14], Simulation-Based Learning (SBL) is the utilization of simulations for the goal of learning. In this section, we provide relevant definitions for the two components of this phrase, namely 'learning' and 'simulation'. Learning is a multifaceted subject, as seen by the diverse range of topics included in the current encyclopedia. Kinshuk et al. [15], Rodrigues et al. [16], and Zhu et al. [17] adopt a comprehensive definition, where learning is described as the process of acquiring or improving information and abilities, encompassing cognitive, physical, social, and other aspects. Simulations have been employed throughout numerous scientific fields, resulting in a range of definitions that often reflect the unique influences and considerations of each subject. For example, certain scholars propose that simulations are inherently linked to computers. Simulations have existed long before the advent of the Computer Age. In fact, the ancient Chinese game of Go (also known as Weiqi) can be considered a form of military simulation to some degree.

Holzinger et al. [18], Alinier et al. [19], Lamb et al. [20], and Dunleavy et al. [21] argue that the main objective of simulations is to facilitate learning. While the current item focuses on simulations for educational reasons, it will be demonstrated later that simulations with different goals can also indirectly promote learning, serving as illustrative elements, for example. It would be insufficient to use a definition that does not take into account the educational value of simulations that try to provide theoretical evidence or depict natural occurrences, to name only a few samples. Nadaraya [22], and Brooks et al. [23] provides an intriguing contribution towards establishing a comprehensive definition of simulation. He asserts that a simulation replicates one process through another process. An essential component of this description is the temporal nature of simulations, as the processes they allude to are seen as elements that change and develop over time.

According to Cooper et al. [24], and Vlachopoulos et al. [25], simulation environments facilitate a novel approach to learning, defined by interactive and adaptive experiences. Physicians are capable of performing cardiac surgery, whereas pilots have the ability to safely land airplanes even in the event of engine failure. Students get the opportunity to engage with simulated characters in order to gain expertise in dealing with emotionally challenging circumstances. Considering the growing acceptance and extensive utilization of replications for educational purposes, it is logical to contemplate employing simulation settings for valuation as well. Currently, there are various simulations in operation, including the Primum computer-based replicated patient challenges in Step 3 of the United States Medical Licensing Examination [26]-[30]. The transition from a simulation to a SBL is a challenging process. In order to create a legitimate simulation-based assessment, it is essential to incorporate ideas and methods from assessment design and psychometrics, despite the significant overlap in content and technology [31]-[33]. An indispensable asset for creating a design that effectively fulfills the assessment's objectives is a collaborative design framework that allows each team member to understand how their expertise complements that of others. This article outlines a specific framework called Evidence Centered Design (ECD) [34]. The vocabulary and representations provided by ECD assist assessment designers in many projects involving multiple domains, task kinds, and objectives [35]-[39]. Specifically, ECD has been found to be valuable as the design model for simulation-based evaluations, such as science study in virtual worlds, computer network engineering, and problem solving in dental hygiene.

In reference to Bechard et al. [40], Franklin et al. [41], and Khalil et al. [42] the learning outcomes of SBL align with the key capabilities outlined by the American College of Nurse-Midwives (ACNM). Proficient teamwork and communication with fellow members of the healthcare team are distinguishing characteristics of midwifery [43]-[46]. Engaging in activities that guarantee and authenticate high-quality practice are among the professional duties of Certified Midwives (CMs) and Certified Nurse-Midwives (CNMs) [47]-[50]. Proficiently employing strategies to handle emergency complications and atypical intrapartum occurrences is an integral feature of midwifery treatment [51]-[53]. Simulation-based learning can help with the initial acquisition and ongoing maintenance of these fundamental skills. Simulation-based learning is an example of a constructivist learning technique that encourages long-lasting retention, comprehension, and the practical application of knowledge and skills. These are exactly the types of learning outcomes that are essential for midwifery education. SBL is a suitable approach for adult learners and caters to a variety of learner requirements. Simulation-based learning can effectively meet essential learning requirements that are inadequately addressed by conventional clinical and didactic education techniques.

To effectively implement SBL, Horns et al. [54], Chernikova et al. [55], and Topping et al. [56] recommend doing more than just buy simulation equipment. SBL ought to be incorporated within the CNM/CM curriculum. SBL programs can be created using the same methodical evaluation of learner requirements, establishment of learning goals, organization of learning activities, and assessment of course, individual, and program results that defines approved midwifery education. Implementing a simulation-based method in instructional nursing sessions [57]-[60] led to a notable reduction in the observed frequency of medication management errors, and this improvement was maintained for a period of 2-3 months. However, the decrease in errors was not observed when the same content was delivered through a conventional didactic lecture. The conclusive post-intervention assessment of the MICU revealed a rise in mistakes, with an unknown underlying cause. The error rates detected in this study align with the reported rates seen in other investigations, ranging from 3.3% to 44.6% [61]-[64]. Research has shown that using advanced, realistic teaching approaches that mimic real-life situations can lead to better educational results [65]-[69]. The results of our study indicate a positive impact on clinical outcomes, including a decrease in medication errors.

While the value of simulation-based education is well recognized, it is not prevalent in medical education in Japan. Several factors contribute to the limited prevalence of simulation-based education in Japan [70]-[72]. The key reasons are attributed to the scarcity of mannequins, insufficient financing, and inadequate full-time staff. Nevertheless, the lack of desire among teachers in regards to simulation-based teaching is regarded as a more significant factor [73]-[75]. Approximately 81% of medical schools in Japan have skills laboratories dedicated to simulation-based education [76]-[79]. Approximately 83% incorporate them into their standard instructional curriculum [80]-[82].

Nevertheless, over half of the medical schools that incorporate skills labs training into their normal curriculum allocate less than 20 hours per year to simulation-based education. at order to enhance simulation-based education at our country's medical schools, it would be beneficial to implement successful systems from medical schools abroad [83]-[86]. The educational method of role play models is efficacious for students to acquire clinical skills in simulated scenarios that closely resemble actual patient interactions. The utilization of the skills laboratory by students should prove beneficial in addressing the shortage of permanent staff. The utilization of animal resources allows for the development of clinical skills training systems that closely simulate situations seen in the human body.

Simulation-based learning [87]-[90] has become a focal point for researchers and instructional designers that are interested in creating effective learning experiences for professional training and higher education in several fields [91]-[93]. Authors in [94]-[96] seeks to bring together study on the design, utilization, and efficacy of SBL. It presents nine contributions that assess and evaluate SBL in vocational education [97]-[99], professional training, and higher education

[100]-[102] across various fields such as medical education [103]-[105], marine navigation, mountain rescue, automotive mechatronics, political decision-making, and business informatics [106]-[108]. Through the adoption of a broader viewpoint in educational assessment, research on the efficacy of SBL can provide valuable insights into the interaction among learner attributes, learning outcomes, learning processes, and simulation context and design [109]-[111]. This level of comprehensiveness will provide significant benefits for enhancing the design and execution of simulations, particularly in situations that require the acquisition of intricate skills, such as professional training and higher education. Therefore, scholars in [112]-[114] utilize the concept proposed by Schomburg [115], López-García et al. [116], and Lee and Chan [117] to establish a connection between the findings given in this issue and the 3P-model.

III. METHODOLOGY

This research adopts the meta-analytic analysis technique for evaluating the effectiveness of SBL in improving the mastery of complex cognitive learning skills in the higher learning institutions. It includes the analysis, collection, and interpretation of data and segmented as follows:

Literature Search and Selection Criteria

A detailed search was made using the electronic databases such as PubMed, ERIC, and PsycINFO with articles published between December 1903 and March 2024. Search terms employed in the identification of literature included; 'simulation-based learning', 'complex cognitive skills', 'domains' such as medical education, teacher education among others. This search strategy was employed to make sure that there was a proper and efficient identification of studies that would meet the insertion criteria of this meta-study. Studies were encompassed if they met the following criteria: Specific criteria include: (1) Emphasize simulation-based learning interventions for the improvement of sophisticated cognitive abilities, (2) Document the extent and growth of skills quantitatively as the major outcome indicators, (3) Published in at least an international peer-reviewed scientific journal or an international conference, and (4) Contain enough data in terms of Effect Size (ES) and clear descriptions of the instructional support measures used in the simulation environment. According to these criteria, 145 articles were considered for this review and meta-synthesis, involving 10,532 participants across different educational fields; however, the largest part of the studies (126) concerned medical education.

Data Extraction

Data extraction meant that the authors of the present systematic review and meta-analysis conducted a structured abstraction of information from each of the qualifying study to identify the effect-size estimates (g) and other related moderator variables. Cohen's Measures of Effect Sizes (ESs) were used whereby the alterations among the control and experimental groups were computed and subsequently standardized based on the sample means and SDs. This process helped maintain the reliability and validity in identifying the quantitative results presented in the primary studies, which are crucial in comparing and aggregating data in various educational environments and simulation scenarios.

Meta-Analytic Procedures

Calculation of ESs

In Eq. (1) The measure of the size of the treatment effect, g, is employed in meta-analysis to contrast the size of the differences between the control and experimental groups. It addresses issues of heterogeneity in terms of the sample size and standard deviation across the studies thus facilitating the comparison of the results on a common measure.

$$\mathrm{g} = \frac{\mathrm{X_{exp}} - \mathrm{X_{con}}}{\mathrm{s_p}} \tag{1}$$

$$S_p = \sqrt{\frac{(n_{exp}-1)s_{exp}^2 + (n_{con}-1)s_{con}^2}{n_{exp}+n_{con}-2}} \tag{2}$$

where $\bar{X}_{exp}$ and $\bar{X}_{com}$ represents the mean score of the control group and experimental group, respectively. In Eq. (2), S_p denotes the pooled standard deviation. In Eq. (3), meta-regression is used to explore the influence of moderator variables on ESs across studies. It allows for the examination of how categorical and continuous variables (moderators) affect the overall relationship between SBL and complex cognitive skill development.

$$gij = \beta_0 + \beta_1 X_{ij1} + \beta_2 X_{ij2} + \cdots + \beta_p X_{ijp} + \epsilon ij \tag{3}$$

where g_{ij} represent the ES for research i and moderator j. $X_{ij1}, X_{ij2} \ldots\ldots, X_{ijp}$ are the moderator variables, $\beta_0, \beta_1, \ldots. \beta_p$ are regression co-efficient and is the error term.

Subgroup and Sensitivity Analysis

Subgroup analysis in Eq. (4) and Eq. (5) categorizes studies into subsets based on predefined characteristics to explore variations in ESs across different conditions or contexts.

$$gk = \frac{\sum_{i \epsilon k} w_i g_i}{\sum_{i \epsilon k} w_i} \tag{4}$$

$$g_{adjusted} = \frac{\sum_{i=1}^{n} w_i g_i + \sum_{j=1}^{m} w_j g_j^{imputed}}{\sum_{i-1}^{n} w_i + \sum_{j-1}^{m} w_j} \tag{5}$$

where $\boldsymbol{g_i}$ is the ES of study $\boldsymbol{i}$, $\boldsymbol{g_j^{adjusted}}$ is the imputed ES of research and $\boldsymbol{w_i}$ represents the weight of research i in the meta-analysis. Sensitivity analysis evaluates the robustness of meta-analytic results by testing the impact of excluding studies with potential biases or outliers. The trim-fill method adjusts for publication bias by imputing potentially missing studies to estimate an unbiased ES.

IV. RESULTS

Results of Literature Search

The analysis included a total of 145 research that met the eligibility criteria. These studies were derived from 128 papers published between 1979 and 2024. In all, there were 409 effect estimations obtained from these investigations. The whole sample size was 10,532 people. The majority of the research, specifically 126, are focused on medical education. Teacher education is signified by seven separate studies, while other fields are covered by 12 independent studies. The majority of studies primarily examined general problem-solving abilities (51) or the mechanical proficiency of a specific complex technique (47). Other areas of interest included diagnosing (8), communication skills (24), managing crucial circumstances (10), and teamwork and collaboration (5). Several studies have indicated multiple complicated skills as learning results.

During initial search, there were 409 instances of SBL, where only 270 provid0ed comprehensive data without any missing codes regarding the instructional assistance methods employed in the simulation. 12% of treatments did not include any further instructional support, but 25% of simulations were accompanied with information conveyance, such as lectures or other expository types of education. It is important to mention that a few simulations exclusively utilized a particular form of scaffolding where only 6% of the participants utilized instances without any extra supporting measures, while 3% incorporated simulations along with induced reflection periods. Additionally, less than 1% relied exclusively on prompts meant to support simulations. The most common mixtures of investigative support actions were the conveyance of knowledge along with samples (82 occurrences), the use of samples with reflection phases (43 occurrences), and the conveyance of knowledge with reflection phases (62 occurrences).

Nevertheless, the study revealed a significant quantity of missing information, showing that the investigative assistance measurements were not clearly or adequately described in the treatment descriptions of the original investigations. In addition, nearly all of the studies included in the analysis reported feedback that contestants got from the studying ecosystem or teacher during or after the simulation. However, this feedback was not specifically coded and was therefore not the main focus of the present study.

Preliminary Analysis and Quality Assessment

There was no indication of publication bias or dubious research practices found using the methods used to appraise the quality of data from primary studies, such as analyzing the symmetry of the funnel plot and the relationship between Effect Size (ES) and Standard Error (SE). This is supported by the findings in **Fig 1** and **Table 1**, which demonstrate the generalizability of the moderator and summary impacts observed in the meta-study. The meta-regression assessment of control variables (including study design, domain, year of publication, type of control, and publication type) revealed that these conditions do not account for any statistically substantial variation in study effects (with p-values over .05).

Table 1. Impact of Simulation Characteristics, Instructional Support, and Literature on the Acquisition of Complex Abilities

Summary impact (random impact model)	***p* of *Q***	***Q (p)***	***g***	**95% CI**	***N (k)***	**τ^2**	**I^2**	***EV (N)***
Simulation vs. controls	<.001	4213.93	0.85	[0.69, 1.02]	10,532 (145)	1.21	95.86%	1 (98)
	Implication of moderators			**ES**		**Heterogeneity**		**Quality evaluation**
Moderating variables	***p* of *Q***	***Q***	***g***	**95% CI**	***n(k)***	**τ^2**	**I^2**	***EV(N)***
Complex skills	<.001	167.61						
Communication skills			0.44	[0.17, 0.72]	2,493 (27)	0.46	91.03%	1 (17)

Diagnostic skills			0.82	[0.41, 1.22]	911 (18)	0.76	92.02%	1 (14)
General Problem solving			0.88	[0.68, 1.08]	6,010 (58)	0.47	91.23%	1 (39)
Management of situation			0.72	[0.14, 1.31]	2,543 (21)	1.04	97.15%	1 (14)
Teamwork/skills			0.50	[0.32, 0.68]	810 (5)	0.03	66.07%	1 (3)
Technical performance			1.06	[0.75, 1.37]	2,933 (63)	1.25	91.10%	1 (43)
Simulation features								
Simulation type	<.001	852.62						
Documents			0.31	[0.07, 0.56]	847 (15)	0.30	82.60%	1 (7)
Virtual objects			0.75	[0.47, 1.03]	3,199 (45)	0.80	95.49%	1 (32)
Role play			0.63	[0.38, 0.89]	1,934 (26)	0.35	87.02%	1 (20)
Mixed (more than one type)			1.56	[0.90, 2.22]	936 (13)	1.18	95.98%	1 (13)
Live model (medical only)			2.27	[1.67, 2.86]	108 (3)	0.08	18.56%	1 (3)
Mannequin (medical only)			0.96	[0.60, 1.31]	3,015 (30)	1.10	94.41%	1 (22)
Model (medical only)			0.79	[0.33, 1.26]	589 (18)	0.81	87.56%	1 (9)
No			0.74	[0.53, 0.96]	4,895 (54)	0.58	91.16%	1 (39)
Computer-supported			0.68	[0.40, 0.97]	2,578 (43)	0.68	91.67%	1 (24)
Simulator (medical only)			1.07	[0.66, 1.47]	1,312 (26)	1.26	94.19%	1 (21)
Virtual reality			0.85	[0.31, 1.39]	1,377 (20)	1.25	97.67%	1 (17)
Simulation duration	<.001	439.42						
Very short (up to 1 hour)			0.65	[0.19, 1.10]	2,210 (26)	1.27	97.22%	1 (17)
Short (up to 1 day)			0.81	[0.65, 0.97]	5,496 (87)	0.62	89.16%	1 (61)
Medium (up to 1 month)			0.80	[0.54, 1.07]	459 (11)	0.13	59.62%	1 (9)
Longe (exceeding 1 month)			1.30	[0.00, 2.63]	518 (4)	1.36	91.12%	1 (3)
Authenticity	<.001	265.57						
Lower			0.58	[0.28, 0.88]	1,598 (26)	0.58	89.57%	1 (15)
Selected			0.69	[0.00, 1.41]	268 (6)	1.04	89.12%	1 (5)
Higher			0.85	[0.64, 1.06]	6,163 (76)	0.82	95.20	1 (56)
Instructional support								
Knowledge conveys	<.001	32.12						
Available			0.87	[0.69, 1.05]	7,925 (98)	0.71	93.95%	1 (75)
Not available			0.72	[0.33, 1.10]	2,323 (46)	1.29	93.15%	1 (30)
Scaffolding	<.001	237.91						
No scaffolding			0.88	[0.64, 1.12]	4,824 (58)	0.68	92.66%	1 (42)

Samples only			0.66	[0.22, 1.10]	1,046 (27)	1.67	93.04%	1 (17)
Prompts only			0.44 ns	[−0.18, 1.07]	554 (11)	1.18	90.94%	1 (4)
Samples + Prompts			1.60	[0.87, 2.34]	187 (4)	0.11	30.85%	1 (4)
Samples + Reflection			0.95	[0.36, 1.54]	1,677 (15)	1.11	97.98%	1 (12)
Prompts + Reflection			0.10 ns	[−0.27, 0.48]	634 (8)	0.21	73.53%	0 (3)
All combined			1.34 ns	[−0.33, 3.02]	90 (2)	1.29	87.37%	Not applicable
Samples present			0.88	[0.54, 1.21]	3,202 (44)	1.33	96.39%	1 (31)
Samples not present			0.81	[0.65, 0.97]	8,312 (101)	0.61	91.88%	1 (87)
Prompts present			0.65	[0.20, 1.10]	1,604 (25)	0.98	90.04%	1 (13)
Prompts not present			0.92	[0.73, 1.10]	8,747 (121)	0.87	94.71%	1 (95)
Reflection phases present			0.78	[0.46, 1.10]	3,210 (39)	0.74	95.46%	1 (29)
No reflection stages			0.81	[0.58, 1.05]	5,299 (81)	1.13	93.82	1 (55)
Previous knowledge								
Familiarity of context	<.001	614.32						
Unfamiliar (low prior knowledge)			0.67	[0.40, 0.94]	5,938 (61)	1.08	96.09%	1 (44)
Familiar (high prior knowledge)			0.83	[0.65, 1.02]	2,511 (63)	0.50	86.05%	1 (48)
Mixed group			1.21	[0.50, 1.93]	1,227 (15)	1.16	97.34%	1 (12)
Level of education	<.001	329.58						
Low (graduate and undergraduate)			0.74	[0.54, 0.94]	7,143 (74)	0.71	94.66%	1 (56)
High (in-service and postgraduate)			0.91	[0.67, 1.16]	3,400 (72)	0.94	93.16%	1 (55)
Familiar context								
Samples			0.85	[0.55, 1.15]	880 (21)	0.63	86.51%	1 (17)
Prompts			0.33 ns	[−0.40, 1.07]	330 (7)	0.37	76.49%	1 (3)
Reflection phases			0.74	[0.48, 1.00]	778 (19)	0.19	71.41%	1 (14)
Unfamiliar context								
Samples			0.71	[0.15, 1.27]	1,993 (19)	1.45	97.82%	1 (17)
Prompts			0.85	[0.19, 1.50]	1,091 (15)	1.39	92.59%	1 (9)
Reflection phases			0.49	[0.17, 0.81]	2,017 (18)	0.37	94.11%	1 (11)
Low level of training								
Samples			0.87	[0.41, 1.34]	1,688 (18)	0.93	97.28%	1 (16)
Prompts			0.74	[0.08, 1.39]	1,011 (17)	1.08	92.11%	1 (8)
Reflection phases			0.52	[0.23, 0.80]	2271 (21)	0.37	93.79%	1 (15)

High level of education						
Samples	0.85	[0.38, 1.32]	1,120 (26)	1.59	93.22%	1 (18)
Prompts	0.50 ns	[−0.08, 1.08]	346 (9)	0.83	84.19%	1 (3)
Reflection phases	1.10	[0.52, 1.68]	763 (18)	0.92	91.42%	1 (13)

Overall Impacts of SBL on Complex Skills

In relation to RQ 1 and 2, SBL had a significant and beneficial impact on developing complex skills when compared to three different aspects: (1) no involvement (waiting control: SE = 0.30, g = 1.02, N = 16); (2) a control group with different instructions (SE = 0.13, g = 0.82, N = 53); and (3) a baseline group (SE = 0.10, g = 0.88, N = 76). Since there were no statistically substantial differences seen among the 3 control circumstances, the overall impact was calculated to be g = 0.85, with a SE 11of 0.08, based on a sample size (N) of 145.

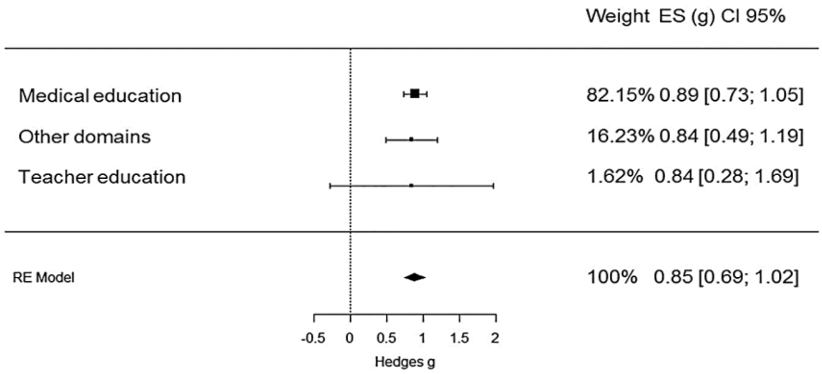

Fig 1. Impact of Simulations on the Advancement of Intricate Abilities Across Several Fields

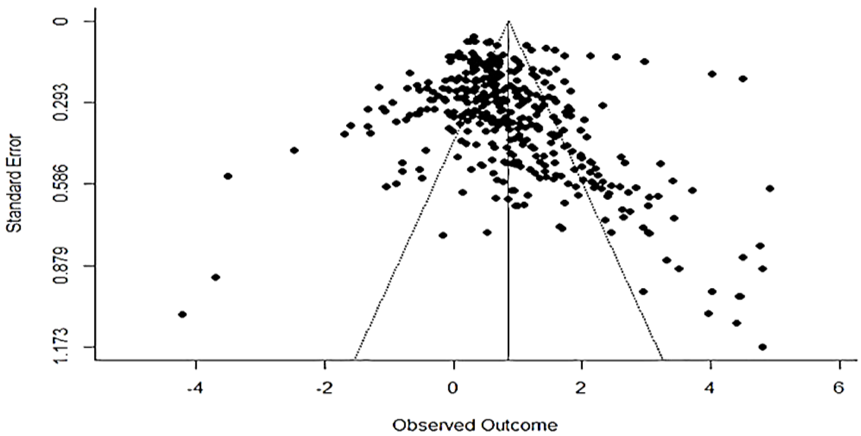

Fig 2. A Funnel Diagram of the Replication Impact on the Development of Complex Abilities

As anticipated, the study also detected significant heterogeneity among the studies: The value of Q is 4213.93 with a p-value less than .0001. Additionally, τ^2 is equal to 1.2 and I^2 is equal to 95.86%. The observed variability could not be accounted for by the control factors, including study design, domain, year of publication, type of control, and publication type. The ESs, weights, confidence intervals, and summary impact from random impacts model assessment are displayed in **Fig 1**. **Fig 2** displays a funnel diagram illustrating the distribution of standard errors and ESs. The use of SBL has a moderate effect on improving communication and collaboration skills (teamwork) with an ES of 0.44 (SE = 0.15) and 0.50 (SE = 0.08) respectively. Simulation-based learning has a higher effect on situation management (SE = 0.30; ES = 0.72,), problem-solving (SE = 0.11; ES = 0.88), and diagnostic competencies (SE = 0.21; ES = 0.82). The key reported effects of replications are seen in improving technical display with an ES of 1.06 (SE = 0.15). The quantity of studies in each category is provided in **Table 1**.

V. DISCUSSION

Learning is a dynamic procedure in which students create their own understanding according to their prior knowledge and through the development, and transformation of their personal experiences [118]-[120]. However, pupils frequently possess numerous contradictory perspectives prior to acquiring new information and construct their collection of opinions without contemplating their preexisting knowledge [121]-[123]. Students' prior knowledge functions as a framework for integrating new knowledge, as the new information is processed and understood in relation to their previous knowledge. Hence, the preexisting knowledge of pupils plays a crucial role in comprehending novel material. Comprehension is closely linked to the development of a unified conceptual framework [124]-[126].

The study did a meta-analysis that examined the vast amount of research on simulation-based learning (SBL) to evaluate its influence on the acquisition of complicated abilities in different fields. A complex cognitive talent is comprised of multiple closely interconnected constituent abilities that demonstrate distinct variations in performance; certain constituent skills necessitate conscious thinking, and all of them display behaviors that are aimed towards achieving specific goals. When it comes to the intended way of leaving, we can distinguish between non-recurrent and recurrent constituent skills. The utilization of non-recurring constituent abilities differs depending on the specific activity, whereas recurring constituent skills can be applied uniformly across multiple activities. When it comes to the intricate cognitive ability of troubleshooting in an alcohol-water distillery, abilities that include thinking about the operation of the distillery utilizing its underlying principles are classified as non-recurrent skills.

Recurrent skills, such as those related to system operation procedures and safety protocols, are of concern [127]. Acquiring abilities that are not repeated demands the development of intricate mental frameworks that can influence how we approach and solve future problems [128]-[130]. Schema creation is the deliberate process of creating abstract concepts based on specific experiences [131]. Acquiring expertise in repetitive activities necessitates the mechanization of schemata, which are specialized rules or methods peculiar to a certain field. The automation of schema primarily depends on the quantity and quality of practice. Our extensive analysis of 145 studies conducted between 1979 and 2024, which included 10,532 participants, confirms that SBL has a significant and beneficial impact on skill development. This study affirms that SBL is effective in both educational and professional settings.

The research we conducted showed that there is a large amount of diversity in the reported effects of SBL. This variation is driven by the measures of instructional support used and the individual abilities that are examined. The success of SBL is greatly influenced by the inclusion of instructional support, namely through the use of strategies like knowledge conveyance and scaffolding, which involve the use of samples and reflection phases. Scaffolding concept is based on the research of Vygotsky (1978) [132], although the term was initially introduced in Wood, Bruner, and Ross (1976) [133]-[135]. In the field of education, scaffolding refers to a metaphorical structure that is implemented to assist learners in achieving their objectives. This structure is gradually dismantled as it becomes unnecessary, similar to how a physical scaffold is erected around a building during its construction and taken down as the project approaches its final stages. While some people believe that the metaphor of providing support during learning that can be removed as the learner no longer needs it is appropriate, Benko [136] argue that it is an unfortunate metaphor. Carroll and Thomas [137] believe that it implies guiding and teaching the learner towards a specific end, which is teacher-centered. However, in reality, scaffolding is an approach that focuses on the student and its effectiveness relies on its capacity to adjust to the learner's specific needs. In a learning context, scaffolding [138] goes beyond just a mere physical support. It involves assisting students in acquiring knowledge of concepts, procedures, strategies, and metacognitive skills [139].

Simulations that included thorough instructional support regularly showed greater effectiveness in improving technical skills and problem-solving abilities compared to simulations that did not have such support [140]. Notably, although communication and collaboration abilities were also enhanced by SBL, the degree of change was rather small, suggesting the need for additional improvements in instructional design. This implies that although SBL has potential in developing interpersonal and teamwork skills, it may require additional methods and resources, such as the Simulation-Based Interprofessional Teamwork Assessment Tool (SITAT) [141], to maximize its effectiveness in these areas. This technology intends to address deficiencies in simulation-based education by offering personalized evaluation of team members through a limited number of tasks to be carried out by an observer. The SITAT offers the opportunity to explore various unexplored research inquiries regarding interprofessional education (IPE) training on a global scale, identify distinct behavioral patterns among students in different specialties, and potentially inspire faculty to create and customize IPE [142] curricula to meet the specific training requirements of individual students.

Our meta-regression analysis, which investigated the impact of different methodological factors such as study design and publication type, did not find any significant ability to explain the variation in ESs. This emphasizes the necessity for future research to thoroughly investigate the intricate connections among instructional assistance techniques, simulation attributes, and skill results. Brydges et al. [143] conducted a systematic analysis of simulation literature and discovered a substantial correlation among the amount of time spent practicing on advanced medical simulators and the achievement of standardized learning outcomes. Further research is needed to establish the same effect on a “lower-fidelity simulator”. While the frequency of performing an operation, whether in a clinical setting or on a simulator, is linked to progress towards a performance standard, it is insufficient to solely rely on repetition as a measure of competence [144]. The precise number of iterations required to attain proficiency in procedures is not explicitly specified, but it is likely to differ among persons and procedures. Simulation models have become increasingly complex (as well as more expensive) without undergoing necessary validation procedures. The specific methods that should be taught on animal models instead of simulators are still unknown. The design and utilization of a simulator model should be guided by well-defined performance targets, outcomes, or benchmarks for each level of learner.

Although our findings are strong, it is important to recognize numerous limitations. The existence of incomplete or insufficiently thorough data in certain primary studies on the deployment of instructional support measures highlights the significance of consistent reporting standards in SBL research. In addition, although we implemented stringent inclusion criteria to minimize biases such as publication bias, it is possible that intrinsic biases present in the individual studies may have impacted our overall findings. In the future, there is a need to make use of the emerging technologies such as artificial intelligence and virtual reality in enhancing the realism and efficiency of SBL settings. Longitudinal surveys, in an attempt to establish the extent to which skills gained from SBL are retained and portable in different workplaces, will provide valuable data on its long-term impact on workforce capability and output.

VI. CONCLUSION

This meta-analysis of simulation-based learning (SBL) in higher educational institutions reveals a fairly extensive body of research in the application of higher forms of thinking in various disciplines such as medicine. The results of this study indicate that on average, SBL has a positive impact with a likelihood of being a powerful educative interference more than the traditional modes of instructions. Some of the benchmarks that were developed included Simulation type, Period of Simulation, Degree of instruction support such as scaffolding and feedback among others. The results of the analyzed studies show a certain variation but the majority of them show the efficiency of SBL that can be explained by the fact that this approach is quite sensitive to the characteristics of the teaching and learning processes and the learning outcomes. The quality assessment and sensitivity analysis support these findings and form the premise of the conclusion by highlighting the sources of bias and difference in the methodology used. Hence, more research should be directed towards the question of the extent to which SBL is as effective in the long-term and the effects it has on real-world performance and long-term knowledge retention of complex skills. Furthermore, it is worth examining other potentially useful and not very explored technologies like virtual or augmented reality used in SBL to find deeper reasons for increasing its effectiveness.

CRediT Author Statement

The author reviewed the results and approved the final version of the manuscript.

Data Availability

No data was used to support this study.

Conflicts of Interests

The author declares that they have no conflicts of interest.

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Competing Interests

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