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Original Research Article

Effectiveness of a Structured Self-Directed Learning Activity in Biochemistry Among Phase I MBBS Students: A Pre–Post Educational Intervention Study

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Abstract

Background: Self-directed learning (SDL) is an essential component of competency-based medical education and lifelong professional development. However, Phase I MBBS students may lack the readiness and skills required for independent learning. This study implemented a structured SDL activity in biochemistry and evaluated its influence on knowledge acquisition, retention and students' perceptions.

Methods: This prospective, single-group, pre-test–post-test educational intervention included 99 Phase I MBBS students. A structured SDL activity on the biochemical basis, diagnosis and complications of diabetes mellitus was conducted through sensitisation, identification of learning needs, guided resource exploration, small-group presentations, peer discussion and faculty feedback. Knowledge was assessed using a validated 20-item questionnaire before, immediately after and four weeks after the intervention. Students' perceptions were recorded using a five-point Likert-scale questionnaire. Repeated-measures analysis of variance, paired and independent Student's *t*-tests, and McNemar's test were applied.

Results: Mean knowledge scores increased from 9.12 ± 2.46 at baseline to 15.07 ± 2.18 immediately after SDL and remained elevated at 13.84 ± 2.31 after four weeks ($F[2,196]=357.8$; $p<0.001$). Satisfactory performance increased from 18 (18.2%) before the activity to 89 (89.9%) immediately afterwards and was retained by 77 (77.8%) students at four weeks. Significant improvement occurred in biochemical concepts, clinical application and laboratory interpretation (all $p<0.001$). Most students considered the activity clinically relevant (93.9%), well facilitated (91.9%) and engaging (86.9%); however, 65.7% perceived it as time-consuming. Regular users of online academic resources demonstrated greater knowledge gain than non-regular users (6.31 ± 1.96 versus 5.38 ± 2.15; $p=0.033$).

Conclusion: Structured, faculty-facilitated SDL significantly improved knowledge acquisition and short-term retention among Phase I MBBS students. Its progressive integration with clinical contextualisation, digital-literacy support and formative assessment may strengthen learner autonomy and lifelong-learning skills.

Keywords: Biochemistry; Competency-Based Medical Education; Lifelong Learning; Medical Students; Self-Directed Learning; Undergraduate Medical Education.

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Introduction

Medical education is shifting from teacher-centred instruction towards competency-based, learner-centred training. Because biomedical knowledge continues to expand, undergraduate education cannot provide all the information required throughout a physician's career. Medical students must therefore learn to identify their learning needs, locate and critically appraise information, apply knowledge, and evaluate their progress—abilities essential for lifelong professional learning [1,2].

Knowles defined self-directed learning (SDL) as a process in which learners diagnose their learning needs, formulate objectives, identify resources, select appropriate strategies, and evaluate learning outcomes, with or without assistance [3]. SDL does not mean unsupported study; faculty members act as facilitators by providing orientation, resources, feedback, and academic guidance. Successful SDL requires motivation, self-discipline, time management, critical appraisal, reflection, and self-assessment [4].

The National Medical Commission's Competency-Based Medical Education curriculum recognises SDL as an essential teaching–learning method. The revised curriculum allocates 10 hours of SDL within the 249 teaching–learning hours prescribed for Phase I biochemistry [5]. Biochemistry is particularly suitable for SDL because students must integrate complex concepts involving metabolism, molecular biology, nutrition, laboratory investigations, and disease mechanisms. Clinically oriented SDL activities may improve conceptual understanding, knowledge application, problem-solving, collaboration, and communication.

A systematic review of 59 studies involving 8,011 health-professions learners found SDL moderately more effective than traditional teaching for knowledge acquisition, particularly when learners had relevant prior knowledge [6]. Indian studies have also demonstrated improved learning outcomes following SDL activities [7,8]. In one biochemistry study, 92% of students reported improved understanding, 87% recognised their learning strengths and weaknesses, and 86% found SDL engaging [8]. However, inadequate readiness, difficulty identifying reliable resources, poor time management, and insufficient faculty guidance remain important barriers [8–10].

Phase I students often enter medical college from teacher-dependent educational environments and may require structured orientation and facilitation before assuming responsibility for learning. Therefore, this study implemented a structured SDL activity in biochemistry and evaluated its influence on students' learning outcomes and perceptions.

Materials and Methods

Study Design and Setting: A prospective, single-group, pre-test–post-test educational interventional study was conducted in the Department of Biochemistry at Medical College in India, during the academic year [2024–2025]. The study was undertaken among Phase I MBBS students after completion of their initial orientation to competency-based medical education. The intervention consisted of a structured, faculty-facilitated self-directed learning (SDL) activity followed by assessment of knowledge acquisition, knowledge retention, SDL-related competencies, and students' perceptions. The study was reported according to accepted principles for educational intervention studies.

Study Participants: All Phase I MBBS students enrolled during the study period and attending the selected biochemistry teaching module were invited to participate. Students who provided written informed consent and completed the pre-test, SDL activity, and immediate post-test were included in the analysis. Students who remained absent during any major stage of the intervention or submitted incomplete assessment or feedback forms were excluded. Participation in the study was voluntary and did not influence internal assessment marks or academic progression.

Sample Size and Sampling: A universal sampling method was adopted, and all eligible students from the Phase I MBBS batch were approached. The minimum sample size was calculated for detecting a paired mean difference between pre-test and post-test knowledge scores. Assuming a moderate standardized effect size of 0.30, a two-sided alpha error of 5%, statistical power of 80%, and an anticipated non-response or incomplete-participation rate of 10%, the minimum required sample was approximately 97 students. However, all eligible students were invited to improve the precision and representativeness of the findings (n=99).

Development of the SDL Module: The SDL module was developed by faculty members from the Department of Biochemistry in alignment with the National Medical Commission's competency-based curriculum. The selected topic was "Biochemical Basis, Diagnosis and Complications of Diabetes Mellitus," as it required integration of carbohydrate metabolism, hormonal regulation, laboratory investigations, diagnostic criteria, and clinical application. The module was reviewed by three subject experts and one medical educationist for content relevance, feasibility, curricular alignment, and appropriateness for Phase I learners.

Specific learning objectives were formulated to enable students to explain the biochemical basis of diabetes mellitus, differentiate its major types, interpret plasma glucose and glycated haemoglobin values, describe the oral glucose tolerance test, correlate metabolic abnormalities with clinical manifestations, and explain the biochemical basis of acute and chronic complications.

Conduct of the SDL Activity: Before the intervention, students attended a 30-minute sensitisation session explaining the concept, stages, expected outcomes, and individual responsibilities associated with SDL. No formal teaching of the selected topic was provided during sensitisation. Students then completed a 20-item multiple-choice question pre-test under supervision within 20 minutes. The SDL process was conducted over seven days. Students were divided into small groups of 8–10 members using computer-generated random allocation. Each group identified its existing knowledge, learning gaps, and group-specific learning objectives with the assistance of a faculty facilitator. Students independently consulted recommended textbooks, peer-reviewed articles, clinical guidelines, and authenticated online resources. A resource guide was provided, but students were encouraged to identify additional reliable sources and document them in an SDL worksheet. The worksheet recorded learning needs, objectives, resources consulted, key findings, and individual reflections.

At the end of the preparation period, a two-hour facilitated session was conducted. Each group presented its findings using a clinical case, concept map, flowchart, or brief presentation. Presentations were followed by peer questioning, case-based discussion, interpretation of laboratory reports, and facilitator feedback. Faculty members clarified misconceptions and ensured that all predefined learning objectives were addressed without converting the activity into a conventional lecture.

Assessment Instruments: Knowledge was assessed using 20 single-best-answer multiple-choice questions carrying one mark each, with no negative marking. Parallel but comparable question sets were used for the pre-test and immediate post-test to minimise recall bias. Questions covered recall, understanding, clinical application, and interpretation of biochemical investigations. Content validity was established by expert review, and item difficulty and discrimination indices were examined during pilot testing among students from the preceding batch who were not included in the main study. The internal consistency of the knowledge questionnaire was assessed using Kuder–Richardson Formula 20.

Students' perceptions were evaluated using a structured, anonymous questionnaire containing statements rated on a five-point Likert scale ranging from strongly disagree to strongly agree. The questionnaire assessed clarity of objectives, learner engagement, identification of learning needs, resource utilisation, teamwork, confidence, clinical relevance, facilitator support, time adequacy, and willingness to participate in future SDL sessions. Two open-ended questions explored perceived benefits, difficulties, and suggestions for improvement. The questionnaire was reviewed for content validity and pilot-tested before administration.

Outcome Measures: The primary outcome was the change in mean knowledge score from pre-test to immediate post-test. Secondary outcomes included the proportion of students achieving a predefined satisfactory score of at least 60%, delayed knowledge-retention scores obtained four weeks after the activity, students' perception ratings, and commonly reported facilitators and barriers to SDL. Attendance and completion of SDL worksheets were used as indicators of participation.

Data Collection and Statistical Analysis: Data were entered into Microsoft Excel and analysed using IBM SPSS Statistics version 20.0. Continuous variables were expressed as mean ± standard deviation or median with interquartile range according to distribution, while categorical variables were summarised as frequency and percentage. Normality was assessed using the Shapiro–Wilk test.

Pre-test, immediate post-test, and retention-test scores were compared using repeated-measures analysis of variance with Bonferroni-adjusted pairwise comparisons or the Friedman test with appropriate post-hoc analysis. The proportions achieving satisfactory scores were compared using McNemar's test. Effect size was reported using Cohen's d for paired observations. Likert-scale responses were presented as frequencies, percentages, and median scores. Open-ended responses were independently coded and grouped into recurring themes by two investigators. A two-sided p value <0.05 was considered statistically significant.

Ethical Considerations: Approval was obtained from the Institutional Ethics Committee before commencement of the study. Written informed consent was obtained from all participants. Confidentiality was maintained using coded identifiers, and the findings were reported in aggregate form. Students who did not consent received the same educational activity but their data were not included in the study.

Results

The mean age of participants was 18.7 ± 0.9 years, with 54 (54.5%) females. Overall, 60 (60.6%) students belonged to urban/semi-urban areas, 67 (67.7%) had studied in English medium, and 69 (69.7%) were first-generation medical students. Only 16 (16.2%) had previous formal SDL exposure, although 62 (62.6%) regularly used online academic resources and 95 (96.0%) had access to a personal internet-enabled device (Table 1).

Table 1: Baseline Demographic, Educational and Digital-Learning Characteristics of Phase I MBBS Students (N=99)

Characteristic	Frequency (%) / Mean ± SD
Age (years)	18.7 ± 0.9
Age group	
17–18 years	47 (47.5)
19–20 years	48 (48.5)
>20 years	4 (4.0)

Gender	
Male	45 (45.5)
Female	54 (54.5)
Place of residence before admission	
Rural	39 (39.4)
Urban/semi-urban	60 (60.6)
Medium of instruction in Class XII	
English	67 (67.7)
Regional language	32 (32.3)
First-generation medical student	69 (69.7)
Previous formal exposure to SDL	16 (16.2)
Regularly used online resources for academic learning	62 (62.6)
Personal smartphone/tablet with internet access	95 (96.0)
Personal computer/laptop availability	71 (71.7)
Preferred conventional classroom teaching before intervention	57 (57.6)
Preferred blended/active learning before intervention	42 (42.4)

SDL, self-directed learning.

Mean knowledge scores increased from 9.12 ± 2.46 at pre-test to 15.07 ± 2.18 immediately after SDL and remained higher at 13.84 ± 2.31 after four weeks. The overall difference was significant ($F[2,196]=357.8$, $p<0.001$; partial $\eta^2=0.785$). Although retention scores declined by 1.23 points from immediate post-test values ($p<0.001$), they remained 4.72 points above baseline ($p<0.001$) (Table 2).

Table 2: Comparison of Pre-test, Immediate Post-test and Four-week Retention-test Knowledge Scores Following the Structured SDL Activity (N=99)

Assessment	Score (Mean ± SD)	Median (IQR)	Mean change from pre-test (95% CI)	p-value
Pre-test	9.12 ± 2.46	9 (7–11)	Reference	—
Immediate post-test	15.07 ± 2.18	15 (14–17)	5.95 (5.53–6.37)	<0.001
Four-week retention test	13.84 ± 2.31	14 (12–16)	4.72 (4.28–5.16)	<0.001
Immediate post-test versus retention test	—	—	−1.23 (−1.60 to −0.86)	<0.001

Maximum score=20. IQR: interquartile range. CI, confidence interval; SDL, self-directed learning. Comparisons were performed using repeated-measures analysis of variance with Bonferroni-adjusted pairwise comparisons.

The proportion achieving satisfactory performance (≥60%) increased from 18 (18.2%) at pre-test to 89 (89.9%) immediately after SDL ($p<0.001$) and was maintained in 77 (77.8%) students at four weeks ($p<0.001$ versus pre-test).

High achievement increased from 3 (3.0%) to 55 (55.6%) immediately after the activity and remained evident in 34 (34.3%) students at retention assessment (Table 3).

Table 3: Distribution of Participants According to Knowledge-performance Categories Before and After the Structured SDL Activity (N=99)

Performance category	Pre-test	Immediate post-test	Retention test	Overall p-value
	Frequency (%)			
Unsatisfactory: <60% (<12/20)	81 (81.8)	10 (10.1)	22 (22.2)	<0.001
Satisfactory: 60–74% (12–14/20)	15 (15.2)	34 (34.3)	43 (43.4)	
High achievement: ≥75% (≥15/20)	3 (3.0)	55 (55.6)	34 (34.3)	
Overall satisfactory performance: ≥60%	18 (18.2)	89 (89.9)	77 (77.8)	<0.001

Unsatisfactory performance=<60% (<12/20); satisfactory performance=60–74% (12–14/20); high achievement=≥75% (≥15/20). SDL, self-directed learning. Changes in paired satisfactory proportions were assessed using McNemar's test. Significant improvement occurred across all assessed domains.

Mean gains were 1.88 points for fundamental biochemical concepts, 2.76 points for clinical application and disease mechanisms, and 1.31

points for laboratory interpretation and diagnostic reasoning (all p<0.001).

The overall knowledge score increased by 5.95 points (95% CI: 5.53–6.37; p<0.001) (Table 4).

Table 4: Domain-wise Comparison of Knowledge Scores Before and Immediately After the Structured SDL Activity (N=99)

Knowledge domain	Maximum score	Pre-test, Mean ± SD	Immediate post-test, Mean ± SD	Mean gain (95% CI)	p-value
		Mean ± SD			
Fundamental biochemical concepts	6	2.91 ± 1.11	4.79 ± 0.89	1.88 (1.66–2.10)	<0.001
Clinical application and disease mechanisms	8	3.25 ± 1.28	6.01 ± 1.09	2.76 (2.51–3.01)	<0.001
Laboratory interpretation and diagnostic reasoning	6	2.96 ± 1.09	4.27 ± 0.98	1.31 (1.10–1.52)	<0.001
Overall knowledge	20	9.12 ± 2.46	15.07 ± 2.18	5.95 (5.53–6.37)	<0.001

CI, confidence interval;; SDL, self-directed learning. Pre-test and post-test scores were compared using paired Student's t-test with Bonferroni correction.

Most students considered the activity clinically relevant (93.9%), reported clearly defined objectives (91.9%), and found facilitator guidance adequate (91.9%). The activity helped 88.9% identify learning gaps, while 86.9% found it engaging and 88.9% supported its inclusion in other topics.

However, only 54.5% considered the available time adequate, and 65.7% perceived the activity as time-consuming (Table 5).

Table 5: Students' Perceptions Regarding the Structured SDL Activity in Biochemistry (N=99)

Perception statement	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Positive response
	Frequency (%)					
Learning objectives were clearly defined	1 (1.0)	2 (2.0)	5 (5.1)	51 (51.5)	40 (40.4)	91 (91.9)
Activity helped identify learning gaps	1 (1.0)	3 (3.0)	7 (7.1)	49 (49.5)	39 (39.4)	88 (88.9)
Topic was relevant to clinical practice	0 (0.0)	2 (2.0)	4 (4.0)	43 (43.4)	50 (50.5)	93 (93.9)
Activity was engaging and interesting	1 (1.0)	4 (4.0)	8 (8.1)	48 (48.5)	38 (38.4)	86 (86.9)
Activity improved the ability to locate reliable resources	2 (2.0)	6 (6.1)	15 (15.2)	50 (50.5)	26 (26.3)	76 (76.8)
Small-group work promoted peer learning	1 (1.0)	5 (5.1)	9 (9.1)	49 (49.5)	35 (35.4)	84 (84.8)
Facilitator guidance was adequate	0 (0.0)	2 (2.0)	6 (6.1)	46 (46.5)	45 (45.5)	91 (91.9)
Time provided for completing the activity was adequate	8 (8.1)	17 (17.2)	20 (20.2)	39 (39.4)	15 (15.2)	54 (54.5)
The SDL activity was time-consuming	4 (4.0)	12 (12.1)	18 (18.2)	44 (44.4)	21 (21.2)	65 (65.7)
Similar SDL activities should be included in other topics	1 (1.0)	3 (3.0)	7 (7.1)	44 (44.4)	44 (44.4)	88 (88.9)

Responses are presented as frequencyon a five-point Likert scale. Positive response represents the combined "agree" and "strongly agree" categories. SDL, self-directed learning.

Knowledge gain did not differ significantly according to gender (p=0.570), residence (p=0.349), medium of instruction (p=0.082), or previous formal SDL exposure (p=0.153).

Students who regularly used online academic resources demonstrated greater improvement than non-regular users (6.31 ± 1.96 versus 5.38 ± 2.15; p=0.033) (Table 6).

Table 6: Comparison of Knowledge-score Improvement Across Selected Participant Characteristics (N=99)

Characteristic	Mean knowledge gain ± SD	Test statistic	p-value
Gender			
Male (n=45)	5.82 ± 2.12	t=−0.57	0.57
Female (n=54)	6.06 ± 2.04		
Residence			
Rural (n=39)	5.71 ± 2.13	t=−0.94	0.349
Urban/semi-urban (n=60)	6.11 ± 2.03		
Class XII medium of instruction			
English (n=67)	6.19 ± 1.99	t=1.76	0.082
Hindi/regional language (n=32)	5.42 ± 2.15		
Previous formal exposure to SDL			
Yes (n=16)	6.63 ± 1.82	t=1.44	0.153
No (n=83)	5.82 ± 2.10		
Regular prior use of online academic resources			
Yes (n=62)	6.31 ± 1.96	t=2.17	0.033
No (n=37)	5.38 ± 2.15		

SDL, self-directed learning. Subgroups were compared using independent Student's t-test; $p<0.05$ was considered statistically significant.

Discussion

The present study demonstrated that a structured, faculty-facilitated SDL activity substantially improved biochemistry learning among Phase I MBBS students. The mean knowledge score increased from 9.12 ± 2.46 before the activity to 15.07 ± 2.18 immediately afterwards, representing a mean gain of 5.95 points ($p<0.001$) and a large effect size (Cohen's d=2.48). Correspondingly, satisfactory performance increased from 18.2% to 89.9%, while high achievement rose from 3.0% to 55.6%. These findings indicate that SDL, when supported by explicit objectives, suitable resources, small-group interaction and faculty facilitation, can produce meaningful cognitive improvement even among students in the initial phase of medical training.

The observed improvement is consistent with Thota et al., who reported significant increases in post-test scores after both SDL alone and lecture-supported SDL among 158 first-year MBBS students [8]. Agrawal et al., similarly demonstrated the feasibility and educational utility of a structured SDL module in undergraduate biochemistry [11]. In a systematic review of 59 studies involving 8,011 health-professions learners, Murad et al., concluded that SDL was moderately superior to traditional teaching for knowledge outcomes, particularly when learners possessed relevant prior knowledge and applied learning to authentic problems [6]. More recently, Aulakh et al., analysed 14 studies involving 1,792 medical students and reported a pooled improvement favouring SDL over traditional teaching (mean difference: 2.399; 95% CI: 0.121–4.678), although considerable heterogeneity was present (I^2=98.56%) [12]. The larger improvement in the present study may be related to its clinically contextualised biochemistry topic, structured learning worksheets, small-group discussion, peer explanation and immediate formative assessment.

The educational effect was evident across all knowledge domains. The largest mean gain occurred in clinical application and disease mechanisms (2.76 points), followed by fundamental biochemical concepts (1.88 points) and laboratory interpretation (1.31 points), with all comparisons achieving $p<0.001$. This suggests that SDL was particularly effective in helping students connect metabolic mechanisms with clinical manifestations and disease processes. Clinical problems activate prior knowledge and provide an organising framework into which new biochemical information can be incorporated [13]. Searching for explanations, discussing alternative interpretations and teaching peers encourage elaboration and retrieval, which strengthen memory pathways more effectively than passive information reception [14]. Nevertheless, the comparatively smaller gain in laboratory interpretation indicates that novice learners may require additional guided practice with biochemical reports, diagnostic thresholds and clinical decision-making [15].

Although the retention score declined significantly from 15.07 ± 2.18 immediately after SDL to 13.84 ± 2.31 after four weeks ($p<0.001$), it remained substantially above the baseline score by 4.72 points ($p<0.001$). Satisfactory performance was also maintained in 77.8% of students compared with only 18.2% before the activity. The modest decline likely reflects normal forgetting when newly acquired information is not repeatedly retrieved. However, the persistence of a considerable learning advantage suggests that active information searching, concept organisation, peer discussion and application to a clinical problem promoted deeper encoding [16]. Periodic retrieval exercises, spaced revision and subsequent case-based assessments may further reduce this decline. Pai et al., likewise found SDL effective for teaching physiology to first-year medical students, although supplementing it with additional didactic instruction did not provide consistent benefit [7].

Students' perceptions supported the quantitative learning outcomes. Clinical relevance was recognised by 93.9%, clearly defined objectives and adequate facilitator support by 91.9% each, and identification of learning gaps by 88.9%. Furthermore, 86.9% found the activity engaging and 88.9% wanted similar activities incorporated into other topics. These findings closely resemble those of Thota et al., in which 92% reported improved understanding, 87% recognised their strengths and weaknesses and 86% considered SDL engaging [8]. Patra et al., also observed favourable student perceptions following implementation of a structured SDL module, particularly regarding active participation, teamwork and responsibility for learning [17]. Positive responses in the present study may reflect the combination of learner autonomy with structured scaffolding; complete independence can overwhelm inexperienced learners, whereas excessive direction can undermine ownership [18,19].

Despite overall acceptability, only 54.5% considered the allotted time adequate, and 65.7% regarded SDL as time-consuming. Difficulty managing time, locating reliable information and understanding complex topics has been repeatedly identified as a barrier to undergraduate SDL [9]. First-year students may spend excessive time searching because they have not yet developed efficient information-retrieval and source-appraisal skills. Providing an initial resource framework, training in literature searching, clearly limiting the scope of objectives and scheduling protected SDL time may improve efficiency without eliminating learner autonomy [20,21].

Knowledge gain did not differ significantly by gender, residence, school medium or previous formal exposure to SDL. This relative uniformity suggests that a structured and facilitated intervention can be accessible to learners from varied educational backgrounds. The absence of gender differences is consistent with Premkumar et al., who found no significant effect of gender or age on SDL readiness among 452 Indian medical students [10]. However, regular users of online academic resources achieved a greater gain than non-regular users (6.31 ± 1.96 versus 5.38 ± 2.15; $p=0.033$). Familiarity with digital searching may enable learners to locate, compare and synthesise information more efficiently [22]. This association should nevertheless be interpreted cautiously because it was based on an unadjusted subgroup comparison and may reflect underlying differences in digital literacy, motivation or prior academic habits [23].

Limitations: This study had several limitations. Its single-centre, single-group design without a conventional teaching control limited causal inference and generalisability. Immediate improvement may partly reflect testing, facilitator or Hawthorne effects. Knowledge was evaluated using researcher-developed MCQs, while long-term retention was assessed only once after four weeks. Self-reported perceptions were susceptible to social-desirability bias. Additionally, subgroup analyses were unadjusted, and the study did not assess sustained SDL readiness or behavioural change.

Conclusion

Structured, faculty-facilitated SDL was an effective and well-accepted strategy for teaching clinically oriented biochemistry to Phase I MBBS students. It produced substantial improvements in overall knowledge, clinical application and laboratory interpretation, with most of the learning advantage retained at four weeks. Students valued the clinical relevance, clear objectives, peer interaction and facilitator support, although inadequate time and the perceived workload remained concerns.

Comparable gains across most demographic and educational groups suggest that structured scaffolding can support diverse learners. Regular online academic-resource use was associated with greater improvement. Incorporating progressively scaffolded SDL sessions, supported by digital-literacy training and spaced formative assessment, may strengthen lifelong-learning skills within competency-based medical education.

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