

Table 1. Summary of Research Instruments

Instrument	Purpose	Components / Indicators	Scale / Participants	Validity & Reliability
Practical Skills Assessment (Rubric)	To measure students' technical competencies in Computer Network Engineering tasks.	• Network configuration and assembly competence • Measurement and configuration accuracy • Troubleshooting ability • Interpretation of network behavior	Performance rubric	Validated by three subject-matter experts; Inter-rater reliability, Cohen's κ = 0.82
Student Engagement Questionnaire	To assess students' behavioral, emotional, and cognitive engagement during learning activities.	• Behavioral engagement (participation, effort) • Emotional engagement (interest, motivation) • Cognitive engagement (focus, strategy use)	Five-point Likert scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree	Adapted from established engagement frameworks(W. Li, 2024; Wang et al., 2025; Zhang, 2026); Cronbach's α = 0.89
Observation Checklist	To document observable learning behaviors during instruction.	• Task participation • Attention during instruction • Interaction with virtual lab features • Collaboration during practical activities	Observation of all 62 students throughout six instructional sessions	Expert-reviewed for clarity and content relevance
Semi-Structured Interview Guide	To explore students' perceptions of virtual lab usage and learning experiences.	• Perceived usefulness • Benefits and challenges • Engagement and motivation • Suggestions for improvement	12 purposively selected students (4 high-, 4 moderate-, and 4 low-performing students); 20–30-minute interviews	Content validity confirmed through expert review; findings triangulated with observations and quantitative results

Table 2. Summary of Data Collection Procedures

Phase	Description	Activities Conducted
Pretest Phase	Establish baseline equivalence between groups.	• Practical skills pretest administered to both groups. • Engagement baseline survey completed by all participants.
Intervention Phase	Implement instructional treatments for each group over 6 sessions.	Experimental group: – Used virtual lab tools (Multisim, Tinkercad). – Conducted guided simulations and independent Computer Network exploration. Control Group: – Used traditional tools (breadboards, multimeters, power supplies). – Completed parallel tasks without simulation aids.
Blended Practicum Integration	Provide hands-on reinforcement for both groups.	• All students performed a final physical practicum to apply skills acquired during the intervention.
Posttest Phase	Assess learning gains and capture qualitative insights.	• Practical skills posttest administered to both groups. • Engagement survey re-administered. • Semi-structured interviews were conducted with selected students.

Table 3. Improvement in Practical Skills Between Experimental and Control Groups

Assessment	Group	Mean (M)	SD	Statistical Test	p-value	Effect Size (d)
Pretest	Experimental	67.81	7.23	$t(60) = 0.54$	0.592	0.14 (Small)

Table 4. Subskill Performance Improvement in the Experimental Group

Table 5. Student Engagement Scores for Experimental and Control Groups

Table 6. Detailed Analysis of Student Engagement Survey Results

Engagement Dimension	Group	n	Mean (M)	SD	Levene's F	Levene's p	t(60)	p-value	Cohen's d	Interpretation
Behavioral Engagement	Experimental	32	4.25	0.30	0.39	0.533	8.00	< 0.001	2.03	Large
	Control	30	3.59	0.35						
Emotional Engagement	Experimental	32	4.28	0.32	0.56	0.457	8.84	< 0.001	2.25	Large
	Control	30	3.49	0.38						
Cognitive Engagement	Experimental	32	4.31	0.42	2.16	0.147	8.10	< 0.001	2.06	Large
	Control	30	3.55	0.32						
Overall Engagement	Experimental	32	4.28	0.25	1.01	0.318	12.43	< 0.001	3.16	Large
	Control	30	3.54	0.22						
Virtual Lab Perception	Experimental	32	4.49	0.27	0.40	0.528	14.48	< 0.001	3.68	Large
	Control	30	3.39	0.33						

Table 7. Reliability Analysis of the Student Engagement Instrument

Scale	Item Numbers	Number of Items	Cronbach's α	Reliability Interpretation
Behavioral Engagement	Q1–Q5	5	0.511	Low
Emotional Engagement	Q6–Q10	5	0.594	Questionable
Cognitive Engagement	Q11–Q15	5	0.643	Questionable
Overall Student Engagement	Q1–Q15	15	0.816	Good
Virtual Lab Perception	Q16–Q20	5	0.715	Acceptable