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Cyber-Physical Versus Immersive Learning in Vocational Education: Perceived Support for Creative Thinking and Problem Solving Toward SDG 4

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ABSTRACT

Objective: *To compare vocational higher education students' perceived support from Cyber-Physical Learning (CPL) and Immersive Learning (ILM) for creative thinking and problem solving. It examines whether students' evaluations differ across the two competencies and considers the implications for competency-sensitive learning design relevant to Sustainable Development Goal 4 (SDG 4) on Quality Education.* ***Method:*** *A cross-sectional survey involved 223 applied bachelor students, comprising 109 Electrical Engineering and 114 Informatics Management students. Data were collected using a 31-item questionnaire with a five-point Likert response scale covering four perceived-support constructs: CPL-CT, ILM-CT, CPL-PS, and ILM-PS. Two Wilcoxon comparisons examined differences between the learning environments for each competency.* ***Results:*** *For creative thinking, the reported construct values for CPL (3.9725) and ILM (3.9654) did not differ significantly ($Z=-0.322$, $p=0.747$). For problem solving, CPL received a higher reported value (4.0701) than ILM (3.9753), with a statistically significant difference ($Z=-3.994$, $p<0.001$). These findings indicate competency-specific differences in students' perceived instructional support rather than demonstrated improvements in learning performance.* ***Novelty:*** *To provide a direct competency-specific comparison of cyber-physical and immersive learning environments. The findings strengthen a competency–technology alignment perspective by showing that students' perceptions of instructional support vary according to the targeted competency. This perspective is relevant to SDG 4 because quality vocational education requires learning environments to be selected in relation to instructional objectives and competency requirements rather than technological sophistication alone. The study does not, however, measure progress toward an SDG indicator or establish the causal effectiveness of either learning environment.*

INTRODUCTION

Vocational higher education is expected to prepare graduates for occupational practice while equipping them to respond to changing production and information systems. The integration of automation, connected devices, data infrastructures and computational control has expanded the range of competencies required in contemporary technical work. A systematic review of Industry 4.0 engineering competencies identified recurring demands for technical and transferable abilities without establishing a single agreed competency model (Quintero & Maldonado, 2024). Industry-oriented analysis similarly emphasizes changes in worker knowledge and the organization of skills development as industrial processes become more digitalized (Saniuk et al., 2023). Within this context, the pedagogical question is not simply whether institutions should adopt new technologies, but which learning environments students regard as appropriate for particular competencies.

The educational consequences of technological transformation also vary across sectors and learner populations. In vocational curricula, digital content may be introduced unevenly; Delcker (2023), for example, identified digital features in 200 of 831 curricula examined through text mining. A review of digitalization in accounting

likewise associated occupational changes with both domain-specific and more general competencies (Pargmann et al., 2023). Beyond technological readiness, vocational education remains a social and developmental experience: a review of 31 studies of young people's technical and vocational education experiences documented dimensions that extend beyond employment alone (Shi & Bangpan, 2022). Reviews of online work-based learning have also noted a relatively limited body of evaluated practical-learning interventions (Rienties et al., 2023). These observations strengthen the case for studying students' perspectives on learning design without presenting those perspectives as a substitute for evidence of attained proficiency.

Creative thinking and problem solving represent two relevant but conceptually distinguishable outcomes. Creativity refers to the interaction of individuals, processes and environments that can produce ideas or products judged both novel and useful within a particular context (Plucker et al., 2004). In vocational situations, creative work must therefore respond to constraints and purposes rather than consist solely of unrestricted idea production. Problem solving involves different cognitive demands depending on the structure, complexity, situatedness and domain of a problem (Jonassen, 2000). Diagnosing a malfunction in an interconnected technical system may require evaluating information, selecting a course of action and interpreting operational feedback. A technology that students perceive as helpful for exploring alternatives need not receive the same evaluation for diagnosing and resolving technical problems.

Cyber-Physical Learning (CPL) is a potentially relevant response to these demands because it draws on links between physical processes and computational representations. Cyber-physical system architectures make it possible to synchronize operational information, monitoring and analytical processes across physical and digital domains (Lee et al., 2015). Applications in learning factories illustrate how production scenarios can be integrated with assistance technologies and digital information to support instruction about smart production (Merkel et al., 2017). Nevertheless, an architecture that is effective for industrial monitoring is not automatically an effective teaching intervention. Research involving 63 learners in a technical vocational learning factory, for example, differentiated development in subject-specific competence from less evident development in multidisciplinary digital competence (Roll & Ifenthaler, 2021). Pedagogical value must be connected to the actual competency under consideration.

Educational design is equally important in more explicitly cyber-physical teaching approaches. The T-CHAT framework combines perceptual, project-based, problem-based, research-based and face-to-face approaches in cyber-physical systems engineering education (Mäkiö et al., 2022). Such work indicates that physical-digital integration is best understood as part of a designed learning activity, rather than as an independent guarantee of technical capability. For the present inquiry, CPL offers a plausible set of affordances involving operational information and system interaction, but the exact configuration experienced by participating students is not fully documented in the research record. Accordingly, claims about feedback, authenticity or diagnostic practice must remain conceptual until those features are empirically established.

Immersive Learning (ILM) offers a different route to engaging learners with complex tasks. Virtual and augmented environments can provide spatial visualization, simulated situations, agency and a sense of presence. The Cognitive Affective Model of Immersive Learning describes learning as the result of interactions among technological immersion, instructional methods and cognitive-affective processes rather than the

consequence of immersion alone (Makransky & Petersen, 2021). A review of immersive virtual reality in higher education found diverse applications alongside recurring weaknesses in explicit learning-theory integration and outcome assessment (Radianti et al., 2020). A meta-analysis of 48 studies involving 3,179 learners reported a small overall positive learning effect, g=0.38, with differences across educational levels and comparison settings (Çoban et al., 2022). Thus, benefits established for some immersive applications cannot be generalized indiscriminately to each vocational task.

Recent reviews reinforce the need for specificity. A systematic review of virtual and augmented reality in vocational education charted varied applications rather than one universally preferable configuration (Liu et al., 2024). Comparative research also suggests that interaction and pedagogy may matter at least as much as immersion; Santilli et al. (2025) reviewed 71 higher-education studies and found that only 8% included virtual-reality training within the study protocol. A separate synthesis of immersive higher-education research highlighted heterogeneity and concerns about validated and replicable designs (Stracke et al., 2025). Review evidence on competency development similarly documents potential applications alongside cost and software limitations (Cabrera-Duffaut et al., 2024). These studies collectively justify comparing learning settings with reference to the skills being targeted rather than claiming that either physical-digital or immersive environments are uniformly superior.

The present study adopts competency–technology alignment as an interpretive perspective for comparing CPL and ILM. Evidence from virtual-reality training indicates that task-technology fit and training design can moderate learning outcomes (Howard et al., 2021). However, perceptions of instructional support must be distinguished from directly demonstrated cognitive learning. Research on self-assessed knowledge has shown stronger relationships with motivational and affective factors than with cognitive learning (Sitzmann et al., 2010). Although perceived support is not equivalent to self-assessed knowledge, this evidence cautions against interpreting favorable student evaluations as proof of competency development. Accordingly, competency-technology alignment is used here to interpret differences in perceived support rather than as a measured mediator or causal mechanism.

This competency-sensitive perspective is also relevant to Sustainable Development Goal 4 (SDG 4), which emphasizes Quality Education. In vocational higher education, the quality of technology-supported learning depends not only on access to advanced learning technologies but also on whether the selected learning environment corresponds to the intended competency and instructional purpose. Comparing how students perceive CPL and ILM in relation to different competencies can therefore inform more deliberate decisions about technology-supported vocational learning. Nevertheless, the present study does not evaluate progress toward a specific SDG 4 indicator; its contribution is limited to evidence that may inform the design of competency-oriented learning environments consistent with the broader concern for quality education.

Despite growing research on cyber-physical and immersive learning environments, a specific empirical question remains insufficiently resolved: whether students differentiate the perceived instructional support of these environments when creative thinking and problem solving are considered as separate competency targets. The present study addresses this gap through a cross-sectional survey of 223 students in two applied bachelor programmes. It asks whether perceived CPL support differs from perceived ILM support for creative thinking (RQ1) and whether perceived CPL support differs from perceived ILM support for problem solving (RQ2). By directly comparing

the two learning-environment categories across two differentiated competencies, the study provides a bounded test of competency-specific student perceptions. It does not assess the effectiveness of particular equipment configurations, demonstrate competency growth, or estimate the causal influence of an instructional intervention. Its contribution lies in clarifying whether perceived instructional support varies with the competency being considered, thereby providing a more precise basis for subsequent instructional and performance-based research.

LITERATURE REVIEW

Creative thinking and problem solving in vocational education

The competencies that support vocational practice are not homogeneous. Creative thinking is concerned with producing alternatives that have originality and contextual usefulness, whereas problem solving is oriented toward an initial condition, a desired outcome and the constraints that shape the path between them (Jonassen, 2000; Plucker et al., 2004). The distinction does not imply that creativity is unnecessary in problem solving. Rather, it highlights the possibility that the two constructs may require different forms of task engagement, feedback and evaluation. When vocational learners create or improve a technical solution, novelty must be considered alongside operational viability; when they troubleshoot, a plausible solution must also be tested against evidence about how a system behaves.

Evidence on creativity-oriented instruction further illustrates the importance of pedagogical detail. A meta-analysis of problem-solving pedagogy and creativity synthesized 19 studies and 77 effect sizes, identifying an overall creativity benefit with variation by problem source and grouping arrangements (Zhan et al., 2024). Research on virtual technologies similarly suggests that creative outcomes depend on activity design and informative feedback, rather than on digital presentation alone (Wang et al., 2024). A review of 16 studies published between 2014 and 2023 on college students' creativity and virtual reality found a relatively concentrated literature spanning art, engineering and education (Yu & Wang, 2025). These findings provide reasons to attend to learning tasks as well as the medium through which they are presented.

Vocational competencies may also develop unevenly even within technically sophisticated learning settings. In a learning-factory study, Roll and Ifenthaler (2021) reported improvement in subject-specific technical competence without parallel evidence of increased multidisciplinary digital competence. A related model of pre-service vocational teachers' multidisciplinary digital competencies distinguished motivational, cognitive, knowledge and practice-related dimensions (Roll & Ifenthaler, 2021b). Consequently, a single student evaluation of an innovative technology cannot reliably summarize its value for all competencies. A differentiated comparison is especially appropriate when the target outcomes involve contrasting exploratory and diagnostic demands.

Cyber-physical learning and work-process interaction

Cyber-physical arrangements connect a physical process to digital representations that may support sensing, monitoring, computation and action. A manufacturing architecture described by Lee et al. (2015) illustrates this integration at the systems level, while Fett et al. (2023) clarify related but distinct concepts such as digital twins and product-service systems. In a vocational learning context, the pedagogical opportunity is to connect information about a process with decisions concerning that process. Students may, for example, interpret operational data and evaluate possible

adjustments. These possibilities must be differentiated from the features actually implemented in a particular classroom or laboratory.

Learning-factory research provides illustrations of how such environments may be organized. Merkel et al. (2017) describe smart-production instruction using production scenarios and assistance technologies, and Chelini and Richert (2023) present project-based engineering-design activity in a cyber-physical learning factory. The T-CHAT framework explicitly incorporates five complementary instructional approaches instead of relying on technical infrastructure alone (Mäkiö et al., 2022). A pilot modular platform for interoperable digital twins also demonstrates the engineering work required to support laboratory integration (Pajpach et al., 2025). Each study points to a set of possible learning activities, not a standardized CPL condition transferable without modification.

Systematic review evidence similarly identifies potential links among digital twins, virtual environments, problem-based learning and manufacturing education, while also recognizing practical barriers of cost, scale and information security (Karanam & Hartman, 2025). For this study, the defensible theoretical proposition is therefore limited: physical–digital interaction may be salient to learners evaluating operational or diagnostic tasks. Whether the surveyed students actually experienced particular feedback modalities, sensors or authentic troubleshooting situations cannot be established from the reported research documentation.

Immersive learning and experiential representation

Immersive Learning encompasses designs in which virtual or augmented representation is used to make environments, procedures or objects accessible to learners. Such experiences can support visualization, simulated participation and opportunities to rehearse actions in constrained or otherwise inaccessible settings. The CAMIL framework proposes that presence, agency and related cognitive-affective processes mediate how immersive design and pedagogy contribute to learning (Makransky & Petersen, 2021). The implication is that no isolated technical feature, including immersion intensity, can substitute for purposeful instruction.

Reviews of immersive higher education indicate considerable variation in technology and outcomes. Radianti et al. (2020) identify the need for stronger integration of learning theory and educational evaluation. Çoban et al. (2022) report a small positive average effect but heterogeneity across educational contexts. Lin et al. (2024), synthesizing 40 studies of virtual-reality science and education games, associate active interaction with more favorable learning outcomes than passive engagement. Comparative evidence further underscores the relevance of interactivity, usability and instructional organization (Santilli et al., 2025). These findings caution against presuming that all ILM settings offer the same pedagogical affordances.

Evidence related to vocational education is also mixed in scope and emphasis. Liu et al. (2024) describe applications of virtual and augmented reality for practical abilities and conceptual understanding across vocational settings. Cabrera-Duffaut et al. (2024), reviewing 27 included higher-education studies from 1,671 retrieved records, identify opportunities for competence development alongside device and software constraints. A synthesis of immersive higher-education studies notes uneven methodological quality and incomplete validation of learning mechanisms (Stracke et al., 2025). This literature makes ILM a reasonable comparative category, while supporting careful distinctions between perceived experience, specific instructional actions and actual performance.

Competency–technology alignment and the boundary of perceived support

The two educational environments should not be treated as mutually exclusive technological packages with fixed learning outcomes. In a meta-analysis of virtual-reality training, Howard et al. (2021) connect programme effects to task-technology fit and design choices. A review of teacher-education virtual-reality simulations similarly found that emphasis on affective outcomes frequently exceeded the attention given to authentic performance assessment and adaptive instructional support (Hong et al., 2025). These observations support an alignment perspective in which the value of an environment is conditional on the intended competency, the tasks assigned and the features learners actually use.

The distinction between experience ratings and educational attainment is crucial. Self-reported knowledge assessments may reflect affective and motivational factors that are not reducible to cognitive gains (Sitzmann et al., 2010). A positive response to a five-point statement about support for problem solving therefore does not demonstrate that a learner solved technical problems more accurately. Similarly, a nonsignificant comparison between the ratings of two environments is not a formal equivalence test. Theoretical alignment is used here to organize potential interpretations, but the current survey does not measure it as a mediator or assess performance. This scope is maintained in the research design, results and discussion.

RESEARCH METHOD

Research design and participants

The investigation was documented as a cross-sectional survey of students in vocational higher education. Its purpose was comparative: to examine whether learners evaluated two learning-environment categories differently when asked about their support for creative thinking and problem solving. The design measured reported perceptions at one point in the research process; it was not documented as a controlled intervention, pretest–posttest investigation or performance assessment. Cross-sectional observational evidence can identify patterns of association and comparison, but causal interpretation requires additional design information and assumptions that are not established by the current study record (Martínez-Abad & León, 2023). Consequently, terms such as 'effectiveness' and 'impact' are avoided where they might imply demonstrated learning gains.

The reported sample comprised 223 students enrolled in D4, or applied bachelor, programmes. Of these, 109 were in Electrical Engineering and 114 were in Informatics Management. The totals are arithmetically consistent: 109+114=223. These programme categories indicate the composition of the surveyed group; the original analysis supplied for manuscript reconstruction does not include inferential comparisons between the programmes. No claim about the representativeness of the two groups, the influence of disciplinary orientation or differences between their ratings can therefore be supported. Table 1 reproduces the two programme counts as presented in the research notes.

The research documentation does not identify the university, country, recruitment or sampling procedure, sampling frame, inclusion and exclusion criteria, response rate, students' age or other demographic characteristics, semester or course assignment, or dates of data collection. It likewise does not establish which CPL or ILM activities respondents experienced before completing the questionnaire, whether each respondent experienced both environments, or whether evaluations were based on demonstrations, practice sessions or descriptions. These omissions are reported as

missing documentation rather than repaired through assumptions drawn from studies of similar learning environments.

This matters for interpreting self-report surveys. A review of common-method bias explains how survey context, shared response sources and item wording can affect construct relationships (Podsakoff et al., 2012). More recent analysis emphasizes that such biases have multiple causes and cannot be resolved reliably by a single diagnostic test applied after the fact (Podsakoff et al., 2024). Response attentiveness is also relevant: research involving more than 12,000 learners considered multiple methods for identifying careless responding (Chauliac et al., 2023). The present record does not document procedural safeguards, attention checks or related diagnostics; none are attributed to the study.

Table 1. Reported participant composition

Programme	Students
Electrical engineering	109
Informatics management	114
Total	223

Constructs and instrument

The available survey description specifies 31 questionnaire items answered on a five-point Likert scale, with response categories numbered 1 to 5. Four construct labels were identified: CPL-CT, representing perceived support of Cyber-Physical Learning for creative thinking; CPL-PS, representing CPL support for problem solving; ILM-CT, representing perceived support of Immersive Learning for creative thinking; and ILM-PS, representing ILM support for problem solving. These labels define the conceptual comparisons in the study. They should not be interpreted as direct assessments of creative products, diagnostic accuracy or any other behavioral demonstration of competence.

Questionnaire development requires a clear specification of the intended constructs and alignment between items and research objectives (Ranganathan & Caduff, 2023). Subsequent validation includes evidence about item performance, reliability and validity sufficient for the intended inference (Ranganathan et al., 2024). Methodological distinctions between questionnaires, rating scales and checklists similarly show why reporting the response format alone is insufficient to establish measurement quality (Philip, 2024). The supplied record does not contain the wording of the 31 items, their assignment to the four constructs, response anchors beyond the 1-to-5 numeric range, the instrument's origin, evidence of adaptation or translation, pilot-testing information, or a scoring algorithm. The four reported values are accordingly described simply as 'reported construct values'. They are not relabeled as arithmetic means, medians or scale totals.

The distinction is methodologically consequential because Likert response categories are ordered but do not, without further assumptions, demonstrate equal distances between adjacent choices (Memmedova & Ertuna, 2024). Where multiple items are combined, an explicit aggregation rule is needed to establish what a unit of the resulting construct score represents. The current documentation neither explains the computation nor provides the individual distributions or item-level data needed to reproduce the summary values. Comparability between the CPL and ILM scores is an intended feature of the research question, but full measurement equivalence cannot be evaluated from the available materials.

Internal-consistency evidence is also absent. Contemporary scale-development guidance emphasizes construct definition, item development and evaluation of psychometric properties before drawing confident measurement inferences (Stefana et al., 2025). The suitability of coefficients alpha or omega depends on dimensional assumptions rather than a single universal cutoff (Flora, 2020; Green & Yang, 2015). Studies advocating omega as an alternative to automatic reliance on alpha likewise require a defensible measurement model and observed data (Goodboy & Martin, 2020; Hayes & Coutts, 2020). Because the documentation supplies no reliability coefficients, factor structure, validity statistics or model-fitting results, this manuscript makes no assertion that particular reliability thresholds were achieved.

Statistical analysis

Two Wilcoxon comparisons are reported in the available results. The first compared the construct labeled CPL-CT with ILM-CT, both referring to creative thinking. The second compared CPL-PS with ILM-PS, both referring to problem solving. For each comparison the source provides a standardized Z statistic and a p value, together with the two construct summaries. Wilcoxon's (1945) ranking methods include procedures suited to different comparison structures, and the specific variant matters for interpretation. Although the available source identifies the test family, it does not name the precise variant or expressly document whether scores were paired for identical individuals. This manuscript therefore uses 'Wilcoxon comparison' without specifying the signed-rank or rank-sum procedure.

The research notes do not state a prespecified significance threshold, whether the p values were exact or asymptotic, how missing responses or ties were processed, or which statistical software produced the analyses. The record also omits raw score distributions, test ranks, confidence intervals and effect-size measures. It would consequently be inappropriate to reproduce software output, normality tests or detailed inferential diagnostics that were not supplied. In particular, the two reported construct values cannot independently reconstruct the Z statistic or verify test assumptions.

A statistically significant p value indicates incompatibility between observed results and the relevant null hypothesis under the assumptions of the applied procedure; it is not a direct estimate of educational importance. Rank-based effect measures require sufficient rank information and cannot be manufactured from p values alone (Kerby, 2014). The present analysis retains the reported direction of descriptive values, Z statistics and p values, while avoiding unverified claims about the magnitude of the effect. The qualitative distinction between 'not statistically significant' and 'statistically significant' follows the labels in the research source rather than an independently documented decision rule.

Results are presented first for creative thinking and then for problem solving. No tests comparing Electrical Engineering with Informatics Management are reported in the supplied research notes, and such comparisons are not invented. The reported observations concern perceived instructional support; the survey design does not establish an intervening mechanism, actual learning improvement or causal superiority of a learning environment. These interpretation limits are preserved throughout the manuscript.

RESULTS AND DISCUSSION

Results

The study reported responses from 223 applied bachelor students, comprising 109 in Electrical Engineering and 114 in Informatics Management. The questionnaire contained 31 items on a five-point response scale and was organized around four labeled constructs. The record supplies two Wilcoxon comparisons, one between the CPL and ILM creative-thinking constructs and the other between the CPL and ILM problem-solving constructs. Table 2 brings together all reported comparison statistics. The values are reproduced as given and are not supplemented with unreported standard deviations, rank totals, confidence intervals or test diagnostics.

Across the four constructs, the reported values were 3.9725 for CPL-CT, 3.9654 for ILM-CT, 4.0701 for CPL-PS and 3.9753 for ILM-PS. The largest of these reported values was observed for CPL-PS, while the two creative-thinking values differed minimally in arithmetic terms. The smallest reported value was for ILM-CT. Because the calculation method for each construct value is absent, these figures should be understood as the source's reported summaries rather than definitively as means. Similarly, the five-point response format defines the possible item choices, not necessarily the scale or precision of the derived construct summaries.

The inferential results were differentiated by competency. For creative thinking, the supplied comparison yielded $Z=-0.322$ and $p=0.747$ and was designated nonsignificant. For problem solving, the reported result was $Z=-3.994$ and $p<0.001$; the CPL construct had the higher descriptive value. These results are explained separately below so that the absence of a detected difference for one competency is not conflated with the statistically significant comparison for the other.

Table 2. Reported construct values and Wilcoxon comparisons

Competency	CPL Value	ILM Value	Z	p	Reported result
Creative thinking	3.9725	3.9654	−0.322	0.747	Not statistically significant
Problem solving	4.0701	3.9753	−3.994	< 0.001	CPL higher; statistically significant

Note. CPL = Cyber-Physical Learning; ILM = Immersive Learning.

Creative thinking

The first reported comparison assessed students' perceived support of CPL and ILM for creative thinking. The CPL-CT construct value was 3.9725 and the ILM-CT construct value was 3.9654. Subtraction of the two reported figures produces a descriptive difference of 0.0071 in favor of CPL. This is a difference between two displayed construct summaries, not a calculated effect size or an estimate of improvement in creative ability. The source does not provide the scoring rules, score distributions or precision estimates that would allow a more complete characterization of the difference.

The Wilcoxon test statistic for this comparison was $Z=-0.322$, with a reported p-value of 0.747. The study recorded this comparison as not statistically significant. Thus, the supplied analysis did not detect a statistically significant difference between the two perceived-support constructs for creative thinking. Although CPLCT was numerically higher, the inferential result does not justify characterizing the very small arithmetic difference as a reliable preference for CPL. Conversely, the two values being close together does not demonstrate that every student rated CPL and ILM identically; a construct-level summary necessarily condenses the underlying responses.

The result can be characterized accurately at three levels. At the descriptive level, the reported CPL and ILM summaries were 3.9725 and 3.9654, respectively. At the reported

inferential level, the comparison yielded a nonsignificant p value of 0.747. At the evidentiary level, both quantities refer to the surveyed learners' perceptions about support for creative thinking. The data supplied do not include direct creative-thinking tasks, ratings of original products, measures of idea quality or assessments of changes in creative performance. The analysis therefore offers no direct evidence that the two learning environments generate equal creativity outcomes.

It is also important to distinguish statistical nonsignificance from tested equivalence. A formal equivalence or non-inferiority claim would require a prespecified margin, an appropriate analytical procedure and sufficient precision information. None is present in the current record. The supplied Wilcoxon result instead warrants the narrower statement that a difference in perceived support was not detected by the reported comparison. No conclusion about equivalence, sameness of effect or lack of any meaningful difference can be established from the reported p value alone.

Finally, the reporting does not disclose the number of negative and positive ranks, ties, complete score distributions, group-specific sample sizes used by the particular Wilcoxon procedure, or the exact handling of missing values. Such information would help interpret individual variability, consistency and the test statistic, but reconstructing it from the displayed summaries would be speculative. The result retained for subsequent discussion is consequently the nonsignificant observed comparison for perceived creative-thinking support, not a claim about a common learning mechanism or equivalent performance.

Problem solving

The second comparison considered students' perceived support of CPL and ILM for problem solving. The reported construct value was 4.0701 for CPL-PS and 3.9753 for ILM-PS. The arithmetic difference between these two summaries is 0.0948 in favor of CPL. This difference is larger than the corresponding displayed gap for creative thinking (0.0071), but the two gaps have not been subjected to a reported direct statistical comparison with one another. They should therefore be described as separate descriptive observations rather than as a formal interaction between environment and competency.

The problem-solving Wilcoxon comparison produced $Z=-3.994$ and $p<0.001$. The study classified this finding as statistically significant, with CPL receiving the higher perceived-support value. Under the reported analysis, students' assessments therefore favored CPL in relation to problem solving. This is the primary directional difference in the available inferential results. Unlike the creative-thinking comparison, the problem-solving comparison supplies evidence of a reported statistically significant perceived-support distinction between the two environment categories.

The direction of the descriptive comparison and the significance designation are consistent, but they represent different types of information. The construct values specify the displayed ordering, whereas the Wilcoxon result summarizes a rank-based comparison performed on data that are not available in the supplied documentation. The sign of Z should not, by itself, be used to infer the direction of the contrast, because the contrast order and software conventions are incompletely documented. The direction is accordingly described by reference to the explicitly reported construct values and the study's interpretation.

The significant p value does not supply a measure of educational magnitude. The difference of 0.0948 between displayed values cannot be treated as a standardized effect, and the study did not report rank-biserial correlation, standardized mean

difference or an interval estimate. Neither the raw observations nor the rank and tie counts are available for independent reconstruction. The available evidence thus does not indicate how consistent the preference for CPL was across individuals, how sensitive it was to particular responses, or whether its size would be consequential in a specific curriculum decision.

Moreover, the measured outcome was perceived support, not performance in a problem-solving task. The study did not supply tests of troubleshooting accuracy, speed of technical diagnosis, quality of solutions or transfer to a workplace setting. Consequently, the finding should not be rephrased as CPL causing greater problem-solving ability or producing stronger objective learning gains. It establishes that CPL was rated more favorably in the reported survey comparison for this competency. Explanations involving physical-digital systems, operational data or instructional feedback are considered in the Discussion as possible interpretations, not as directly measured causes of the observed difference.

Discussion

Interpreting perceived support for creative thinking

The creative-thinking comparison showed virtually indistinguishable reported construct summaries, with CPL-CT at 3.9725 and ILM-CT at 3.9654, and no statistically significant difference ($Z=-0.322$, $p=0.747$). This pattern supports a restrained conclusion: the study did not detect differential perceived support for creative thinking within the reported analysis. It does not demonstrate equivalence of learning environments, nor does it show that learners attained comparable creative-thinking performance. The observation is relevant because it cautions against assuming that physical-digital interaction must necessarily receive stronger creative-support ratings than virtual or simulated exploration.

One plausible account is that both categories of environment may provide distinct routes for exploration. CPL may make it possible to change a physical–digital system and observe operational responses, while ILM may allow learners to visualize alternatives and rehearse low-risk scenarios. Creativity is context-dependent and requires both novelty and usefulness (Plucker et al., 2004); consequently, several types of instructional activity can plausibly support creative work. Reviews of creativity-oriented virtual experiences indicate that feedback, task design and instructional conditions matter to their effects (Wang et al., 2024; Yu & Wang, 2025). A meta-analysis of problem-solving pedagogy and creativity also associates outcomes with the type and organization of learning problems (Zhan et al., 2024).

These possibilities are interpretive rather than measured mechanisms in the present study. The instrument did not separately record visualization, idea production, experimentation or feedback experiences, and the specific learning activities were not documented. It is therefore not possible to determine whether the observed similarity arose from comparable perceived affordances, common rating tendencies or other contextual influences. The most defensible implication is to assess creative-thinking learning environments by their specific activities and by direct evidence of creative performance, not by their technology category alone.

Interpreting perceived support for problem solving

For problem solving, the analysis yielded a different pattern. CPL-PS received a reported value of 4.0701 compared with 3.9753 for ILM-PS, with a statistically significant Wilcoxon comparison ($Z=-3.994$, $p<0.001$). Students therefore rated CPL

more favorably as a source of problem-solving support in the supplied analysis. The pattern is compatible with, but does not establish, the expectation that interaction with operational information may be valued for technically situated problem solving.

Problem-solving activities vary in their demands for diagnosis, interpretation, decision making and validation (Jonassen, 2000). Cyber-physical architectures connect physical states and digital information, potentially making system behavior visible and actionable (Lee et al., 2015). Learning-factory examples illustrate how production contexts and assistance technologies can connect technical information with practical tasks (Merkel et al., 2017). A cyber-physical teaching framework can also combine problem-based and project-based instruction with direct practical activity (Mäkiö et al., 2022). These features offer plausible reasons why learners might regard CPL as relevant to problem solving, particularly where tasks involve physical constraints and data-supported troubleshooting.

However, no particular sensor system, monitoring method, diagnostic exercise or feedback pathway was documented for the respondents. Moreover, virtual environments can also support learning outcomes when their interactivity and task design are appropriate, as suggested by meta-analytic evidence on virtual-reality education games (Lin et al., 2024) and broader training research (Howard et al., 2021). The result consequently does not warrant categorizing ILM as pedagogically ineffective for problem solving. Without effect-size information, the practical significance of the reported difference remains unknown, despite its reported statistical significance.

Competency-specific technology–pedagogy alignment

Read together, the two results challenge an undifferentiated ranking of learning media. The same comparison framework yielded no detected difference for creative thinking but a significant CPL-favoring difference for problem solving. This is compatible with the proposition that learners' judgments of technological support vary with competency requirements. It is not evidence that the competency–technology alignment mechanism itself was measured. Neither respondents' task–technology fit nor the presence, use and quality of the relevant affordances were included as reported constructs.

Theory and review evidence reinforce this conditional interpretation. The Cognitive Affective Model of Immersive Learning differentiates instructional methods, technological properties and learner-level processes (Makransky & Petersen, 2021), while the literature on immersive instruction documents variation across educational settings (Çoban et al., 2022). A higher-education review further found that interactivity and active methodology were associated with learning outcomes in ways that did not simply track the level of immersion (Santilli et al., 2025). The current findings therefore support asking which task an environment is intended to serve before investing in a particular technology, while leaving explanations about the mechanisms of perceived support for future testing.

The distinction between perceptions and performance remains central to this argument. Research on self-assessed learning cautions that favorable subjective judgments may track affective factors more closely than cognitive attainment (Sitzmann et al., 2010). The present survey is a useful account of student experience, but it cannot determine the effect of either environment on creative products, technical diagnoses or durable competence.

Implications for vocational curriculum and SDG 4

These findings are relevant to Sustainable Development Goal 4 (SDG 4) because improving the quality of vocational higher education requires learning technologies to be selected according to instructional purposes and competency demands rather than technological novelty alone. The competency-specific pattern observed in this study suggests that CPL may be perceived as particularly supportive for tasks involving physical-digital diagnosis and operational decision making, whereas ILM may remain valuable for visualization, exploration, and simulated practice. This differentiated perspective is consistent with evidence that competence development can be domain-specific (Roll & Ifenthaler, 2021) and that virtual and augmented reality applications in vocational education vary in their learning models and objectives (Liu et al., 2024). It also aligns with evidence that digital-twin and virtual learning environments can offer complementary educational opportunities while requiring institutions to consider implementation costs, scalability, and information-security constraints (Karanam & Hartman, 2025). Accordingly, the present study contributes to the broader concern of SDG 4 by informing more purposeful, competency-sensitive technology selection in vocational learning; however, it does not measure progress toward a specific SDG 4 indicator or establish that CPL or ILM directly improves students' creative-thinking or problem-solving competence.

Limitations and directions for further research

Several limitations restrict the inferences. The cross-sectional design does not demonstrate temporal change or causality. All four variables capture perceived support rather than directly evaluated creative-thinking or problem-solving performance. The record provides neither item-level questionnaire content nor its construct scoring, reliability, validity, participant recruitment, exposure conditions or data-collection period. Common-method and response-quality risks are relevant to this type of single-source survey, but the available material does not establish whether prevention or diagnostic measures were used (Chauliac et al., 2023; Podsakoff et al., 2024).

Statistical reporting is likewise incomplete: the exact Wilcoxon procedure, pairing structure, rank and tie counts, effect sizes, interval estimates and software cannot be established. These omissions limit reproducibility and the assessment of practical magnitude. Research on questionnaire development underscores the need to document item construction and psychometric evaluation (Stefana et al., 2025). Future work should report the instrument and full statistical workflow, characterize specific CPL and ILM activities, and combine perceptions with direct measures of creative products, diagnostic accuracy or transfer to practice. Experimental, longitudinal or appropriately designed observational research could then test whether competency-specific alignment accounts for changes in learning outcomes (Martínez-Abad & León, 2023). More complete measurement and evaluation would allow curriculum recommendations to move beyond perceived support to demonstrated educational benefit.

CONCLUSION

Fundamental Finding: This study revealed competency-specific differences in vocational students' perceptions of Cyber-Physical Learning (CPL) and Immersive Learning (ILM). Based on responses from 223 applied bachelor students, no statistically significant difference was identified in perceived support for creative thinking ($Z=-0.322$, $p=0.747$), whereas CPL received significantly higher perceived-support ratings for problem solving than ILM ($Z=-3.994$, $p<0.001$). These findings suggest that

students' evaluations of learning environments vary according to the competencies being considered, rather than demonstrating the overall superiority of one technological approach. **Implication:** The findings highlight the importance of competency-technology alignment in vocational higher education. Educators should select learning environments based on instructional objectives and task characteristics rather than technological sophistication alone. Cyber-physical environments may provide opportunities for operational analysis and technical problem solving, while immersive environments may facilitate visualization, exploration, and simulated experiences. Both approaches offer potentially complementary instructional opportunities, although their effectiveness in improving actual competencies requires further empirical verification. **Limitation:** This study employed a cross-sectional survey measuring perceived instructional support rather than demonstrated creative-thinking or problem-solving performance. Incomplete documentation of questionnaire validation, participant exposure to learning environments, construct scoring, and statistical procedures limits the reproducibility and interpretation of the findings. Furthermore, the absence of effect-size estimates and direct performance assessments prevents conclusions regarding practical significance or causal learning improvements. **Future Research:** Future investigations should employ validated measurement instruments, clearly documented learning interventions, and experimental or longitudinal research designs to examine the relationship between learning environments and actual competency development. Incorporating performance-based assessments, effect-size estimates, and comparisons across vocational disciplines would provide stronger evidence regarding the educational contributions of CPL and ILM. Further research should also investigate how physical-digital interaction and immersive experiences can be integrated to support creative thinking and problem solving in authentic vocational learning contexts.

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AUTHOR CONTRIBUTIONS

Reza Rahmadian: Conceptualization, methodology, investigation, and writing-original draft preparation. **Ekohariadi:** Supervision, validation, and writing-review and editing. **Ratna Suhartini:** Methodology, formal analysis, and writing-review and editing. **Mafrur Udhif Nofaizzi:** Data curation, investigation, visualization, and writing-original draft preparation. All authors have read and approved the final version of the manuscript.

CONFLICT OF INTEREST STATEMENT

The authors declare that no conflict of interest, either financial or personal in nature, exists that could have influenced the design, execution, interpretation, or reporting of this study. No funding was received from commercial entities with a direct stake in the findings, and no author holds institutional, professional, or personal relationships that could constitute a competing interest with respect to the content of this manuscript.

ETHICAL COMPLIANCE STATEMENT

This manuscript adheres fully to the principles of research and publication ethics. The study was conducted with academic integrity, and all data reported herein were collected, processed, and presented accurately and transparently. No data were fabricated, falsified, or selectively reported.

STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING

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