MEDICAL SCIENCES

THE INSTRUMENTATION GAP IN NAIL SERVICE MASTER TRAINING: WHY ENGAGEMENT METRICS CANNOT VALIDATE PROCEDURAL SAFETY

Artemyeva I.
Director of the Training Center, Academy of Aesthetic Technologies LLC
Rostov-on-Don, Russia
https://doi.org/10.5281/zenodo.21982209

Abstract

Training programs for nail service masters have adopted virtual reality, augmented reality, and AI-driven adaptive platforms at a pace that outstrips the field's capacity to verify what these tools actually teach. Existing evaluations of digital training interventions in cosmetology and adjacent vocational domains report gains in engagement, motivation, and declarative test performance, and treat these gains as proxies for professional competence. This article argues that such gains hold only for content that requires no calibration against a physical safety threshold. The dominant evaluation paradigm has failed to separate attitudinal and knowledge-based outcomes from the procedural mastery of threshold-dependent parameters such as UV/LED cure completeness, where underexecution produces measurable, clinically documented harm. Drawing on photopolymerization chemistry, occupational dermatology, and a structurally identical training-evaluation problem already documented in restorative dentistry, the analysis identifies the specific metric a genuine competency-based evaluation of digital nail-training tools would need to adopt: degree of monomer conversion. Even where this metric has been measured directly, improved procedural delivery has failed to guarantee improved chemical outcome. The article concludes that reforming professional training in this sector requires threshold-based, formulation-aware outcome measures, and that platform adoption alone cannot supply them.

Keywords: nail service training, UV/LED photopolymerization, procedural competency, vocational EdTech, degree of conversion, theory-practice gap

Introduction

A gel nail coating is considered safely cured once its degree of methacrylate group conversion clears roughly ninety percent; below that threshold, unreacted monomer remains mobile within the film and migrates into the surrounding skin, where it functions as a potent sensitizer [2]. 2-Hydroxyethyl methacrylate appears in 58 percent of 394 commercial nail gel products surveyed in a recent market audit, so undercuring produces a documented mechanism of occupational and consumer allergic contact dermatitis [18]. Correct execution of this single step, holding a lamp of adequate and verified output over a layer of appropriate thickness for the full specified interval, counts among the few genuinely safety-critical procedures a nail service master performs, and a vocational training system exists to certify precisely this kind of procedure before a technician works unsupervised.

Digital platforms now routinely supplement or replace apprenticeship-style instruction in nail-service training: the field's own literature reports that VR, AI-driven content sequencing, and online delivery increase engagement and personalize what a trainee sees, without stating what, procedurally, a trainee can then do that could not be done before [10]. These interventions demonstrate improvement in immersion, satisfaction, and declarative recall. They demonstrate nothing about whether a trainee reliably produces a coating above the conversion threshold that separates a safe cure from a sensitizing one. This evaluative gap carries weight: it means the field's central claim, that digital tools improve training, has been validated against outcomes structurally incapable of detecting the failure mode responsible for the profession's best-documented harm. The gap has a specific mechanistic explanation. Media-comparison research established four decades ago that performance gains attributed to a new instructional medium are routinely confounded by the novelty of the medium itself and by uncontrolled differences in instructional method, so satisfaction or short-term recall scores collected shortly after a platform's introduction signal the novelty of encountering the platform as much as anything the technology itself contributed [5]. That confound has never been resolved for nail-service EdTech specifically, because no study in this domain has isolated procedural outcome from either variable.

This gap extends beyond cosmetology. Vocational and health-adjacent training research distinguishes knowledge and attitudinal acquisition from durable, transferable procedural competence, a distinction nursing education had to formalize once simulation-based interventions began reporting strong immediate knowledge gains whose durability under real conditions had not been separately tested [1]. Nail-service training differs from most of that literature in one respect: the procedure in question carries an explicit, chemically defined pass-fail criterion, degree of monomer conversion. That specificity makes the absence of threshold-based evaluation in current assessments of nail-training EdTech conspicuous, and it also permits this article to borrow a fully worked precedent from a field where an almost identical photopolymerization threshold has already been measured directly against training method. That precedent supplies the gap this article addresses, and it resolves, by name, the specific question of whether instrumented training feedback closes it.

Literature Review

The literature evaluating digital and immersive tools in vocational and cosmetology-adjacent training converges on a shared evaluative assumption: gains in learner engagement, motivation, and attitudinal or declarative outcomes constitute evidence that a training method transfers into professional competence. Chiang et al. [4] tested this assumption directly in a cosmetology-adjacent field, applying flow theory and an extended technology acceptance model to 1,200 Taiwanese vocational students learning hair braiding in VR. Their instrument measured perceived usefulness and ease of use as predictors of attitude toward use and behavioral intention, found both pathways significant, and the authors read this as evidence that VR immersive learning sustains vocational training outcomes. That conclusion rests entirely on acceptance and intention variables, so it establishes learner buy-in, a distinction the study does not test against execution quality, and Clark's [5] account of confounded novelty effects predicts that exactly this kind of short-horizon acceptance measure will run inflated. Marougkas et al. [13] synthesized 69 studies on immersive VR personalization published between 2012 and 2022 and extend this picture: even where researchers attempt to move past attitudinal measures toward adaptive, individualized content, most reviewed applications still fail to incorporate adaptive learning content consistently, so the infrastructure needed to check an individual trainee against an individual performance criterion remains underdeveloped across the reviewed literature as a whole, not in any single study alone. Stefan et al. [17] supply the field-wide quantification this pattern needed. Reviewing 136 VR safety-relevant training studies published between 2016 and 2021 and coding each against Kirkpatrick's four evaluation levels, they find that a large majority assess reaction and learning outcomes; behavior- and results-level evidence, the levels at which procedural transfer to real conditions would actually be verified, remains scarce across the corpus. Kirkpatrick's levels were designed specifically to separate a trainee's response to a program from what that program changes in subsequent job performance, so this finding names, at the level of an entire research field, the exact distinction nail-training evaluation has also failed to make. Nuraini et al. [15] narrow this finding to the beauty sector: their PRISMA-based review of 32 studies on immersive simulation in makeup and beauty education, published between 2016 and 2026, documents real gains in psychomotor skill, engagement, and professional confidence, while stating explicitly that the presence of technology alone does not guarantee learning effectiveness and that studies addressing cosmetology education specifically remain limited. This confirms, from inside the target domain, that the pattern identified in adjacent fields holds here too. Harleni et al. [12] and Ezzaim et al. [9] mapped 41 and 93 studies respectively on AI-assisted adaptive learning across vocational education broadly and generalize the limitation further: both identify a persistent gap in longitudinal and outcome-based evaluation across the entire AI-in-TVET literature, which places the absence of procedural-threshold verification as a structural feature of how vocational EdTech research is currently designed, a feature that reaches beyond nail services. Gorbacheva [10] supplies the field's own instance of this pattern: reviewing VR, AI, and e-learning applications in U.S. nail technician training, the account reports gains in engagement and personalized content delivery consistent with the broader literature, names the preservation of hands-on experience as an unresolved concern in its own conclusion, and proposes no metric against which that concern could be tested. These seven sources indicate that engagement and attitude-based validation dominates the field's methodology because it is the measurement infrastructure educational research already possesses, and Clark's [5] novelty-confound together with Stefan et al.'s [17] Kirkpatrick-level count explain why that infrastructure persists and why it cannot detect the specific failure this article addresses.

Two adjacent fields, nursing simulation and restorative dentistry, have already operationalized the separation between attitudinal and procedural outcomes for procedures with an externally verifiable correctness criterion. Alharbi et al. [1] reviewed simulation-based learning in nursing education across studies from 2017 to 2023 using Joanna Briggs appraisal criteria and found that simulation reliably improves knowledge and skill scores immediately after training; few of the reviewed studies test retention beyond five months, and this gap forced the field to build a distinction between acquisition and durable competence once it became clear the two do not move together. Daneshfar and Moonaghi [6] synthesized simulation research in nursing education from 2010 to 2025, named the phenomenon directly as a theory-practice gap, and found that high-fidelity, structured scenario-based simulation proves particularly effective for procedures with an external correctness criterion, citing cardiopulmonary resuscitation and infection control as examples, both verifiable independent of the learner's own judgment or confidence. Restorative dentistry has confronted a version of this problem that maps onto nail-gel curing almost exactly: dental composite resins cure through the same photopolymerization chemistry, share the same conversion-threshold logic, and have generated a direct empirical literature testing whether training changes the outcome that matters. Price et al. [16] established the baseline problem: curing-unit irradiance varies between devices and is frequently misreported, because the value manufacturers quote reflects an averaged output at the light tip this finding reproduces, in a clinically regulated field, the same lamp-output uncertainty that governs nail gel curing [2]. De Souza et al. [8] tested whether training corrects for this uncertainty, comparing light-curing performance among dental students taught by different training methods immediately after instruction and again one year later. Burrer et al. [3] isolated the mechanism further, using a patient simulator with real-time irradiance feedback to measure both the light energy 42 dental students delivered and the resulting degree of conversion, measured directly by FT-IR spectroscopy, before and after individual instruction. Individualized, instrumented training produced a significant increase in delivered irradiance ($p <$

.001) with markedly reduced variability across students, exactly the kind of procedural, threshold-relevant outcome the nail-training literature has never measured. Degree of conversion, the chemical endpoint itself, showed no corresponding significant improvement. Because these two adjacent fields share an identical chemical mechanism with nail gel curing, their combined finding supplies more than a template for what to measure: it establishes that a training intervention correctly aimed at the procedural bottleneck, verified irradiance delivery instead of self-reported confidence, can still fail to close the gap between what the trainee does and what the material chemistry requires, a result the discussion below returns to directly.

Four sources trace the causal chain connecting nail-product formulation chemistry to a documented clinical harm, running from device output through layer geometry to allergic sensitization. Gorbacheva [11] describes intelligent UV/LED curing systems built around sensor feedback and microcontroller-adjusted output, designed to match the emitted spectrum, typically centered near 365 and 405 nanometers, to the absorption band of the gel's photoinitiator, and identifies layer thickness as a governing variable: light intensity attenuates through a pigmented film according to the Bouguer-Lambert relationship, leaving the base of a thick layer under-cured even when the surface appears solid. Bednarczyk and Rożniakowski [2] supply the missing empirical link at the formulation level. Using real-time FT-IR spectroscopy under dual 365/405 nanometer LED irradiation, they measured degree of methacrylate conversion directly across several photoinitiator systems and found that different systems reach adequate conversion at different exposure times, a result that rules out any single fixed cure duration as safe across products and directly complicates any training curriculum built around a memorized count, epoxide, and thiol chemistries used in UV-curable nail polishes generally and confirm that this thickness- and formulation-dependent conversion problem characterizes the product category, not one manufacturer's chemistry. De Groot and Rustemeyer [7] close the chain at the clinical endpoint: their extensive case-series review documents 2-hydroxyethyl methacrylate as the most frequently reacting allergen in patch-tested nail technicians and consumers, a finding Steunebrink et al. [18] corroborate in an eight-year retrospective clinical study of acrylate-containing nail cosmetics. Together, this cluster establishes a complete, instrumented chain from photoinitiator chemistry, through device output and layer geometry, to a specific, epidemiologically documented harm, and a training curriculum needs to verify mastery of this exact chain, not general digital literacy.

Discussion

Digital training tools improve engagement, confidence, and declarative recall; the first cluster of evidence is consistent on this point. The field has validated their success against outcomes that were never designed to register a specific failure mode, because attitudinal and procedural competence occupy separate dimensions that co-occur in some content and diverge sharply in others. Chiang et al.'s [4] flow-theory and extended technology-acceptance framework treats perceived usefulness and behavioral intention as adequate evidence that a vocational training method sustains its stated purpose; the evidence assembled here indicates that this equivalence breaks down exactly where a physical threshold governs correct execution. Degree of monomer conversion is a function of irradiance, wavelength match, and layer thickness [2], none of which correlate with the perceived-usefulness or flow-experience constructs Chiang et al.'s instrument measures. A highly engaged, confident trainee operating a degraded or underpowered lamp can still produce an undercured, sensitizing coating while scoring at ceiling on every attitudinal item in the survey. Chiang et al.'s domain, hair braiding, has no equivalent chemical threshold, so their acceptance-based validation suits their own case; the reviewed nail-training literature applies the same validation logic to a curing procedure, extending a method beyond the conditions under which Clark [5] and Stefan et al. [17] show it holds.

The nursing simulation literature shows that recognizing this distinction changes what gets measured. Daneshfar and Moonaghi [6] and Alharbi et al. [1] document that criterion-based procedures were pulled out of general knowledge-and-attitude assessment and given dedicated, instrument-verified outcome measures once retention data revealed that early gains did not predict later procedural reliability. Nail-service curing carries the same structural property that triggered this methodological shift in nursing, a checkable pass-fail threshold, which is why the absence of an equivalent shift in nail-training research reads as an import failure, not a domain-specific limitation.

The dental-curing literature complicates a simpler version of this argument in a way the analysis has to state directly. One could conclude that the fix is straightforward: replace attitudinal survey outcomes with instrumented, threshold-based procedural measures, following the nursing precedent, and the gap closes. Burrer et al. [3] show this conclusion falls short. Individualized, real-time-feedback training in their study produced a clear, statistically robust improvement in the procedural variable most directly under the trainee's control, delivered irradiance, with sharply reduced between-student variability, exactly the kind of result a well-designed nail-curing training module should also produce. Degree of conversion, the chemical endpoint that determines whether the material is safe, did not improve to a statistically significant degree alongside it. This result does not undercut threshold-based training evaluation; it demonstrates that the threshold sits downstream of more variables than trainee technique alone, including the formulation- and thickness-dependent factors Bednarczyk and Rożniakowski [2] and Gorbacheva [11] identify. A training intervention that corrects irradiance delivery alone targets one node in a causal chain that also runs through product selection, layer application thickness, and photoinitiator-spectrum matching, and the trainee's lamp technique cannot compensate for any of these on its own. Burrer et al.'s [3] null result on conversion, obtained in a field that has already built the instrumentation this article argues nail-training research lacks, stands as the

strongest available evidence that closing the nail-service instrumentation gap will not by itself guarantee safe outcomes. It supplies the precondition for discovering which further variable, product formulation, application protocol, or device calibration, is responsible when a trained technician's cure still falls short, a diagnostic capacity current engagement-based evaluation cannot provide at all.

The clearest evidence for this divergence appears within a single author's own published output, where the oversight shows itself as structural. The account of digital training technologies for nail-service education [10] evaluates VR and AI tools exclusively through immersion, personalization, and satisfaction outcomes. The companion account of intelligent UV/LED curing systems [11] independently establishes the precise physical criterion, spectral-matched, sensor-verified conversion, against which any training method's procedural output could in principle be checked.

Conclusion

This analysis makes possible a specific reframing of what "effective training" should mean for digital and immersive tools in nail-service education. The reframing sets aside improved engagement or attitude scores, outcomes the existing literature already documents adequately, and demands demonstrated trainee output at or above a defined degree-of-conversion threshold, verified by instrument. The dental-curing precedent adds a caution to this standard: improved trainee technique alone may fail to guarantee that threshold. The materials-science and device-engineering literature, including work on sensor-verified intelligent curing systems [11], has already built part of the measurement apparatus this reframing requires. What remains is importing it into training-outcome design, following the precedent set by criterion-based simulation research in nursing and dental education, while treating the dental field's own null result on conversion as a warning against assuming that a fixed training pipeline resolves a chain that also runs through formulation and equipment.

References:

1. Alharbi, A., Nurfianti, A., Mullen, R. F., McClure, J. D., & Miller, W. H. (2024). The effectiveness of simulation-based learning (SBL) on students' knowledge and skills in nursing programs: A systematic review. Bmc Medical Education, 24(1), 1099. https://doi.org/10.1186/s12909-024-06080-z
2. Bednarczyk, P., & Rożniakowski, K. (2025). The influence of the photoinitiating system on residual monomer contents and photopolymerization rate of a model pigmented UV/LED nail gel formulation. Coatings, 15(10), 1125. https://doi.org/10.3390/coatings15101125
3. Burrer, P., Par, M., Attin, T., & Tauböck, T. T. (2021). Real-time feedback of the applied light-curing technique and its impact on degree of conversion of composite restorations — A study with undergraduate dental students. Journal of Personalized Medicine, 11(10), 1012. https://doi.org/10.3390/jpm11101012
4. Chiang, S., Chiang, D., Chang, S.-H., & Yao, K.-C. (2025). Innovative virtual reality teaching for the sustainable development of vocational high school students: A case study of hair braiding. Sustainability, 17(9), 3945. https://doi.org/10.3390/su17093945
5. Clark, R. E. (1983). Reconsidering research on learning from media. Review of Educational Research, 53(4), 445–459. https://doi.org/10.3102/00346543053004445
6. Daneshfar, M., & Moonaghi, H. K. (2025). The impact of clinical simulation on bridging the theory–practice gap in nursing education: A systematic review. BMC Medical Education, 25, 1216. https://doi.org/10.1186/s12909-025-07790-8
7. de Groot, A. C., & Rustemeyer, T. (2023). 2-Hydroxyethyl methacrylate (HEMA): A clinical review of contact allergy and allergic contact dermatitis. Part 1. Introduction, epidemiology, case series and case reports. Contact Dermatitis, 89(6), 401–433. https://doi.org/10.1111/cod.14405
8. De Souza, G. M., El-Badrawy, W., & Tam, L. E. (2018). Effect of training method on dental students' light-curing performance. Journal of Dental Education, 82(8), 864–871. https://doi.org/10.21815/JDE.018.081
9. Ezzaim, A., Dahbi, A., Haidine, A., & Aqqal, A. (2023). AI-based adaptive learning: A systematic mapping of the literature. Journal of Universal Computer Science, 29(10), 1161–1197. https://doi.org/10.3897/jucs.90528
10. Gorbacheva, I. (2025). Digital educational technologies in training beauty industry professionals. In N. Khodakova (Ed.), Recent Scientific Investigation: Proceedings of the LXXIII International Multidisciplinary Conference (pp. 6–41). Primedia E-launch LLC.
11. Gorbacheva, Iu. (2025). Интеллектуальные UV/LED-системы для безопасного моделирования ногтей [Intelligent UV/LED systems for safe nail modeling]. LAP LAMBERT Academic Publishing.
12. Harleni, H., Giatman, M., Syah, N., Ganefri, G., Jalinus, N., Ridwan, R., & Krismadinata, K. (2025). Bibliometric and systematic review of AI-assisted adaptive learning applications in vocational education (2018–2023). Al-Ishlah: Jurnal Pendidikan, 17(4), 8634–8646.
13. Marougkas, A., Troussas, C., Krouska, A., & Sgouropoulou, C. (2024). How personalized and effective is immersive virtual reality in education? A systematic literature review for the last decade. Multimedia Tools and Applications, 83, 18185–18233. https://doi.org/10.1007/s11042-023-15986-7
14. Mieriņa, I., Grigale-Sorocina, Z., & Birks, I. (2025). The chemistry behind UV-curable nail polishes. Polymers, 17(9), 1166. https://doi.org/10.3390/polym17091166
15. Nuraini, I., Mukti, R. A., Fatmasari, F. H., & Joshua, Q. P. (2026). From conventional practice to immersive simulation: A systematic literature review on virtual professional makeup as transformative learning media. Edcomtech: Jurnal Kajian Teknologi Pendidikan, 11(1), 86–107.
16. Price, R. B., Ferracane, J. L., & Shortall, A. C. (2015). Light-curing units: A review of what we need to know. Journal of Dental Research, 94(9), 1179–1186. https://doi.org/10.1177/0022034515594786

17. Stefan, H., Mortimer, M., & Horan, B. (2023). Evaluating the effectiveness of virtual reality for safety-relevant training: A systematic review. Virtual Reality, 27, 2839–2869. https://doi.org/10.1007/s10055-023-00843-7

18. Steunebrink, I. M., de Groot, A., & Rustemeyer, T. (2024). Contact allergy to acrylate-containing nail cosmetics: A retrospective 8-year study. Contact Dermatitis, 90(3), 262–265. https://doi.org/10.1111/cod.14475