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Association Between Diagnostic Error Educational Content and Diagnostic Error Recognition in Resident Physicians: A Nationwide Cross-sectional Study

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Association Between Diagnostic Error Educational Content and Diagnostic Error Recognition in Resident Physicians: A Nationwide Cross-sectional Study

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Abstract

Background: Diagnostic error (DE) recognition, an essential and modifiable component of DE reduction, can be influenced by educational content; however, the types of DE education associated with DE recognition remain unclear. We tested the hypothesis that the association between DE education and DE recognition differs by educational content.

Methods: We conducted a nationwide cross-sectional study of Japanese resident physicians from 696 hospitals who completed the General Medicine In-Training Examination in January 2024 and a post-examination survey. The independent variables were self-reported exposure to nine DE education domains: medical knowledge, clinical reasoning, system-related errors, patient involvement in diagnosis, diagnostic uncertainty, patient experience, patient safety, DE case reflection, and simulation-based education. The outcome was DE recognition during clinical training. Associations were examined using multilevel Poisson regression with hospital-clustered robust standard errors, adjusting for prespecified covariates and multiple comparisons.

Results: Among 6,240 respondents to the DE education question, 3,801 (60.9%) reported having received DE education. Of 6,180 respondents to the DE recognition question, 3,302 (53.4%) reported recognizing DE during training. DE recognition was associated with education on clinical reasoning (adjusted prevalence ratio [aPR] 1.16, 95% confidence interval [CI] 1.07–1.27), system-related errors (aPR 1.15, 95% CI 1.06–1.25), diagnostic

uncertainty (aPR 1.18, 95% CI 1.09–1.29), and DE case reflection (aPR 1.22, 95% CI 1.12–1.33).

Conclusions: DE recognition was more strongly associated with reflective, system-focused DE education that addresses diagnostic uncertainty than with knowledge-focused instruction or simulation-based education. This approach may play an important role in future efforts to reduce DE.

Keywords: diagnostic error; diagnostic error education; resident physicians; clinical reasoning; diagnostic uncertainty.

Background Diagnostic error (DE) is defined as the failure to establish an accurate and timely explanation for a patient's health problem or to communicate that explanation to the patient [1]. DE is common, reportedly occurring in 5%–10% of routine clinical practice [2, 3]. When DE occurs, it causes harm to the patient in approximately half of cases [4]. Furthermore, DE is the most common cause of medical malpractice lawsuits and accounts for the highest litigation costs [5, 6]. Therefore, reducing DE is imperative.

The ability to recognize whether a DE has occurred is essential for reducing DE [4, 7]. Previous studies of medical students have shown that DE education is associated with DE recognition, suggesting that DE educational interventions may influence DE recognition [8]. DE education is diverse, encompassing reflection on case histories, enhancement of clinical knowledge, and simulation-based education, all of which have been shown to improve diagnostic accuracy [9–11].

However, few studies have investigated DE recognition itself or examined which types of education lead to DE recognition. A fundamental premise of this study is that DE is common; therefore, the probability of not encountering DE during training is low. We believe that the key issue is whether trainees recognize DE that occurs at the point of care. We hypothesized that practice-based reflective learning and simulation-based education would be associated with greater DE recognition, whereas educational approaches focused primarily on strengthening clinical knowledge outside the clinical context do not. To test this hypothesis, we examined the association between each type of DE educational approach and DE recognition.

Methods

Setting and Participants

This cross-sectional study was conducted in January 2024, targeting resident physicians in

Japan. The survey was conducted after the General Medicine In-Training Examination (GM-ITE®), and examinees who did not provide consent were excluded. The participants were postgraduate year 1 (PGY-1) and postgraduate year 2 (PGY-2) resident physicians from 696 hospitals, representing 68% of all hospitals with residency training programs nationwide. Japanese resident physicians choose either a university hospital or a community-based hospital to undergo a 2-year training program administered by the Ministry of Health, Labour and Welfare. During this period, they rotate through required clinical departments, including internal medicine, surgery, obstetrics and gynecology, pediatrics, psychiatry, and emergency medicine, as well as elective departments [12, 13].

The GM-ITE®, an annual assessment test developed by the Japan Institute for Advancement of Medical Education Program, measures the general clinical knowledge and applied skills of Japanese postgraduate trainees through 80 multiple-choice questions. Trainees voluntarily apply to participate, with 49.1% of Japan's trainees having participated in 2023.

Variables

The primary outcome was determined using the following survey question: "Did you recognize diagnostic errors during your clinical training, including those involving patients other than your own?" This question was developed from a review of the existing literature and subsequently refined through focus group discussions among members of the research

team to ensure content validity, in accordance with established guidelines for questionnaire development in medical education research [14]. Participants responded either “Yes” or “No.” To assess DE education, participants were first asked, “Have you ever received diagnostic error education?” and responded either “Yes” or “No.” Participants who responded “Yes” were then asked to identify all previously received educational content from the following nine options (multiple responses permitted): education to strengthen medical knowledge to reduce errors, education to strengthen clinical reasoning to reduce errors, education to foster understanding of system-related errors, education to effectively involve patients in diagnosis, education to understand diagnostic uncertainty, education based on patient experiences, education on patient safety, education involving reviews of actual DE cases, and simulation-based education [1, 9–11, 15]. Participants could also provide a nonspecific answer. Additional data collected included postgraduate year (PGY-1 or PGY-2), sex, age, number of hospital beds, hospital location (urban, defined as the 20 cities designated by the Ministry of Internal Affairs and Communications and the 23 wards of Tokyo, or rural, defined as all other areas), hospital type (community-based hospital or university hospital), average monthly number of emergency on-call shifts, average daily number of inpatients, average daily study time, weekly working hours, and number of co-residents.

Ethical Considerations

This study was approved by the Ethics Committee of the Japan Institute for Advancement of

Medical Education Program (No. 23–17). The study was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines and conducted in accordance with the principles of the Declaration of Helsinki [16]. All methods were performed in accordance with the Ethical Guidelines for Medical and Health Research Involving Human Subjects. Before participation, all participants reviewed a research document detailing data anonymization and the publication of research results and provided written informed consent. The participants were free to withdraw from the study at any time.

Statistical Analysis

All background variables were summarized using descriptive statistics, stratified by receipt of DE education. Continuous variables were presented as means with standard deviations. For categorical variables, missing responses were shown in a separate row but were excluded from the denominator when percentages were calculated. For continuous variables, all available observations were analyzed without imputation.

Associations between covariates and DE recognition were examined using Poisson regression models with a log link to estimate prevalence ratios (PRs) and 95% confidence intervals (CIs). Because residents were clustered within hospitals, multilevel Poisson regression models with a random intercept for hospital were fitted. Robust standard errors clustered at the hospital level were used to account for within-hospital correlation. Effect

estimates were reported as exponentiated fixed-effect coefficients.

Univariable models were fitted separately for each predictor. Multivariable models included all prespecified covariates: postgraduate year, sex, age category, number of beds (per 10-bed increase, mean-centered), hospital location, hospital type, on-call frequency, inpatient caseload, daily study time, weekly working hours, number of co-residents, and receipt of DE education. Continuous variables were modeled linearly. Variance inflation factors (VIFs) were examined to assess multicollinearity, with a VIF $\geq$10 considered indicative of high collinearity. “Unsure” responses for on-call frequency and inpatient caseload were treated as missing and excluded from the regression analyses. Analyses were conducted using complete-case data for the variables included in each model.

For the primary analyses of DE education, nine separate multivariable multilevel Poisson regression models were fitted. Each model included one education content category in addition to the prespecified covariate set described above. As educational content variables allowed multiple responses (participants could endorse more than one item), individual models estimated the association of each content type without fully disentangling overlapping effects across items. Adjusted PRs (aPRs) and 95% CIs are reported.

To account for multiple comparisons across the nine educational content categories, Bonferroni-adjusted p-values were also calculated.

All statistical tests were two-sided, with a significance level of 0.05. All analyses

were performed using R software (version 4.4.1).

Results

A total of 9,106 individuals completed the GM-ITE. After excluding 2,522 examinees who did not provide consent for the questionnaire survey, 6,584 participants were included in the analysis. Among the participants, 3,432 (52.1%) were PGY-1 residents, 2,164 (32.9%) were female, and 1,966 were aged 26 years (30.0%). The mean number of hospital beds was 556 ± 224. A total of 4,466 participants (67.8%) were from rural hospitals, and 5,406 (82.1%) were from community-based hospitals. Regarding the participants' work backgrounds, the most common categories were 3–5 emergency on-call shifts per month (4,516 participants, 69.3%), an average of 5–9 inpatients under their care (3,380, 51.7%), an average daily study time of 0–30 min (2,797, 43.3%), a weekly working time of <60 h (3,604, 55.7%), and 6–10 co-residents (1,826, 28.2%). Among the 6,240 respondents to the DE education question, 3,801 (60.9%) had received DE education. Among the 6,180 respondents to the DE recognition question, 3,302 (53.4%) had recognized DE. The most common type of DE education was medical knowledge reinforcement (2,050, 53.9%), followed by education on system-related errors (1,957, 51.5%) and education on diagnostic uncertainty (1,448, 38.1%). In contrast, education based on patient experiences was the least common (263, 6.9%) (Table 1).

The multivariable analysis identified the following characteristics as being

associated with DE recognition: PGY-2 status, male sex, a rural hospital location, employment at a community-based hospital, and an inpatient caseload of ≥10 patients (Table 2). Additionally, participants who had received DE education had a higher prevalence of DE recognition (aPR 1.61, 95% CI 1.52–1.70, $p < 0.001$). All VIF values were <10, indicating the absence of significant multicollinearity.

After Bonferroni correction, DE recognition was associated with education on clinical reasoning (aPR 1.16, 95% CI 1.07–1.27), system-related errors (aPR 1.15, 95% CI 1.06–1.25), diagnostic uncertainty (aPR 1.18, 95% CI 1.09–1.29), and error case reflection (aPR 1.22, 95% CI 1.12–1.33). Education on medical knowledge, patient involvement in diagnosis, patient experience, and patient safety, as well as simulation-based education, was not significantly associated with DE recognition after this correction (Table 3).

Discussion

The results of this study indicate that DE recognition was associated with education on clinical reasoning, system-related errors, diagnostic uncertainty, and error case reflection. In contrast, neither education focused on enhancing medical knowledge nor simulation-based education showed an association with DE recognition.

Previous studies have reported that enhancing medical knowledge is relatively effective in reducing DE. Specifically, increased knowledge of clinical findings may reduce

susceptibility to cognitive biases, thereby reducing DE, and greater knowledge of how to distinguish similar diseases may further reduce DE [9, 17, 18]. However, studies that have evaluated the effectiveness of knowledge reinforcement have primarily used paper-based assessment formats, and investigations into the extent to which learned knowledge influences clinical practice have been limited. Our findings suggest that reinforcement of medical knowledge is not associated with DE recognition, and issues related to knowledge retention and application may have contributed to this finding. To consolidate knowledge, it is crucial to repeat and review learned concepts. Educators must also move beyond simply providing knowledge in the classroom and instead create learning opportunities focused on practical application [19, 20].

Simulation-based education is widely used, particularly in the field of patient safety, and multiple studies have demonstrated its effectiveness at the workplace level. “In situ simulation” conducted in actual clinical settings, such as hospital wards, may improve certain patient outcomes, primarily through process improvement and resuscitation response [21]. Furthermore, introducing simulation-based training for central venous catheter insertion has been associated with significant reductions in catheter-related bloodstream infections in actual clinical practice [22]. In the field of DE, simulation-based education has been reported to improve diagnostic accuracy rates within simulations, enhance the ability to gather information from patients to reduce DE, and facilitate recognition of red-flag conditions

through video-based education [23–25]. However, unlike research in the field of medical safety, research on DE has undergone limited validation in clinical settings. Contrary to our hypothesis, simulation-based education was not associated with DE recognition. One possible explanation is that skills acquired during simulation may not transfer directly to the clinical setting and may require additional reinforcement to be effectively applied. In addition, challenges related to adaptive and flexible clinical reasoning may limit the translation of simulated learning into practice [26, 27]. Therefore, simulation-based DE education may be more effective when focused on improving clinical reasoning or centered on specific diseases and situations.

The challenge for both knowledge-focused and simulation-based education is practical application in the clinical setting. Reflection on DE cases, which was associated with DE recognition in this study, may help address this challenge. Previous studies have suggested that case reflection is an effective method for reducing DE [28, 29]. Reports indicate that reflection on actual cases improves diagnostic accuracy and that deliberate reflection on cases enhances the ability to identify key disease characteristics [10, 30]. Therefore, reflection on diagnostic error cases may facilitate the recognition of future DE. In particular, reflecting on cases personally experienced or observed among colleagues may be especially memorable and more easily applied to future experiences. Furthermore, reflecting on successful diagnostic cases, consistent with the Safety-II concept, may also be effective

for the recognition of DE [31]. Reflection on clinical cases may therefore play a key role in recognizing DE, clarifying challenges in reducing DE that occurs on-site, and building a diagnostic safety culture.

A deeper understanding of system-related errors, although differing in focus from reflection on cases, may also be important for DE recognition. Previous studies have reported that system-related factors are important causes of DE [2, 32]. For example, reports on hospitalists suggest that systemic issues—such as communication within and outside electronic medical records, siloed organizational structures, handoffs, interruptions, time constraints, and the physical environment—can lead to failures in cognitive processes, including inadequate information gathering, processing, and verification [33]. Therefore, learning about and attempting to resolve system-related errors is critically important. Several studies have examined the effects of understanding systems. Reports indicate that incident reporting education improves attitudes and intentions toward incident reporting among residents and that learning systems thinking improves systems thinking scores among medical students [34, 35]. For learners with limited exposure to healthcare systems, including medical students and residents, such educational approaches may substantially improve systems awareness and understanding. In Japan, opportunities for medical students and residents to learn about the healthcare system remain limited; therefore, educational interventions targeting systems understanding may have a particularly strong impact. We

249 believe that a dual-track educational approach combining case reflection and systems
250 learning may be particularly effective for beginners. In addition to these two approaches,
251 learning clinical reasoning and understanding the uncertainty inherent in medicine may lead
252 to recognizing DE and ultimately reducing it.
253
254 **Limitations**
255 This study has some limitations. First, owing to its cross-sectional design, causality cannot be
256 established, and the temporal relationship between DE recognition and DE education remains
257 unclear. Second, the study did not examine the quality of DE education; therefore, it remains
258 unclear which specific educational approaches within each category were most effective.
259 Third, the number of educational sessions received was not investigated. Fourth, although
260 this study involved a large-scale survey of Japanese residents, the generalizability of its
261 findings to residents or medical students in other countries remains poor. Fifth, both DE
262 education and DE recognition were based on self-reported data. Sixth, because participants
263 could select multiple educational categories, the single-item models were unable to fully
264 disentangle overlapping effects among the different types of education. Nevertheless, to our
265 knowledge, this is the first study to examine which types of DE education are associated with
266 DE recognition among resident physicians.
267

Conclusion

DE recognition was more strongly associated with reflective, system-focused DE educational approaches that addressed diagnostic uncertainty than with knowledge-based instruction or simulation-based education. This approach may play a crucial role in future efforts to reduce DE. In future research, we aim to focus on more specific educational content and explore teaching methods that are more effective in improving DE recognition.

Abbreviations

aPR: Adjusted prevalence ratio

CI: Confidence interval

DE: Diagnostic error

GM-ITE: General Medicine In-Training Examination

PGY-1: Postgraduate year 1

PGY-2: Postgraduate year 2

PR: Prevalence ratio

STROBE: Strengthening the Reporting of Observational Studies in Epidemiology

VIF: Variance inflation factor

Declarations

Ethics approval and consent to participate: This study was approved by the Ethics Committee of the Japan Institute for Advancement of Medical Education Program (No. 23–17). Written informed consent was obtained from all participants.

Consent for publication Not applicable

Data availability statement

The data are unavailable due to participants' non-consent for public data sharing.

Competing interests statement

Dr. Nishizaki received an honorarium from JAMEP as GM-ITE project manager. Dr. Tokuda is the JAMEP director. Dr. Tokuda received an honorarium from JAMEP as speakers of the JAMEP lecture. Dr. Shimizu received an honorarium from JAMEP as exam preparers of GM-ITE. This research was presented orally at the 56th Annual Meeting of the Japan Society for Medical Education on 10 August 2024. The other authors have no competing interests to declare.

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Author contributions

TM and YN had full access to all of the data in the study, and they take responsibility for the integrity of the data and the accuracy of the data analysis.

Conceptualization: TM, YN, MS, TS, TW, YY and YT.

Data curation: TM, YN and MS.

Formal analysis: TM, YN, MS and KR.

Funding acquisition: YN, TN and YT.

Investigation: TM, YN, YY, TS, WT, KR, TN and YT.

Methodology: TM, YN, TS, YY and YT.

Project administration: TM, YN, TN and YT.

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Software: TM, YN, MS and TW.

Supervision: TS, TN, KR and YT.

Validation & Visualization: TM, YN, KR and YT.

Writing-original draft: TM and YN.

Writing-review and editing: All authors.

Acknowledgments: N/A

Appendices

Appendix table 1: Categories and definitions of diagnostic error education

Appendix Table 2: The Relationship Between Diagnostic Recognition and Education to Strengthen Medical Knowledge

Appendix Table 3: The Relationship Between Diagnostic Recognition and Education to Strengthen Clinical Reasoning

Appendix Table 4: The Relationship Between Diagnostic Recognition and Education to Foster Understanding of System-related Errors

Appendix Table 5: The Relationship Between Diagnostic Recognition and Education to Effectively Engage Patients in the Diagnostic Process

Appendix Table 6: The Relationship Between Diagnostic Recognition and Education to Understand Diagnostic Uncertainty

Appendix Table 7: The Relationship Between Diagnostic Recognition and Education Designed to Help Healthcare Professionals Experience the Patient perspective

Appendix Table 8: The Relationship Between Diagnostic Recognition and Education to Understand Patient Safety Principles and Concepts Related to Diagnostic Errors

Appendix Table 9: The Relationship Between Diagnostic Recognition and Education Involving Review and Analysis of Real Diagnostic Error Cases

Appendix Table 10: The Relationship Between Diagnostic Recognition and Simulation-based Training to Learn About Diagnostic Errors

References

1. Balogh EP, Miller BT, Ball JR, editors; Committee on Diagnostic Error in Health Care; Board on Health Care Services; Institute of Medicine; The National Academies of Sciences, Engineering, and Medicine. Improving Diagnosis in Health Care. Washington, DC: National Academies Press; 2015.
2. Graber ML, Franklin N, Gordon R. Diagnostic error in internal medicine. Arch Intern Med. 2005;165:1493–9. DOI: 10.1001/archinte.165.13.1493.
3. Singh H, Meyer AN, Thomas EJ. The frequency of diagnostic errors in outpatient care: estimations from three large observational studies involving US adult populations. BMJ Qual Saf. 2014;23:727–31. DOI: 10.1136/bmjqs-2013-002627.
4. Singh H, Giardina TD, Meyer AN, Forjuoh SN, Reis MD, Thomas EJ. The global burden of diagnostic errors in primary care. BMJ Qual Saf. 2017;26:484–94. DOI: 10.1136/bmjqs-2016-005401.
5. Grenon V, Blais R, Le Borgne M, et al. Factors associated with diagnostic error: an analysis of closed medical malpractice claims. J Patient Saf. 2023;19:211–5. DOI: 10.1097/pts.0000000000001105.

6. Saber Tehrani AS, Lee H, Mathews SC, et al. 25-year summary of US malpractice claims for diagnostic errors 1986–2010: an analysis from the National Practitioner Data Bank. BMJ Qual Saf. 2013;22:672–80. DOI: 10.1136/bmjqs-2012-001550.
7. Croskerry P. Clinical cognition and diagnostic error: applications of a dual process model of reasoning. Adv Health Sci Educ Theory Pract. 2009;14:27–35. DOI: 10.1007/s10459-009-9182-2.
8. Miyagami T, Shimizu T, Tokuda Y, et al. Association of diagnostic error education and recognition frequency among Japanese medical students: a nationwide cross-sectional study. Diagnosis (Berl). 2024;11:192–4. DOI: 10.1515/dx-2023-0105.
9. Mamede S, Schmidt HG, van den Berg S, et al. Specific disease knowledge as predictor of susceptibility to availability bias in diagnostic reasoning: a randomized controlled experiment. J Gen Intern Med. 2021;36:640–6. DOI: 10.1007/s11606-020-06182-6.
10. Mamede S, Schmidt HG, Penaforte JC. Effects of reflective practice on the accuracy of medical diagnoses. Med Educ. 2008;42:468–75. DOI: 10.1111/j.1365-2923.2008.03030.x.
11. Kotwal S, Ebrahim R, Cudemus G, et al. Real-world virtual patient simulation to improve diagnostic performance through deliberate practice: a prospective quasi-experimental study. Diagnosis (Berl). 2021;8:489–96. DOI: 10.1515/dx-2020-0127.

12. Nishigori H. Medical education in Japan. Med Teach. 2024;46:S4–10. DOI: 10.1080/0142159X.2024.2372108.

13. Ministry of Health, Labour and Welfare. Guideline for Clinical Training of Medical Practitioners—Fiscal Year 2020 Edition. Tokyo: Ministry of Health, Labour and Welfare; 2020. Available from: https://www.mhlw.go.jp/content/10800000/ishirinsyokensyu_guideline_2020.pdf.

14. Artino AR Jr, La Rochelle JS, Dezee KJ, Gehlbach H. Developing questionnaires for educational research: AMEE Guide No. 87. Med Teach. 2014;36:463–74. DOI: 10.3109/0142159X.2014.889814.

15. Mamede S, van Gog T, van den Berge K, et al. Exploring the role of salient distracting clinical features in the emergence of diagnostic errors and the mechanisms through which reflection counteracts mistakes. BMJ Qual Saf. 2012;21:295–300. DOI: 10.1136/bmjqs-2011-000518.

16. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP; STROBE Initiative. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. Lancet. 2007;370:1453–7. DOI: 10.1016/S0140-6736(07)61602-X.

17. Mamede S, Schmidt HG, Rikers RM, et al. “Immunising” physicians against availability bias in diagnostic reasoning: a randomised controlled experiment. BMJ

399 Qual Saf. 2020;29:550–9. DOI: 10.1136/bmjqs-2019-010079.
400 18. Mamede S, van den Berg S, van Gog T, et al. Role of knowledge and reasoning
401 processes as predictors of resident physicians' susceptibility to anchoring bias in
402 diagnostic reasoning: a randomised controlled experiment. BMJ Qual Saf.
403 2024;33:563–72. DOI: 10.1136/bmjqs-2023-016621.
404 19. Cook DA, Levinson AJ, Garside S, Dupras DM, Erwin PJ, Montori VM. Instructional
405 design variations in internet-based learning for health professions education: a
406 systematic review and meta-analysis. Acad Med. 2010;85:909–22. DOI:
407 10.1097/ACM.0b013e3181d6c319.
408 20. Albert FA, Currie MJ, Clanchy KM, Brien JA. A systematic review of medical
409 practitioners' retention and application of basic sciences to clinical practice. BMC
410 Med Educ. 2024;24:997. DOI: 10.1186/s12909-024-05952-8.
411 21. Goldshtein D, Ben-Tovim DI, Ben-David M. In situ simulation and its effects on
412 patient outcomes: a systematic review. BMJ Simul Technol Enhanc Learn. 2020;6:3–
413 9. DOI: 10.1136/bmjstel-2018-000387.
414 22. Barsuk JH, Cohen ER, Feinglass J, McGaghie WC, Wayne DB. Use of simulation-
415 based education to reduce catheter-related bloodstream infections. Arch Intern Med.
416 2009;169:1420–3. DOI: 10.1001/archinternmed.2009.215.
417 23. Dekhtyar M, Apter AJ, Matsui EC, et al. Use of a structured approach and virtual

418 simulation practice to improve diagnostic reasoning. Diagnosis (Berl). 2022;9:69–76.
419 DOI: 10.1515/dx-2020-0160.
420 24. Plackett R, Kassianos AP, Nair S, et al. Online patient simulation training to improve
421 clinical reasoning: a feasibility randomised controlled trial. BMC Med Educ.
422 2020;20:245. DOI: 10.1186/s12909-020-02168-4.
423 25. Miyagami T, Shimizu T, Tokuda Y. A mixed methods study comparing video based
424 and paper based diagnostic error education for medical students. Sci Rep.
425 2025;15:2432. DOI: 10.1038/s41598-025-32339-6.
426 26. Masoomi R, Roudbari M, Fard M, et al. Transfer of learning from simulated setting to
427 the clinical setting: identifying instructional design features. Med J Islam Repub Iran.
428 2021;35:90. DOI: 10.47176/mjiri.35.90.
429 27. Plackett R, Kassianos AP, Skeens M, et al. The effectiveness of using virtual patient
430 educational tools to improve medical students' clinical reasoning skills: a systematic
431 review. BMC Med Educ. 2022;22:365. DOI: 10.1186/s12909-022-03410-x.
432 28. Schiff GD, Hasan O, Kim S, et al. Diagnostic error in medicine: analysis of 583
433 physician-reported errors. Arch Intern Med. 2009;169:1881–7. DOI:
434 10.1001/archinternmed.2009.333.
435 29. Lambe KA, O'Reilly G, Kelly BD, Curley HM. Dual-process cognitive interventions
436 to enhance diagnostic reasoning: a systematic review. BMJ Qual Saf. 2016;25:808–

20. DOI: 10.1136/bmjqs-2015-004417.

30. Kuhn J, Wiese B, Ortwein H. Teaching medical students to apply deliberate reflection. Med Teach. 2024;46:65–72. DOI: 10.1080/0142159X.2023.2229504.

31. Shimizu T. Learning from what goes right: a safety-II framework for improving diagnosis at the point of care. Diagnosis (Berl). 2025;12:181–6. DOI: 10.1515/dx-2025-0086.

32. Singh H, Naik AD, Rao R, et al. System-related interventions to reduce diagnostic errors: a narrative review. BMJ Qual Saf. 2012;21:160–70. DOI: 10.1136/bmjqs-2011-000150.

33. Gupta A, Murphy D, Singh H. Mind the overlap: how system problems contribute to cognitive failure and diagnostic errors. Diagnosis (Berl). 2018;5:151–6. DOI: 10.1515/dx-2018-0014.

34. Gaupp R, Körner M, Fabry G. Effects of a case-based interactive e-learning course on knowledge and attitudes about patient safety: a quasi-experimental study with third-year medical students. BMC Med Educ. 2016;16:172. DOI: 10.1186/s12909-016-0691-4.

35. Jansma JD, Wagner C, Grobbee DE, Assendelft WJ. Do specialty registrars change their attitudes, intentions and behaviour towards reporting incidents following a patient safety course? BMC Health Serv Res. 2010;10:100. DOI: 10.1186/1472-6963-

456 10-100.

457

Table 1: Participant background		N (total)	
Postgraduate year (PGY-1 or PGY-2)		6,584	
	PGY-1		3,432 (52.1%)
	PGY-2		3,152 (47.9%)
Sex		6,584	
	Male		4,420 (67.1%)
	Female		2,164 (32.9%)
Age (years)		6,549	
	24		227 (3.5%)
	25		1,405 (21.5%)
	26		1,966 (30.0%)
	27		1,341 (20.5%)
	28		597 (9.1%)
	29		292 (4.5%)
	≥30		721 (11.0%)
	Missing		35
Number of hospital beds		6,584	

	Mean (SD)		555.5 (224.3)
Location of the hospital		6,584	
	Rural		4,466 (67.8%)
	Urban		2,118 (32.2%)
Hospital type		6,584	
	Community-based hospital		5,406 (82.1%)
	University hospital		1,178 (17.9%)
Average number of ED on-call shifts per month		6,512	
	0		195 (3.0%)
	1–2		1,207 (18.5%)
	3–5		4,516 (69.3%)
	≥6		571 (8.8%)
	Unsure		23 (0.4%)
	Missing		72
Average number of inpatients usually under the respondent's care		6,534	
	0–4		2,342 (35.8%)
	5–9		3,380 (51.7%)
	10–14		505 (7.7%)
	≥15		162 (2.5%)

	Unsure	145 (2.2%)
	Missing	50
Average daily study time, min	6,457	
	None	204 (3.2%)
	0–30	2,797 (43.3%)
	31–60	2,589 (40.1%)
	61–90	722 (11.2%)
	≥91	145 (2.2%)
	Missing	127
Average weekly working hours, including on-call standby time, h	6,467	
	<60	3,604 (55.7%)
	60–80	1,952 (30.2%)
	>80	911 (14.1%)
	Missing	117
Number of co-residents	6,468	
	1	74 (1.1%)
	2	150 (2.3%)
	3–5	722 (11.2%)
	6–10	1,826 (28.2%)

	11–15		1,637 (25.3%)
	16–20		736 (11.4%)
	21–30		543 (8.4%)
	>30		780 (12.1%)
	Missing		116
Diagnostic Error **Education Received**		6,240	3,801 (60.9%)
Recognized Diagnostic Errors		6,180	3,302 (53.4%)
Content of Education			
	Medical knowledge	3,801	2,050 (53.9%)
	Clinical reasoning	3,801	1,389 (36.5%)
	System-related errors	3,801	1,957 (51.5%)
	Patient involvement in diagnosis	3,801	454 (11.9%)
	Diagnostic uncertainty	3,801	1,448 (38.1%)
	Patient experience	3,801	263 (6.9%)
	Patient safety	3,801	966 (25.4%)
	Reflection on diagnostic error cases	3,801	1,204 (31.7%)
	Simulation-based education	3,801	527 (13.9%)
	Nonspecific answer	3,801	107 (2.8%)

Values are n (%) for categorical variables and mean (SD) for continuous variables. Multiple responses were allowed for the content of diagnostic error education. For education content items, percentages are calculated among respondents who reported having received diagnostic error education (n = 3,801). ED, emergency department; PGY, postgraduate year; SD, standard deviation.

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Table 2: Univariable and multivariable analyses of factors associated with diagnostic error recognition

		Univariable			Multivariable		
		PR	95% CI	p-value	aPR	95% CI	p-value
Postgraduate year	PGY-1	Ref	–	–	Ref	–	–
	PGY-2	1.19	1.14–1.25	<0.001	1.16	1.10–1.22	<0.001
Sex of the respondent	Male	Ref	–	–	Ref	–	–
	Female	0.81	0.77 – 0.85	<0.001	0.85	0.80 – 0.89	<0.001
Age of the respondent (years)	24	Ref	–	–	Ref	–	–
	25	1.04	0.90–1.21	0.595	0.99	0.86–1.14	0.837
	26	1.09	0.94–1.25	0.261	0.96	0.83–1.10	0.559
	27	1.11	0.96–1.28	0.171	0.94	0.81–1.09	0.394

	28	1.13	0.96–1.32	0.136	0.96	0.82–1.12	0.628
	29	0.98	0.82–1.18	0.831	0.85	0.71–1.03	0.091
	≥30	1.11	0.95–1.29	0.196	0.98	0.84–1.14	0.757
Number of beds	Beds (per 10 beds)	1.00	1.00–1.00	<0.001	1.00	1.00–1.00	0.357
Location of the hospital	Rural	Ref	−	−	Ref	−	−
	Urban	0.94	0.89–0.99	0.015	0.94	0.89–0.98	0.009
Hospital type	Community-based hospital	Ref	-	-	Ref	-	-
	University hospital	0.74	0.69–0.80	<0.001	0.84	0.76–0.92	<0.001
Average number of ED on-call shifts per month	0	Ref	−	−	Ref	−	−
	1–2	1.23	1.01–1.49	0.041	1.08	0.90–1.31	0.393
	3–5	1.45	1.20–1.75	<0.001	1.15	0.96–1.38	0.123
	≥6	1.64	1.35–2.00	<0.001	1.19	0.98–1.44	0.078

	Unsure	1.32	0.83–2.08	0.236	1.30	0.85–2.00	0.231
Average daily number of inpatients	0–4	Ref	–	–	Ref	–	–
	5–9	1.06	1.00–1.11	0.036	1.03	0.98–1.08	0.259
	10–14	1.14	1.05–1.25	0.002	1.12	1.03–1.22	0.007
	≥15	1.20	1.05–1.36	0.008	1.15	1.01–1.31	0.037
	Unsure	0.97	0.81–1.16	0.734	0.97	0.81–1.16	0.770
Average daily study time, min	None	Ref	–	–	Ref	–	–
	0–30	1.09	0.93–1.28	0.276	1.03	0.88–1.20	0.736
	31–60	1.27	1.08–1.49	0.004	1.11	0.95–1.30	0.179
	61–90	1.36	1.15–1.61	<0.001	1.14	0.97–1.34	0.124
	≥91	1.45	1.18–1.76	<0.001	1.16	0.96–1.42	0.131
Average weekly working hours	<60	Ref	–	–	Ref	–	–
	60–80	1.08	1.03–1.14	0.003	1.03	0.98–1.08	0.303
	>80	1.14	1.07–1.21	<0.001	1.03	0.97–1.10	0.355

Number of co-residents	1	Ref	–	–	Ref	–	–
	2	1.00	0.77–1.30	0.992	0.95	0.73–1.24	0.704
	3–5	1.00	0.80–1.26	0.999	0.99	0.79–1.24	0.931
	6–10	0.98	0.78–1.22	0.857	0.97	0.78–1.21	0.793
	11–15	1.05	0.84–1.31	0.660	1.03	0.82–1.29	0.801
	16–20	1.05	0.84–1.32	0.661	1.03	0.82–1.30	0.798
	21–30	0.94	0.75–1.19	0.627	0.99	0.78–1.26	0.958
	>30	0.77	0.61–0.98	0.030	0.94	0.73–1.21	0.636
Diagnostic error education received	No	Ref	–	–	Ref	–	–
	Yes	1.67	1.58–1.77	<0.001	1.61	1.52–1.70	<0.001

Associations between covariates and diagnostic error recognition were examined using Poisson regression models with a log link to estimate the prevalence ratios (PRs) and 95% confidence intervals (CIs). aPR, adjusted prevalence ratio; ED, emergency department; PGY, postgraduate year; Ref, reference.

Table 3: Association between type of diagnostic error education and diagnostic error recognition

Education type	aPR	95% CI	p-value	p Bonf
Medical knowledge	1.05	0.97–1.14	0.240	1.000
Clinical reasoning	1.16	1.07–1.27	<0.001	0.004
System-related errors	1.15	1.06–1.25	0.001	0.012
Patient involvement in diagnosis	1.08	0.96–1.22	0.221	1.000
Diagnostic uncertainty	1.18	1.09–1.29	<0.001	<0.001
Patient experience	1.16	0.99–1.34	0.059	0.593
Patient safety	1.14	1.04–1.25	0.006	0.056
Reflection on diagnostic error cases	1.22	1.12–1.33	<0.001	<0.001
Simulation-based education	1.12	1.00–1.25	0.055	0.548
Nonspecific answer	0.64	0.45–0.89	0.009	0.093

aPR, adjusted prevalence ratio; CI, confidence interval. aPRs were estimated using multilevel Poisson regression models with a log link, including a hospital random intercept and hospital-clustered robust standard errors. Each model included one education content item and the prespecified covariates; analyses used complete-case data for variables included in each model. All p-values are two-sided. When results across the 10

education content items are compared, multiplicity-adjusted p-values (Bonferroni; p Bonf) are additionally reported where applicable.

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Supplementary Files

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- Appendixtable.xlsx