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Telemedicine and digital literacy across medical training: a multicentric analysis of behavioral and educational determinants of readiness

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Abstract

Background The rapid digital transformation of healthcare organizations requires the acquisition of not only clinical but also digital and telemedicine competencies, starting from the academic path. However, despite the emergence of global and national initiatives, the integration of digital health training into medical education remains inconsistent.

Objectives Through a multicentric study, this research aimed to (i) investigate the digital and eHealth literacy profiles among medical students and residents, (ii) assess their experiences, attitudes, and intentions toward telemedicine, and (iii) identify determinants of interest in future telemedicine utilization, focusing on the interplay between technical, behavioral, and educational factors.

Methods A cross-sectional web-based survey was conducted (July 2024–February 2025) across five Italian universities. The survey explored two components of the readiness of future physicians, technical and behavioural. For the technical readiness, items from the IT-eHEALS scale and the DIGCOMP framework were included. Data were analyzed using nonparametric tests, random forest modeling, and multivariable logistic regression to identify predictors of telemedicine readiness.

Results A total of 438 participants (285 students, 153 residents; 62% female) completed the survey. While 68% had heard of telemedicine, only 22% reported personal experience and 13% academic exposure. Most respondents expressed strong interest in telemedicine (83%) and a desire for specific training (83%). eHealth literacy was moderate-to-high (mean IT-eHEALS = 25.9 ± 5.6), though higher-order evaluative skills showed variability across institutions. Logistic regression identified technology enthusiasm (OR = 4.76; $p = 0.001$), smartphone confidence (OR = 3.20; $p = 0.015$), and eHEALS score ($p = 0.050$) as independent predictors of telemedicine readiness, with a significant interaction between enthusiasm and confidence ($p = 0.021$).

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Conclusions Medical trainees show high motivation but uneven preparedness for telemedicine in practice. Educational reforms should embed structured, longitudinal digital-health training that combines technical proficiency with critical, ethical, and behavioral competencies. Strengthening digital readiness at all stages of medical education is essential to prepare physicians for technology-enabled, patient-centered healthcare.

Keywords Telemedicine, Digital health literacy, Medical education, EHealth readiness, Digital competencies

Introduction

The accelerating digital transformation of healthcare systems worldwide has created an urgent demand for healthcare professionals to acquire competencies not only in clinical care but also in digital health technologies, telemedicine, data analytics, and health informatics [1–3]. Beyond mere technical proficiency, these skills encompass digital communication, ethical awareness, data stewardship, and the ability to critically appraise information from technology-enabled systems [4, 5]. International frameworks, such as the World Health Organization's Global Strategy on Digital Health (2020–2025) [6] and the European Union's Digital Education Action Plan [7], highlight that the digital transformation of healthcare must be accompanied by a parallel transformation in medical education to equip health professionals with the necessary digital competencies.

In this context, universities and training institutions are increasingly challenged to design innovative and longitudinal learning pathways that integrate digital health across preclinical and clinical stages, rather than treating it as an optional or peripheral topic. The capacity to combine clinical reasoning with technological literacy, patient-centered communication, and system-level understanding is now recognized as a core professional competency for future physicians [8–11]. Within Europe, several countries have introduced strategic initiatives to accelerate digital transformation in healthcare, with national plans increasingly emphasizing digital innovation and the modernization of workforce training and continuing education [12–15]. Yet, despite these policy commitments, the translation of strategic goals into effective educational practices remains inconsistent.

Recent studies confirm that, although digital-health education is expanding globally, important gaps persist in both content and application. Wani et al. [16], in a national web-based review across all 42 Australian universities, reported that many university programs still overlook crucial areas such as leadership in digital implementation, data analytics, and cybersecurity, while Das et al. [17] found that despite good awareness of e-Health concepts, students' practical use of related technologies remains limited, mainly due to infrastructural and curricular constraints. These findings highlight a key paradox: the motivation and recognition of importance among students and institutions are growing, yet the proportion of teaching programmes that systematically embed digital-health competencies remains limited. This is further corroborated by other recent studies, for instance, a prospective pilot study by Kröplin et al. [18] demonstrated that a dedicated digital-health curriculum significantly improved both perceived competence and relevance of these topics among medical students, underlining the potential impact of structured interventions.

Against this backdrop, postgraduate medical training (residents) represents a critical and somewhat understudied population: while undergraduate curricula may begin to include digital-health modules, the transition to postgraduate training, where clinical responsibility and organizational integration increase, may expose additional gaps in readiness, confidence, and intention to adopt telemedicine and digital health tools.

While previous studies have examined the competencies and readiness of future physicians for digital health and telemedicine, many have been conducted within single-university settings, including our previous study [19]. There is a need for research that compares multiple academic centers to identify common patterns and differences, thereby offering a more comprehensive understanding of the current landscape and providing stronger guidance for decision-makers and policymakers.

The present multicentric study builds directly on the framework previously developed by our research group [19], which conceptualizes digital readiness through two components: (1) technical readiness, capturing general and health-related digital competencies measured using validated scales, and (2) behavioral readiness, examining prior personal and professional experiences as well as intentions related to telemedicine education and implementation.

Extending this earlier work [19], the present study includes both medical students and residents, thus providing a broader perspective across different stages of medical training. Specifically, it aims to analyze digital and eHealth literacy profiles, assess experiences, attitudes, and intentions regarding telemedicine, and identify key determinants influencing interest in future telemedicine use, with particular attention to the interplay between technical and behavioral factors and training level. The insights derived from this study provide evidence to inform the planning and refinement of targeted educational pathways aimed at strengthening digital readiness throughout medical training.

Methods

Study design and setting

This study employed an observational cross-sectional design and was reported in accordance with the Consensus-based Checklist for Reporting of Survey Studies (CROSS) [20]; participation was anonymous and voluntary.

Data were collected from July 2024 to February 2025 across five Italian universities located in distinct macro-areas (3 Northern, 1 Central, 1 Southern). During the study period, no formal telemedicine curriculum was in place at any site; occasional references to telemedicine within conventional courses were left to faculty discretion. In continuity with the original study [19] a non-probability quota sampling approach [21] was adopted to ensure adequate numbers for statistical description and group comparisons.

The web-based questionnaire was administered via EUSurvey (European Commission, DG DIGIT; GDPR registry number DPR-EC-01488), hosted within the EU. All items were set as required, and the survey was multi-device (desktop, tablet, smartphone).

Recruitment relied exclusively on institutional mailing lists provided by the participating universities' student offices (Medicine and Surgery programmes and Residency Schools). An initial invitation was followed by two reminders sent at approximately two-month intervals throughout the collection window. No incentives were offered.

The eligible population included medical students and resident physicians, all ≥ 18 years. No pilot was undertaken because this extension relied on the previously deployed instrument [19], [Additional file 1]. All sections and scales, including IT-eHEALS [22, 23] were retained unchanged from the study of Marsilio et al. [19], except for the detail of residents' postgraduate medical schools and three items about orientation toward telemedicine in future scenarios.

Ethical approval for the extension was granted by the Institutional Review Board (IRB) at the University of Milan (protocol 25/24), linked to the original protocol 21/23; the study complied with the Declaration of Helsinki. All participants provided written informed consent prior to participation. Anonymisation met the conditions set by the Italian Data Protection Authority [24] (i.e. with no direct or indirect identifiers and protection from singling out, linkability, and inference risks) and was GDPR-compliant, supported by the data-protection features of EUSurvey. A CAPTCHA verification was enabled at the point of submission to reduce automated entries. In line with the IRB approval and GDPR data-minimization principles, the survey was configured not to collect or store IP addresses or other technical identifiers.

Finally, the choice of Italy as the setting remains consistent with the prior study's rationale [19]. Namely, post-pandemic investments in telemedicine under the NRRP and ongoing academic initiatives to develop digital-health competencies in medical education.

Questionnaire

The online questionnaire for this multi-site extension retained the three-part structure of the original instrument (i.e. Demographical, Technical, and Behavioural) to ensure construct continuity and comparability with prior work [19]. Demographic information included gender, age, level of education, year of study, and the postgraduate medical school area [25]. The technical section investigated the digital competences of medical students and residents, encompassing technological skills and knowledge, as well as digital and e-health literacy, while the behavioural investigated participants' experiences, attitudes, and intentions with telemedicine, including prior experiences, desire for training and education, and intentions to use telemedicine.

Technical component

This component comprised the following two sections:

1-Digital technology knowledge and skills. Attitudes toward and frequency of use of ICT devices (e.g. smartphone, tablet, PC), together with basic digital skills, were assessed through dedicated questionnaire items. Basic skills were referenced to the DigComp self-assessment grid across five competence areas and the extended DigComp 2.2 framework [26–28]. Additional items covered reactions to learning new applications, device availability at home, self-rated proficiency with computers and digital devices, routine technology use, home Internet access, and possession of skills in information, communication, content creation, safety, and problem solving.

2-Digital health knowledge and skills. The Italian version of the eHEALS (IT-eHEALS) [29] grounded in Norman & Skinner (2006) [22]. The IT-eHEALS demonstrated high reliability (Cronbach's α = 0.90) and unidimensionality, with a single-factor solution explaining 61% of the variance (eigenvalue = 4.9). In the previous single centre study on medical students and residents [19], IT eHEALS showed even higher reliability, with Cronbach's alpha equal to 0.93 and a one factor solution explaining 70.5% of the variance (eigenvalue 5.6).Two COVID-related items, previously used in the literature, were retained to gauge pandemic-related influences [30]. The section further captured mHealth adoption and eHealth uses, as well as perceived informativeness about telemedicine and correct identification of telemedicine scenarios.

Behavioural component

This component included three subsections corresponding to the original study [19] and one further subsection introduced to detect orientation towards telemedicine in healthcare organizations. In accordance with the prior instrument, the behavioural section first explored participants' previous experience with telemedicine, assessing familiarity, any personal or vicarious involvement, participation during the academic pathway, and the specific services encountered (i.e. teleconsultation, telemonitoring, telecontrol, and telerehabilitation). It then characterised interest in telemedicine, documenting attitudes and beliefs together with the desire for training, the willingness to experiment during studies, and the intention to use telemedicine in future clinical practice. Finally, it investigated perceived advantages and disadvantages for patients, alongside perceived challenges and potential benefits for healthcare professionals. As an extension in the present multi-site study, a dedicated subsection was introduced to detect workplace telemedicine orientation in order to better characterise respondents' prospective behaviour within healthcare settings [31]. This was operationalised through three agreement statements designed to capture compliance, championing, and resistance: "I would use telemedicine only if my organisation asked me to" (conditional orientation), "I would advocate for telemedicine in my organisation" (advocacy orientation), and "Even if my organisation asked, I would not be willing to use telemedicine" (refusal orientation). All other behavioural constructs and wording were retained from the original survey to preserve content validity and comparability.

Statistical data analysis

Quantitative variables were characterized using standard measures of central tendency and dispersion, while categorical variables were presented as counts and percentages. Likert scale variables were treated both as ordinal categorical and continuous measures, as appropriate.

For exploring associations and correlations, two-tailed nonparametric inferential tests were employed, with a significance threshold (α) set at 0.05. The Wilcoxon-Mann-Whitney (WMW) test [32, 33] was utilized to evaluate continuous variables against binary indicators to test if the two sub-distributions could be considered equal; the Kruskal-Wallis rank sum (KW) test [34] was adopted to assess whether a continuous variable had the same distribution across ≥ 3 independent groups (H_0, while H_1: at least one sub-distribution differs); the Fisher-Freeman-Halton (FFH) exact test [35] was applied for contingency tables to test the null hypothesis of independence between the two factors. For Likert scale variables, both tests were conducted, determining the presence of association if both were statistically significant.

Concerning specific analyses, survey responses were examined to ascertain whether their distributions varied across demographic variables such as gender, level of education (medical students and resident physicians) and university. Multiple-choice questions were also described in terms of frequency distributions of response combinations.

For the IT-eHEALS scale, the eight constituent items underwent reliability analysis, reporting Cronbach's α, percentage of explained variance, and eigenvalue. Feldt's exact F-distribution was adopted to calculate confidence intervals for coefficient alpha [36]. Based on the reliability results, the overall scale score was computed as the sum of individual item scores (range 0–32) and treated as a continuous variable. Two additional items on eHealth literacy were scored separately and scaled within the same range.

To identify the variables jointly influencing respondents' telemedicine readiness—measured as prospective interest in telemedicine use within future clinical practice — a mixed modelling approach was adopted. This included an initial exploratory phase using a machine-learning algorithm (random forest) followed by a confirmatory phase based on a multivariable logistic regression model, built on the insights derived from machine-learning diagnostics.

The random forest algorithm is an ensemble learning method that employs decision trees as base learners and builds on the ensemble concept by introducing double randomization into the learning process [37]. Among its main advantages are the ability to mitigate overfitting through randomization, to approximate nonlinear relationships [38] to efficiently handle large sets of covariates, and to provide estimates of variable importance (VIMP) [39] and bivariate interactions [40].

A classification random forest was first constructed including all variables from the questionnaire, using methods capable of handling the outcome's class imbalance [41–43]. Subsequently, to estimate the importance of predictors and assess the statistical significance of their contribution to the outcome, a subsampling inference procedure was applied [44]. Variable importance (VIMP) represents a quantitative measure of each predictor's effect on the model's predictive accuracy. A higher VIMP indicates a more influential variable. Standard errors and 90% confidence intervals were estimated through data resampling using subsampled forests (B = 1000). If a variable's VIMP and confidence interval bounds were consistently negative (from the second iteration onward), or if the upper bound was less than 10% of the highest VIMP value, the random forest estimation and subsampling procedures were repeated until the set of variables meeting these criteria was identified.

To detect pairwise interactions among all predictors, a joint-VIMP approach with 10 Monte Carlo replicates was employed. An interaction between two variables was considered present when the joint VIMP differed substantially from the sum of their individual VIMPs, provided that the 90% confidence intervals of each univariate importance did not include zero.

After identifying relevant variables and interactions through the machine-learning algorithm, the procedure proceeded to a multivariable logistic regression model. This phase aimed to estimate, in a parametric framework, the associations between selected covariates and the outcome (odds ratios, OR), while assessing confidence intervals and Wald tests with α set at 0.05.

Model specification included gender, educational level, and university as adjustment variables, while additional predictors were entered based on improvement criteria for nested models, such as the Akaike information criterion (AIC) and likelihood ratio test [45]. During model development, restricted cubic splines [46] with three knots were employed as appropriate to account for potential nonlinear relationships, thereby avoiding the constraint of linearity between predictors and outcome.

All statistical analyses and modeling procedures were conducted using R software, version 4.4.2 (R Core Team, 2024).

Results

Sample characteristics

A total of 438 participants were enrolled, including 285 medical students and 153 resident physicians, from five Italian universities (UNI) representing different macro regions of Italy. The response rate was 2.3% on average (2.1% UNI 1; 2.5% UNI 2; 2.7% UNI 3; 2.5% UNI 4; 1.9% UNI 5). The majority were female (62%), with mean ages of 23.5 ± 4.5 years for students and 30.9 ± 5.2 for residents (Table 1).

Telemedicine experience and attitudes

Although 68% had heard of telemedicine, direct personal experience was limited (22%), and only 13% reported academic exposure. Training stage accounted for substantial differences in exposure: residents were more likely than students to have heard about telemedicine (85.0% vs. 59.3%, $p < 0.001$), to report personal experience (33.3% vs. 16.5%, $p < 0.001$), and to report academic exposure (31.4% vs. 3.5%, $p < 0.001$). Consistently, residents reported higher involvement in specific services, including televisits (22.2% vs. 1.1%, $p < 0.001$), telemonitoring (15.0% vs. 2.1%, $p < 0.001$), and telecontrol (17.6% vs. 1.8%, $p < 0.001$), whereas telerehabilitation was rare and did not differ by educational level (2.6% vs. 1.1%, $p = 0.245$). Teleconsultation was the most frequently encountered application. Interest in telemedicine was remarkably high: 83% expressed the desire for specific training, and 69.9% declared the intention to integrate telemedicine into their future clinical practice. Despite the overall high interest, students more frequently expressed a desire for specific training than residents (85.6% vs. 77.8%,

Table 1 Characteristics of the participants

Characteristics	Levels/Measures	Medical Students ($n = 285$)		Resident Physicians ($n = 153$)	
University, n (%)	UNI 1	6	(2.10%)	NA*	(0.00%)
	UNI 2	36	(12.63%)	31	(20.26%)
	UNI 3	80	(28.07%)	96	(62.75%)
	UNI 4	121	(42.46%)	17	(11.11%)
	UNI 5	42	(14.74%)	9	(5.88%)
Gender, n (%)	Male	99	(34.74%)	64	(41.83%)
	Female	185	(64.91%)	89	(58.17%)
	Non-binary	1	(0.35%)	0	(0.00%)
Age, years	Mean (SD)	23.5	(4.5)	30.9	(5.2)
	Median (IQR)	23	(21–24)	29	(28–32)
	Min - Max		(19–56)		(24–53)
Academic year, n (%)	1st	34	(11.93%)	27	(17.65%)
	2nd	57	(20.00%)	24	(15.69%)
	3rd	54	(18.94%)	47	(30.71%)
	4th	34	(11.93%)	44	(28.76%)
	5th	40	(14.04%)	11	(7.19%)
	6th or higher	66	(23.16%)		

UNI University

*At the UNI 1, no resident physicians were enrolled, since the university does not host postgraduate medical schools

Table 2 Technical and behavioral component

Sections	Domains	*N* (%)/Average (SD)	Statistical significance
TECHNICAL COMPONENT			
Digital and technology knowledge and skills			
	Technology enthusiasm	316 (72.15%)	
	Desktop		
	Confident user	215 (49.09%)	§†
	Frequent user	162 (36.99%)	§†‖
	Laptop		
	Confident user	263 (60.05%)	§
	Frequent user	350 (79.91%)	§
	Smartphone		
	Confident user	337 (76.94%)	
	Frequent user	436 (99.54%)	
	Tablet		
	Confident user	258 (58.90%)	
	Frequent user	219 (50.00%)	§†
	Home Internet connection Availability	425 (97.03%)	‖
	Digital skills proficiency by domain		
	Information	433 (98.86%)	
	Communication	433 (98.86%)	
	Content Creation	403 (92.01%)	
	Safety	423 (96.58%)	
	Problem Solving	406 (92.69%)	§
	Overall Self-evaluated digital skill of use	373 (85.16%)	
Digital health knowledge and skills			
	mHealth user	341 (77.85%)	§
	eHealth user °	329 (75.11%)	§
	eHealth literacy (e-HEALS)	25.9 (SD 5.6)	†
	Covid-related eHealth literacy	22.0 (SD 6.0)	†
	Telemedicine informed	205 (46.80%)	†‖
	Telemedicine correct identification ^	321 (73.29%)	†‖
BEHAVIOURAL COMPONENT			
Previous experience with Telemedicine			
	Heard about	299 (68.26%)	†‖
	Personal experience	98 (22.37%)	†
	Academic experience	58 (13.24%)	†‖
	televisit	37 (8.45%)	†‖
	telemonitoring	29 (6.62%)	†‖
	telecontrol	32 (7.31%)	†‖
	telerehabilitation	7 (1.60%)	
Interest in Telemedicine			
	Get training	363 (82.88%)	†
	Try usage	367 (83.79%)	
	Future utilization	306 (69.86%)	‖
Workplace Telemedicine orientation			
	Use only if required in future setting	124 (28.31%)	
	Propose use in future setting	264 (60.27%)	
	Refuse use even if required	29 (6.62%)	

Notes: "Confident user" refers to self-evaluation answers "high" or "very high", while "Frequent User" is identified when self-reported usage answers were "frequently" or "daily"

§ Statistically significant difference ($p < 0.05$) by gender

† Statistically significant difference ($p < 0.05$) by educational level

‖ Statistically significant difference ($p < 0.05$) by university

° eHealth user if more than 4 out of 8 proposed experiences were selected

^ partecipants who identified both tele visits and telemonitoring as telemedicine

$p = 0.046$). Regarding workplace orientation, 60% would actively promote its use, while 28% would comply only if required, and 6.6% would refuse to adopt it. Detailed results are reported in Table 2.

Digital and eHealth literacy and item-level analysis

As reported Table 2, almost all participants reported home Internet access (97%) and regular use of digital devices. When stratified by educational level, residents reported higher confidence in desktop use than students (58.2% vs. 44.2%, $p = 0.007$), whereas frequent desktop use was markedly more common among residents (80.4% vs. 13.7%, $p < 0.001$). By contrast, students reported frequent tablet use more commonly than residents (60.4% vs. 30.7%, $p < 0.001$), while confidence in tablet use did not differ materially between groups (61.1% vs. 54.9%, $p = 0.223$). Confidence in smartphone use was high (77%), and overall self-assessed digital competence reached 85%. The highest proficiency was observed in information and communication domains, whereas problem solving and content creation showed slightly lower scores. Nearly half of respondents (46.8%) reported feeling sufficiently informed about telemedicine, while 73.3% correctly identified both teleconsultation and telemonitoring as examples of telemedicine. Residents more frequently reported being sufficiently informed about telemedicine than students (64.1% vs. 37.5%, $p < 0.001$). Correct identification of telemedicine scenarios was also higher among residents (83.0% vs. 68.1%, $p < 0.001$).

The overall level of eHealth literacy among participants was generally adequate but displayed noticeable heterogeneity across educational levels (Fig. 1A) and universities (Fig. 1B). The internal consistency of the instrument was assessed using Cronbach's alpha. The reliability coefficient was $\alpha = 0.92$, indicating excellent internal consistency. The Feldt's confidence interval for α (0.91–0.93) confirmed the stability of this estimate. Factor analysis revealed a one-factor solution explaining 68.2% of the total variance, with an eigenvalue of 5.5, supporting the unidimensional structure of the scale. The average IT-eHEALS score was 25.9 ± 5.6 (Kruskal–Wallis $p < 0.05$), indicating a moderate-to-high ability to locate, understand, and apply online health information. Residents showed higher eHealth literacy than students (mean IT-eHEALS 27.8 ± 5.3 vs. 24.9 ± 5.4, $p < 0.001$). COVID-related eHealth literacy was also slightly higher among residents (23.0 ± 6.1 vs. 21.5 ± 6.0, $p = 0.018$).

A more detailed, item-level analysis of the eight IT-eHEALS dimensions, including Access, Search, Select, Find, Use, Evaluate, Discern, and Trust, provided further insight into the distribution of digital competencies. Overall, respondents expressed high self-perceived ability to Access, Search, and Use online health information,

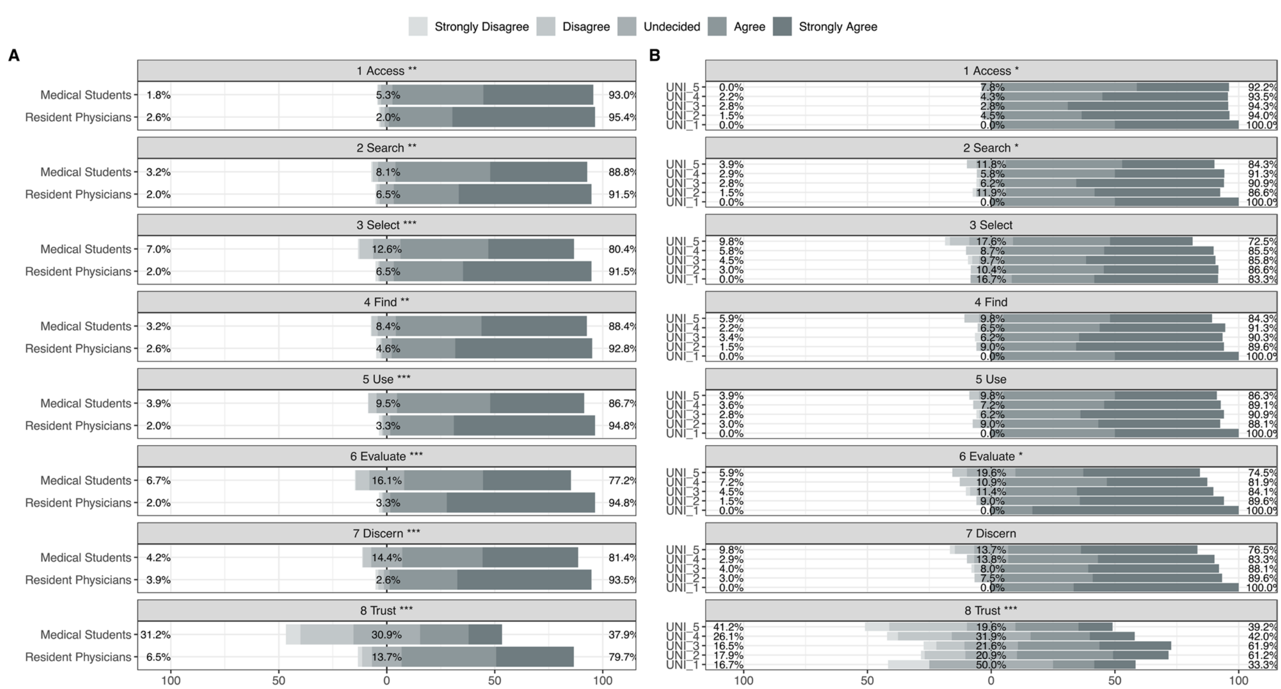

Fig. 1 Item-level distribution of responses across the eight IT-eHEALS dimensions (*Access*, *Search*, *Select*, *Find*, *Use*, *Evaluate*, *Discern*, and *Trust*) by educational level (**A**) and university (**B**). Bars represent the relative frequency (%) of agreement levels on a five-point Likert scale (from *Strongly Disagree* to *Strongly Agree*). Asterisks denote statistically significant between-group differences in item scores (educational level: Wilcoxon–Mann–Whitney tests; university: Kruskal–Wallis tests; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$)

with more than 80% agreeing or strongly agreeing with these statements across all universities.

Conversely, items involving higher-order cognitive and evaluative skills, such as Evaluate and Trust, exhibited greater variability. More than 70% of participants felt confident in their ability to critically assess online health information; however, statistically significant inter-university differences (Kruskal–Wallis $p < 0.05$) suggest uneven development of analytical literacy skills within educational contexts.

The Trust dimension showed the widest dispersion, with some universities reporting a larger share of neutral or undecided responses, possibly reflecting uncertainty in judging the reliability and credibility of digital sources.

Perceived advantages and challenges

Participants expressed a balanced view of the perceived opportunities and limitations associated with telemedicine, highlighting both its transformative potential and its operational barriers.

Perceived advantages for patients primarily included greater accessibility and efficiency of care. The vast majority (84.9%) recognized time-saving as the leading benefit, followed by the opportunity to access remote healthcare facilities (76.9%) and the reduction of personal costs related to travel or absence from work (74.4%). Notably, the proportion of respondents who perceived telemedicine as facilitating access to distant healthcare facilities was significantly higher among residents compared with students ($p = 0.032$).

Disadvantages for patients were strongly centered on technological requirements and usability concerns. Almost all respondents (94.1%) indicated that telemedicine requires a certain level of technological competence, while 84.2% mentioned the risk of communication problems (e.g., poor connection quality or interruptions). Furthermore, 83.6% agreed that older patients may experience difficulties in adapting to virtual healthcare systems. Respondents also noted that telemedicine could exacerbate inequalities between technologically skilled and less skilled users ($p = 0.037$), emphasizing the need for inclusive design and digital training support.

From the professional perspective, telemedicine was seen as a tool that enhances flexibility, collaboration, and work efficiency. Two-thirds of participants (66.7%) identified increased flexibility in managing working hours as the main professional advantage, followed by strengthened collaboration between primary care providers and specialists (57.8%) and improved efficiency in daily work activities (50.2%). These findings reflect an overall positive attitude toward the professional benefits of telemedicine integration.

Conversely, professionals' perceived challenges focused on structural and organizational aspects (Table 3). The most frequently reported issues were the inadequacy of technical support (66.0%), the risk of diagnostic errors in remote settings (66.7%), and patients' resistance to using telemedicine platforms (63.5%). Differences by educational level were statistically significant for several items, including system integration with medical records ($p < 0.001$) and with other digital applications ($p < 0.001$), highlighting that residents, due to their greater clinical exposure, are more likely to recognize infrastructural and interoperability challenges.

The frequencies of response to each item on telemedicine advantages and disadvantages for patients and healthcare professionals are reported in Table 3.

Predictors of future telemedicine utilization

A mixed analytical approach combining random forest variable selection and multivariable logistic regression was used to identify predictors of interest in future telemedicine utilization. Among 28 candidate variables (Fig. 2A), an initial screening excluded redundant or low-informative predictors (e.g., desktop or laptop confidence, home internet connection, and COVID-related eHEALS score). A refined model was then rerun excluding an additional set of highly correlated variables, resulting in a final subset of 20 predictors (Fig. 2B, C).

The random forest analysis identified several potential interaction effects among the candidate predictors. Specifically, 12 variable pairs showed VIMP values exceeding the additive expectation, suggesting synergistic effects rather than simple independent contributions (Fig. 3). Among these, interactions involving technology enthusiasm, smartphone confidence, and educational level were particularly notable, indicating that behavioral and contextual factors may combine to influence telemedicine readiness.

Subsequent nested likelihood-ratio testing was performed to formally evaluate the contribution of each interaction to model fit. Only one interaction term reached statistical significance: technology enthusiasm × smartphone confidence (AIC without interaction = 518.77; AIC with interaction = 515.16; $p = 0.018$). This finding indicates that the joint presence of enthusiasm for technology and self-confidence in smartphone use amplifies the predictive effect on interest in future telemedicine utilization.

Following interaction testing, additional variables identified through the subsampling procedure were re-evaluated for inclusion. Among these, the eHEALS score was retained as a significant non-linear term, improving model performance when introduced as a three-knot restricted cubic spline (AIC model without eHEALS = 515.16; *AIC* model with eHEALS = 512.95; $p = 0.045$). This enhancement confirms that eHealth

Table 3 Frequencies of response to each item on telemedicine advantages for patients (1), disadvantages for patients (2), perceived issues (3) and advantages for healthcare professionals (4). The frequencies are reported by level of education and overall. In order to highlight a different item response distribution between the two levels of education, the unadjusted fisher test p-value is also reported: *, < 0.05; **, < 0.01; ***, < 0.001

	Medical Students (*n*, %)	**Resident Physicians (*n*, %)**	**Total (*n*, %)**	**Fisher test *p***	
(1) According to you, what are the general advantages of Telemedicine for patients?					
Saves the time needed to reach the hospital/clinic	237 (83.2%)	135 (88.2%)	372 (84.9%)	0.165	
Saves waiting time at the clinic	211 (74.0%)	100 (65.4%)	311 (71.0%)	0.061	
Saves money for the patient (travel, time off work, etc.)	205 (71.9%)	121 (79.1%)	326 (74.4%)	0.109	
Eliminates the need to be accompanied to visits	159 (55.8%)	95 (62.1%)	254 (58.0%)	0.224	
Allows the use of healthcare facilities far from home	210 (73.7%)	127 (83.0%)	337 (76.9%)	0.032	*
Makes it easier to explain symptoms	20 (7.0%)	8 (5.2%)	28 (6.4%)	0.543	
Facilitates contacting the doctor/healthcare professional	161 (56.5%)	55 (35.9%)	216 (49.3%)	< 0.001	***
Enables more frequent check-ups/visits/sessions	166 (58.2%)	80 (52.3%)	246 (56.2%)	0.267	
Reduces healthcare costs	158 (55.4%)	98 (64.1%)	256 (58.4%)	0.085	
Puts patients more at ease	45 (15.8%)	22 (14.4%)	67 (15.3%)	0.781	
Facilitates booking	153 (53.7%)	48 (31.4%)	201 (45.9%)	< 0.001	***
Enables the doctor/healthcare professional to have more data for patient care	103 (36.1%)	44 (28.8%)	147 (33.6%)	0.137	
Allows speaking with multiple doctors/healthcare professionals simultaneously	130 (45.6%)	58 (37.9%)	188 (42.9%)	0.130	
Other advantages	11 (3.9%)	7 (4.6%)	18 (4.1%)	0.802	
No advantage	1 (0.4%)	0 (0.0%)	1 (0.2%)	1.000	
(2) According to you, what are the main disadvantages of Telemedicine for patients?					
Limits the ability to ask questions to the healthcare professional	63 (22.1%)	24 (15.7%)	87 (19.9%)	0.132	
Limits personal interaction with the healthcare professional	225 (78.9%)	109 (71.2%)	334 (76.3%)	0.078	
Not as effective as a physical visit for diagnosis or examination	227 (79.6%)	100 (65.4%)	327 (74.7%)	0.001	**
Increases the time to get a visit	5 (1.8%)	3 (2.0%)	8 (1.8%)	1.000	
Subject to technical communication problems (e.g., connection interruptions, poor image quality)	238 (83.5%)	131 (85.6%)	369 (84.2%)	0.586	
Requires the patient to have technology proficiency	267 (93.7%)	145 (94.8%)	412 (94.1%)	0.832	
Requires the patient to possess specific technological tools	224 (78.6%)	126 (82.4%)	350 (79.9%)	0.383	
The patient needs support and explanations to learn how to use it	177 (62.1%)	95 (62.1%)	272 (62.1%)	1.000	
Subject to privacy issues	129 (45.3%)	57 (37.3%)	186 (42.5%)	0.128	
Increases healthcare costs	7 (2.5%)	6 (3.9%)	13 (3.0%)	0.390	
Creates a division between tech-savvy and less tech-savvy patients	193 (67.7%)	88 (57.5%)	281 (64.2%)	0.037	*
Puts older patients in difficulty	243 (85.3%)	123 (80.4%)	366 (83.6%)	0.223	
Other disadvantages	7 (2.5%)	12 (7.8%)	19 (4.3%)	0.012	*
No disadvantage	1 (0.4%)	0 (0.0%)	1 (0.2%)	1.000	
(3) From your perspective, what are the current main issues related to Telemedicine?					
Privacy issues (e.g., risk of data theft, etc.)	122 (42.8%)	61 (39.9%)	183 (41.8%)	0.612	
Issues related to professional responsibility	84 (29.5%)	49 (32.0%)	133 (30.4%)	0.587	
Integration of the telemedicine system with the medical record	97 (34.0%)	80 (52.3%)	177 (40.4%)	< 0.001	***
Integration of the telemedicine system with other company applications	65 (22.8%)	68 (44.4%)	133 (30.4%)	< 0.001	***
Increased effort required in non-clinical activities (e.g., time for technology management)	97 (34.0%)	52 (34.0%)	149 (34.0%)	1.000	
Lack or inadequacy of technical support	179 (62.8%)	110 (71.9%)	289 (66.0%)	0.058	
Higher costs related to the implementation and management of telemedicine platforms	73 (25.6%)	37 (24.2%)	110 (25.1%)	0.817	
Patient resistance to using telemedicine systems	191 (67.0%)	87 (56.9%)	278 (63.5%)	0.038	*
Issues related to reimbursement of services	29 (10.2%)	21 (13.7%)	50 (11.4%)	0.273	
Risk of errors in remote diagnoses	205 (71.9%)	87 (56.9%)	292 (66.7%)	0.002	**
Other issues	6 (2.1%)	4 (2.6%)	10 (2.3%)	0.745	
No issue	2 (0.7%)	0 (0.0%)	2 (0.5%)	0.544	

Table 3 (continued)

	Medical Students (*n*, %)	Resident Physicians (*n*, %)	Total (*n*, %)	Fisher test *p*	
(4) According to you, what are the main advantages of Telemedicine for healthcare professionals?					
Simplifies the bureaucratic part of the work	116 (40.7%)	48 (31.4%)	164 (37.4%)	0.062	
Allows for more efficient work	154 (54.0%)	66 (43.1%)	220 (50.2%)	0.035	*
Allows more time to be dedicated to the patient	50 (17.5%)	20 (13.1%)	70 (16.0%)	0.274	
Provides greater flexibility in managing working hours	189 (66.3%)	103 (67.3%)	292 (66.7%)	0.915	
Allows for greater diagnostic accuracy	12 (4.2%)	7 (4.6%)	19 (4.3%)	1.000	
Ensures higher quality of collected clinical data	56 (19.6%)	23 (15.0%)	79 (18.0%)	0.244	
Facilitates teamwork	75 (26.3%)	40 (26.1%)	115 (26.3%)	1.000	
Enables real collaboration between primary care and specialists	162 (56.8%)	91 (59.5%)	253 (57.8%)	0.613	
Other advantages for the professional	4 (1.4%)	4 (2.6%)	8 (1.8%)	0.458	
No advantage for the professional	10 (3.5%)	11 (7.2%)	21 (4.8%)	0.102	

literacy contributes independently to telemedicine interest, albeit with a non-linear pattern where higher literacy levels show progressively stronger associations with the outcome.

In the final multivariable model, three predictors contributed to the outcome (Table 4). A statistically significant interaction emerged between technology enthusiasm and self-assessed confidence in smartphone use (interaction term $p = 0.021$). Among participants who were not confident in smartphone use, those expressing high technology enthusiasm had substantially higher odds of reporting interest in future telemedicine use (OR = 4.76, 95% CI 1.97–11.51; $p = 0.001$). Smartphone confidence was also associated with telemedicine intention among participants who were not enthusiastic about technology, (OR = 3.20, 95% CI 1.46–7.02; $p = 0.015$).

Finally, the eHEALS score, modelled as a restricted cubic spline with three knots, demonstrated a non-linear association with telemedicine intention ($p = 0.050$): lower literacy levels were not associated with interest in telemedicine, whereas higher eHealth literacy scores were progressively linked to stronger likelihood of future utilization. Adjustment covariates (gender, educational level, and university) were retained in the model as control factors but did not materially alter the observed associations (data not shown).

Discussion

This study reveals that Italian medical students and residents have strong motivation toward the use of telemedicine and digital health pathways yet often lack consistent experience and structured training. The coexistence of high enthusiasm and uneven competence highlights an educational gap that medical curricula should address through targeted, practice-oriented programs. Interestingly, enthusiasm for technology predicts a willingness to use telemedicine mainly among those with lower digital confidence, whereas for already proficient individuals, enthusiasm alone does not significantly influence future adoption in clinical practice.

The assessment of participants' digital skills further clarifies this gap. Overall, they demonstrated solid digital literacy and confidence in using everyday technologies such as smartphones, online learning platforms, and web-based communication tools, suggesting that Italian medical trainees are comfortable in digital environments. However, notable gaps persist in advanced competencies, particularly in critically evaluating digital information, managing data ethically, and integrating telemedicine into clinical decision-making. These findings indicate that while students and residents are digitally fluent as users, they are not yet fully prepared as critical and reflective practitioners of digital medicine.

This imbalance reflects international trends showing that, although digital awareness among health profession learners has increased, practical proficiency and self-efficacy remain inconsistent. Wani et al. [16] reported that in Australian universities, despite the inclusion of digital health topics in most curricula, essential domains such as cybersecurity, data analytics, and leadership in digital transformation are still underrepresented. Similarly, Das et al. [17] found that students in the Middle East recognize the importance of digital health but seldom have access to structured or experiential learning opportunities to apply it. Collectively, these observations indicate that the main challenge lies not in exposure to digital tools, but in the absence of coherent, competency-based educational frameworks capable of transforming awareness into applied professional skills [47, 48].

The Italian scenario described here extends the earlier work by Marsilio et al. [19], confirming that institutional awareness alone does not guarantee effective curricular implementation, by providing evidence from multiple academic centers. The significant interaction observed between technology enthusiasm and smartphone confidence underscores that affective and technical

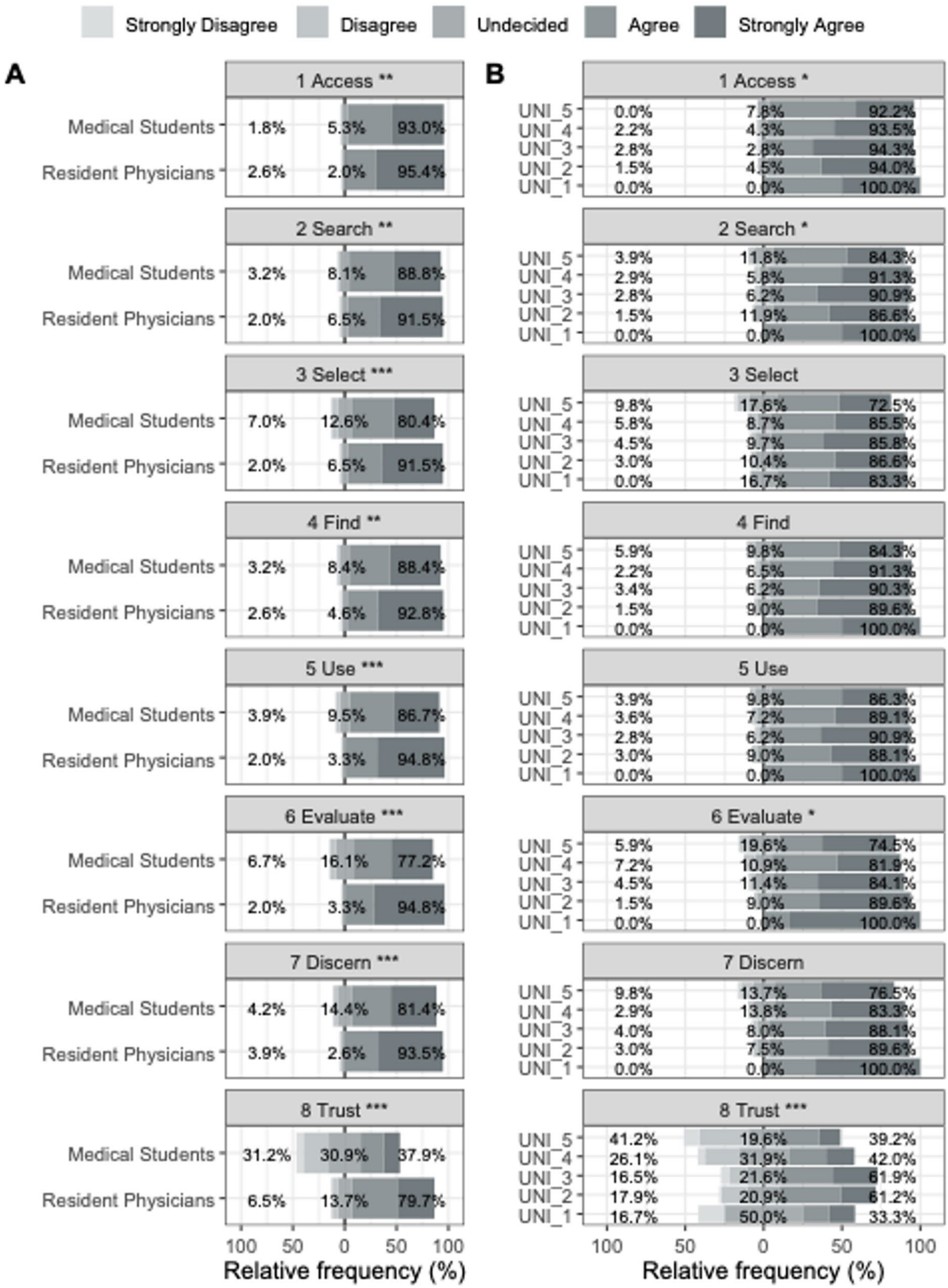

Fig. 2 (See legend on next page.)

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Fig. 2 Resampling-based variable importance (VIMP) estimates from the random forest model predicting telemedicine readiness. Each horizontal boxplot displays the distribution of VIMP values obtained across subsampled forests (B = 1000) for a given predictor, with variables ranked by their median VIMP. Panels **A**–**C** illustrate successive stages of the VIMP-based selection procedure, from the initial set of candidate predictors to the progressively restricted subsets retained for evaluation of pairwise interactions. Boxplot shading and label formatting convey the results of the resampling-based inference: predictors whose 90% confidence interval for VIMP includes zero are displayed in light grey, whereas those whose interval does not include zero are displayed in dark grey, and variables with bold labels indicate predictors retained by the subsampling-based selection procedure for subsequent interaction analysis

dimensions of learning act synergistically in shaping readiness for telemedicine adoption. Enthusiasm can partially offset lower confidence in digital use, supporting motivational theories such as the Technology Acceptance Model and Self-Determination Theory [49, 50]. As shown in pilot experiences by Kröplin et al. [18] and Parsons et al. [51], experiential learning and simulation-based education can successfully convert motivation into competence by fostering self-efficacy and active engagement.

The non-linear association observed between eHealth literacy and the intention to use telemedicine suggests that basic familiarity with digital tools is not sufficient to foster real clinical adoption [52]. Only higher levels of literacy, those integrating critical judgment, information appraisal, and ethical awareness, translate into a genuine readiness to apply telemedicine in professional contexts [53]. In other words, digital literacy evolves from mere technical competence to a more advanced form of digital professionalism, where knowledge, values, and reflective thinking interact to shape responsible technology use.

This interpretation aligns with the Digital Health Competencies in Medical Education Framework proposed by Car et al. [10], which identifies ethical reasoning, patient-centered communication, and evidence-based decision-making as essential components of digital competence. It also resonates with recent perspectives that position technological literacy as a fundamental component of medical professional identity [54, 55]. As highlighted by Shachak et al. [55] and Lawrence and Levine [54], digital competence should be developed not merely as a technical skill set, but as an integral aspect of how future physicians think, act, and define their professional roles within a digitally mediated healthcare ecosystem.

Participants' perceptions of telemedicine revealed both enthusiasm and caution. Many acknowledged its potential to improve healthcare efficiency, accessibility, and flexibility, especially for patients in remote or underserved areas [56]. Telemedicine was viewed as a valuable complement to traditional care, capable of enhancing time management and interprofessional collaboration [57, 58]. However, participants also expressed concerns about digital inequities, particularly among older or less technologically skilled patients, which could deepen existing disparities in healthcare access. Doubts about diagnostic reliability and the loss of human contact in virtual settings were frequently mentioned, together with perceptions of insufficient institutional and infrastructural support. Similar ambivalence has been reported in other European studies [59–62], indicating that the success of telemedicine depends not only on technological competence but also on organizational readiness, ethical awareness, and educational reform.

Several limitations should be acknowledged. The cross-sectional nature of the study precludes causal inference, and self-reported data may be subject to overestimation of skills due to social desirability bias. Although geographically diverse, the sample was limited to five universities and may not fully capture national variability. Because responses were fully anonymous and no technical identifiers (e.g., IP addresses) were collected, it was not possible to implement technical deduplication procedures; therefore, the presence of undetected duplicate submissions cannot be entirely excluded. Furthermore, objective assessments of competence were not conducted, and contextual factors such as institutional support, socioeconomic conditions, and faculty preparedness were not systematically analyzed. Future longitudinal and intervention-based research will be essential to assess how structured digital-health education impacts skill development and professional behaviors over time.

Proposal and perspectives

In light of these findings, it is possible to outline a strategic perspective for integrating telemedicine and digital health more effectively into medical education, as illustrated in Fig. 4. A comprehensive approach should consider digital competence as a longitudinal learning objective that evolves across preclinical, clinical, and postgraduate stages. Early exposure during the initial years of study could focus on foundational digital literacy, ethical principles of data management, and the use of technology in patient communication [63, 64]. This foundation should then expand during clinical rotations to include direct experience with teleconsultation, electronic health records, and virtual collaboration among healthcare teams.

Equally important is the experiential dimension of training. Simulation-based modules, role-playing in teleconsultation scenarios, and interdisciplinary learning environments, where medical students interact with peers in computer science, biomedical engineering, and healthcare management, can foster practical confidence and cross-professional understanding [65, 66]. These active learning strategies reflect the growing recognition

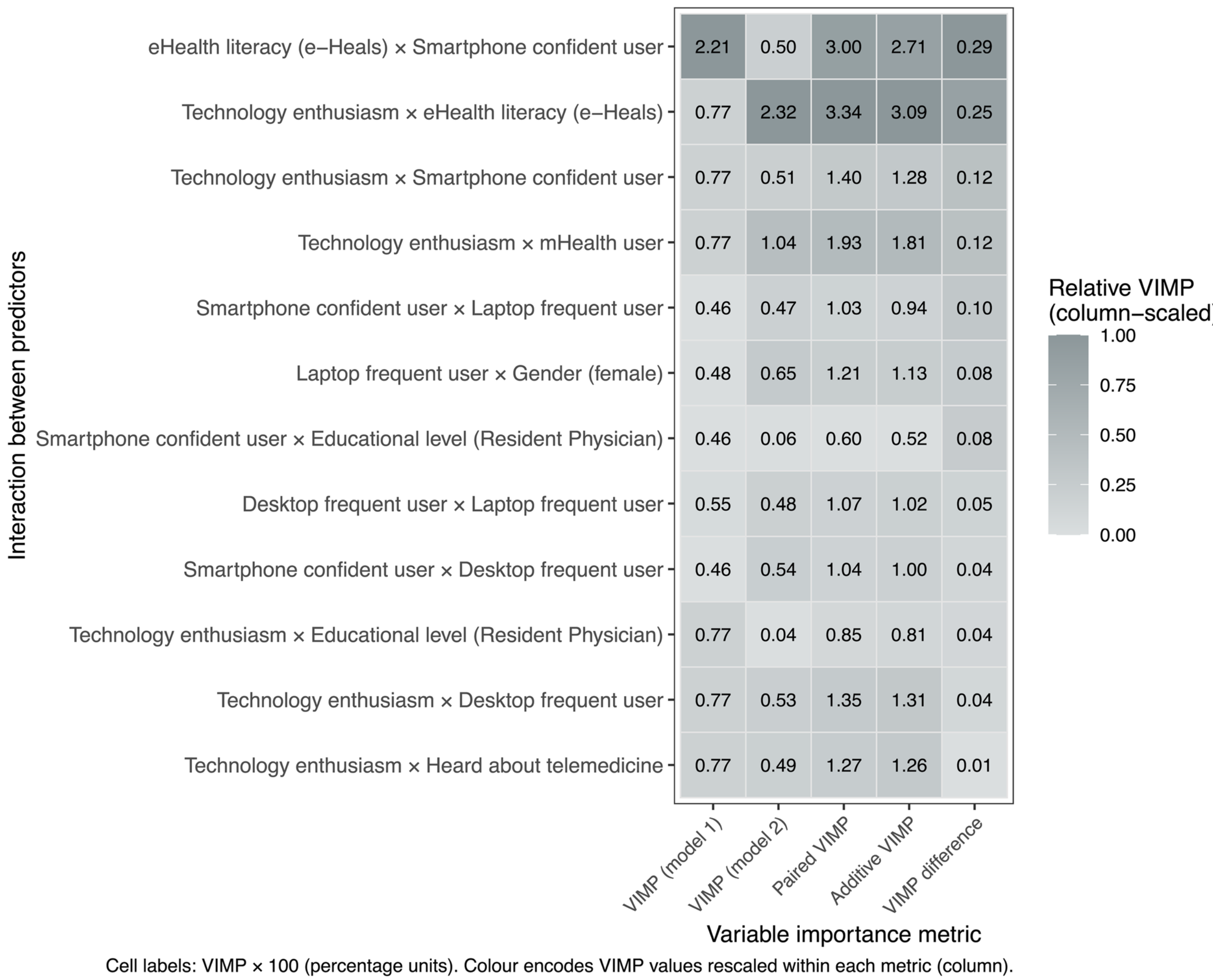

Fig. 3 Column-scaled joint VIMP metrics for pairwise interactions among predictors. Note: Each row represents a predictor pair (ordered by decreasing VIMP difference), and each column reports a different variable-importance metric (VIMP in model 1, VIMP in model 2, paired VIMP, additive VIMP, and VIMP difference). Cell colour encodes the relative magnitude of each metric within its own column (min–max rescaled), while the numeric labels display VIMP × 100 (percentage units). All 12 variable pairs exceed the additive expectation (positive VIMP difference), indicating synergistic interaction effects. The strongest interactions involve technology enthusiasm, smartphone confidence, and educational level (resident physician), suggesting that combined behavioural and contextual factors jointly shape telemedicine readiness

Table 4 Logistic regression analysis of predictors of telemedicine readiness. Odds ratios (OR) with 95% confidence intervals (CI) are shown. Higher *eHEALS* scores, greater technology enthusiasm, and higher confidence in smartphone use were significantly associated with increased odds of telemedicine readiness

Variable	OR	95% CI	*p* (Wald)
eHEALS *			0.050
(+ 10 points increase, 30 vs. 20)	1.638	1.066–2.516	
(+ 10 points increase, 25 vs. 15)	1.024	0.554–1.893	
Technology enthusiasm (Yes vs. No)			0.001
Not confident when using smartphones	4.760	1.969–11.505	
Confident when using smartphones	1.354	0.752–2.437	
Smartphone confident user (Yes vs. No)			0.015
Not enthusiastic about technology	3.199	1.458–7.021	
Enthusiastic about technology	0.910	0.446–1.858	
Interaction term			0.021
(Technology enthusiasm * Smartphone confident user)			

* eHEALS score modelled as 3-knots restricted cubic spline

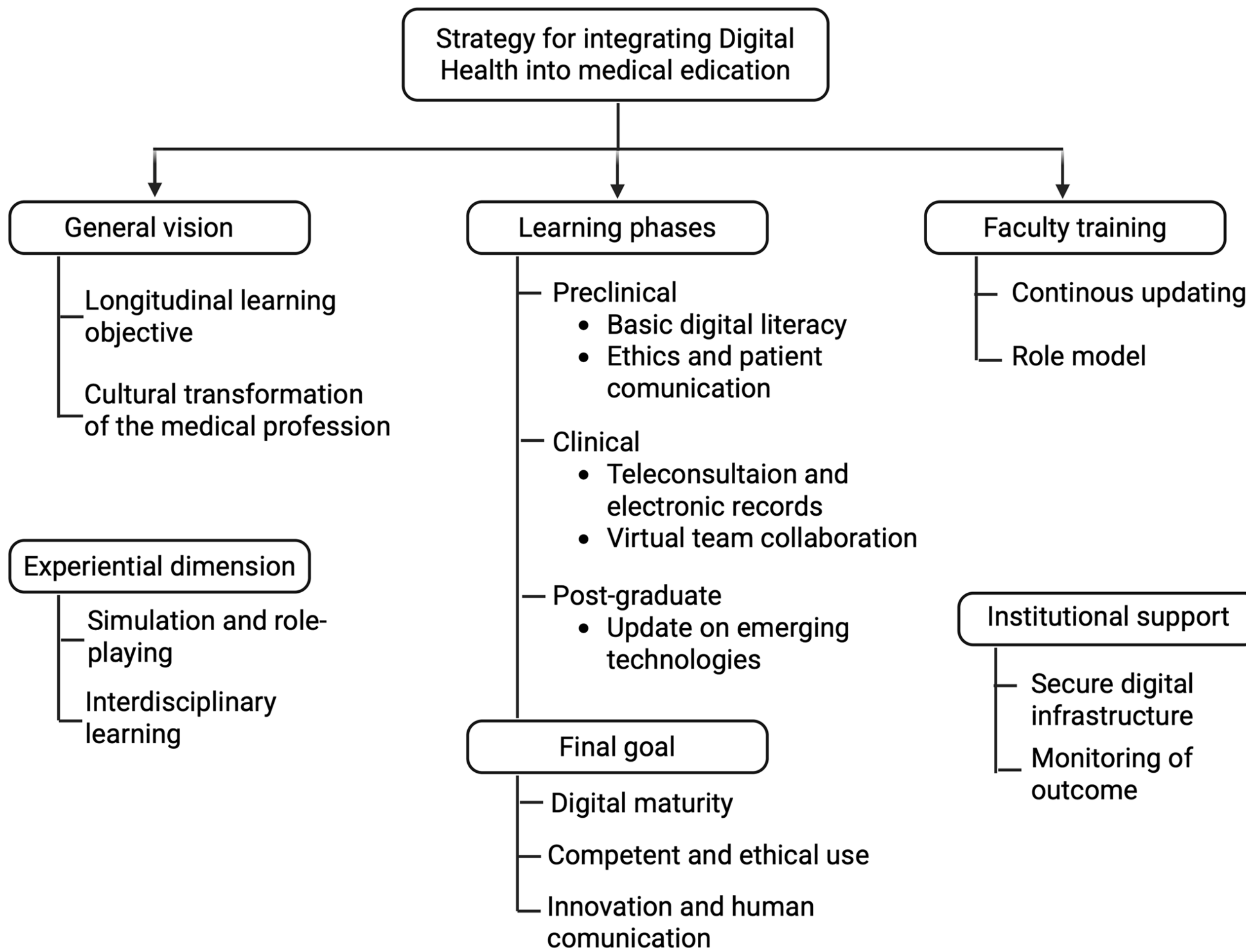

Fig. 4 Strategic perspective for integrating telemedicine and digital health into medical education

that technical competence alone is insufficient unless combined with problem-solving ability, collaboration, and ethical discernment.

Faculty development also represents a critical priority. Teachers and clinical tutors require ongoing preparation in digital pedagogy, telehealth ethics, and virtual education methods to model good digital practice and mentor learners effectively. Institutional commitment is essential to ensure appropriate digital infrastructure, secure platforms, and continuous evaluation of educational outcomes [67]. Aligning curricula with established frameworks such as the WHO Global Strategy on Digital Health [6] and the JAMA Network Open Delphi consensus [10] could foster standardization and comparability of competencies at both national and international levels.

Ultimately, the planning of digital-health education should not be viewed as an isolated technical reform but as part of a broader transformation of professional culture. Developing digital maturity among future physicians requires an educational ecosystem capable of integrating technological literacy with clinical reasoning, patient-centered communication, and ethical responsibility [68]. This integration will allow medical education to anticipate the evolving demands of digitally enabled healthcare systems and prepare graduates who can act as both competent users and critical innovators of telemedicine.

Conclusions

Medical education must evolve to include structured pathways for telemedicine and digital-health training, bridging the gap between enthusiasm and competence. The findings indicate that while motivation among young professionals is strong, consistent digital literacy and confidence remain uneven. Integrating comprehensive, longitudinal, and competency-based digital-health curricula at both undergraduate and postgraduate levels will be crucial to prepare the next generation of physicians for technology-enabled, patient-centered care.

Digital transformation in healthcare demands not only technical readiness but also cultural change. By embedding experiential learning, ethical awareness, and reflective practice within educational systems, medical schools can nurture professionals who are confident, critical, and compassionate leaders of the digital era.

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Authors' contributions
G.V.Z.: Conceptualization; Methodology; Writing Review and Editing Supervision; V.C.: Conceptualization; Methodology; Writing-Original Draft; Writing Review and Editing Supervision; G.I.: Methodology, Formal Statistical Analysis; Writing—Original Draft; Writing Review; M.P.: Methodology; Investigations; Writing—Original Draft; Writing Review; G.D.: Data gathering; Writing—Original Draft; Writing Review; A.P.: Data gathering; M.Mag.: Data gathering; F.F: Data gathering; M.Mars.: Conceptualization; Methodology; Writing Review and Editing Supervision.

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Data availability
The authors confirm that the data supporting the findings of this study are available within the article.

Declarations

Ethics approval and consent to participate
Ethical approval for the extension was granted by the Institutional Review Board at the University of Milan (protocol 25/24), linked to the original protocol 21/23; the study complied with the Declaration of Helsinki. All participants provided written informed consent prior to participation.

Consent for publication
All participants provided explicit written consent for the publication of anonymised data derived from the study. No identifiable personal information is included in the manuscript, and all data meet the anonymisation requirements of the Italian Data Protection Authority and GDPR regulations.

Competing interests
The authors declare no competing interests.

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