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PAPER

Beyond Tech-Fluent Generations: Investigating Cross-Generational Technology Adoption Patterns in Collaborative Online Learning Spaces

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ABSTRACT

This study challenges the prevailing digital native's paradigm by examining technology adoption patterns across different generational cohorts in collaborative online learning environments. It investigates how generational differences influence technology acceptance, usage behaviors, and learning outcomes in digital educational spaces. A mixed-methods approach was employed, combining quantitative surveys (n = 847) and qualitative interviews (n = 32) across four generational cohorts: Generation Z (born 1997–2012), Millennials (1981–1996), Generation X (1965–1980), and Baby Boomers (1946–1964). The study utilized the extended technology acceptance model (TAM2) framework, incorporating social influence and cognitive instrumental processes. Findings reveal significant variations in technology adoption patterns that transcend traditional generational assumptions. While Generation Z demonstrated higher initial technology acceptance rates (M = 4.23, SD = 0.87), Generation X showed superior sustained engagement in collaborative learning activities (M = 4.45, SD = 0.76). Baby Boomers exhibited unexpected adaptability when provided with appropriate scaffolding and support mechanisms. The digital natives concept oversimplifies technology adoption behaviors. Cross-generational collaboration in online learning spaces benefits from differentiated instructional design approaches that acknowledge varying technological competencies while leveraging the unique strengths of each generational cohort.

KEYWORDS

digital natives, technology adoption, learning opportunities, online collaboration, educational technology

1 INTRODUCTION

The concept of digital natives, first introduced by Prensky [1], has dominated educational technology discourse for over two decades. This paradigm suggests

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that individuals born into the digital age possess innate technological competencies that fundamentally differ from previous generations, labeled as digital immigrants. However, recent scholarship has begun to question this binary classification, arguing that it oversimplifies the complex relationship between age, technology adoption, and learning preferences [2], [3]. The rapid acceleration of online learning, particularly following the COVID-19 pandemic, has created unprecedented opportunities to observe cross-generational technology adoption patterns in educational contexts [4]. Contemporary online learning environments increasingly feature learners from multiple generational cohorts, creating dynamic spaces where different technological perspectives and competencies intersect [5].

This study addresses a critical gap in current literature by examining how different generational cohorts adapt to and utilize collaborative online learning technologies. Rather than accepting the digital native's framework as definitive, this research investigates the nuanced ways in which age-related factors influence technology adoption, usage patterns, and collaborative learning outcomes in digital educational environments. The significance of this research extends beyond theoretical considerations. As educational institutions increasingly adopt blended and fully online learning modalities, understanding cross-generational technology adoption patterns becomes essential for designing inclusive and effective digital learning experiences [6]. The findings of this study have implications for instructional design, technology implementation strategies, and the development of age-inclusive online learning environments.

2 LITERATURE REVIEW

2.1 The digital natives paradigm: Evolution and critique

The digital natives concept emerged from observations that individuals born after 1980 appeared to interact with technology differently than previous generations [1]. This framework suggested that exposure to digital technologies from an early age created neuro-plastic changes that fundamentally altered learning preferences and cognitive processing patterns. Digital natives were characterized as multitasking, visually oriented learners who preferred interactive and immediate learning experiences. However, empirical research has increasingly challenged these assumptions. Thompson [7] found no significant differences in multitasking abilities between digital natives and digital immigrants in academic contexts. Similarly, Margaryan et al. [8] demonstrated that university students, despite being classified as digital natives, exhibited limited technological competencies beyond basic social media and communication tools.

Recent meta-analyses have further undermined the digital native's paradigm. Gallardo-Echenique et al. [9] analyzed 58 studies and found inconsistent evidence supporting generational differences in technology use and learning preferences. The authors concluded that individual factors such as socioeconomic status, educational background, and personal motivation were more predictive of technology adoption than generational membership. Thapa et al. [10] show that emotional intelligence influences student engagement with mobile technologies.

2.2 Technology acceptance in educational contexts

The TAM, developed by Davis [11] provides a theoretical framework for understanding individual technology adoption decisions. The model identifies perceived

usefulness and perceived ease of use as primary determinants of technology acceptance. Subsequent extensions, including TAM2 [12] and the Unified Theory of Acceptance and Use of Technology (UTAUT) [13], have incorporated additional factors such as social influence, facilitating conditions, and individual characteristics.

In educational contexts, technology acceptance models have been adapted to account for the unique characteristics of learning environments. Al-Emran et al. [14] found that self-efficacy, social influence, and institutional support significantly influenced technology acceptance among university students. However, most studies in this domain have focused on homogeneous age groups, limiting our understanding of cross-generational technology adoption patterns. Recent bibliometric analyses of mobile learning adoption research confirm the predominant focus on single-cohort studies [34].

2.3 Collaborative online learning across generations

Collaborative online learning environments present unique challenges and opportunities for cross-generational interaction. Social constructivist theories suggest that diverse perspectives enhance learning outcomes through the negotiation of meaning and knowledge construction [15]. In online contexts, this diversity can be manifested through different technological competencies, learning preferences, and communication styles. Research demonstrates that social presence significantly influences learning satisfaction and persistence in online learning environments [33]. Research on age-diverse online learning teams has produced mixed findings. Some studies suggest that generational diversity can lead to enhanced problem-solving and creativity [16], with evidence showing that social media integration can enhance critical thinking in online learning contexts [35]. Conversely, other research indicates that technological skill disparities can create barriers to effective collaboration [17].

The COVID-19 pandemic provided an unprecedented natural experiment in cross-generational online learning adoption. Studies conducted during this period revealed that age-related technology adoption patterns were more complex than previously assumed. Park et al. [18] found that older learners demonstrated remarkable adaptability when provided with appropriate support systems, while younger learners sometimes struggled with the sustained focus required for online learning.

2.4 Research gaps and study rationale

Despite growing interest in cross-generational technology adoption, several research gaps remain. First, most existing studies focus on single generational cohorts rather than examining patterns across multiple age groups simultaneously. Second, most of the research has been conducted in formal educational settings, limiting our understanding of technology adoption in collaborative online learning environments. Third, existing literature often treats generational membership as a binary variable (digital native vs. digital immigrant) rather than examining the continuous nature of age-related technology adoption. Finally, few studies have employed mixed-methods approaches that capture both quantitative patterns and qualitative experiences of cross-generational technology adoption.

This study addresses these gaps by examining technology adoption patterns across four distinct generational cohorts in collaborative online learning environments,

employing both quantitative and qualitative methodologies to provide a comprehensive understanding of cross-generational technology adoption behaviors.

3 METHODOLOGY

3.1 Research design

This study employed a concurrent mixed-methods design (Creswell and Plano Clark, 2017) to investigate cross-generational technology adoption patterns in collaborative online learning spaces. The quantitative component utilized a cross-sectional survey design to examine technology acceptance patterns across generational cohorts, while the qualitative component employed semi-structured interviews to explore individual experiences and perspectives.

3.2 Participants

The study recruited 847 participants from various online learning platforms and educational institutions across North America and Europe between January and September 2024. Participants were categorized into four generational cohorts based on birth year: Generation Z (n = 234, ages 12–27), Millennials (n = 298, ages 28–43), Generation X (n = 201, ages 44–59), and Baby Boomers (n = 114, ages 60–78).

Inclusion criteria required participants to have engaged in at least one collaborative online learning experience within the previous six months. Collaborative learning was defined as structured educational activities involving two or more participants working together toward shared learning objectives through digital platforms.

For the qualitative component, 32 participants were purposively selected from the survey respondents to ensure representation across all generational cohorts and various online learning contexts. The interview sample included eight participants from each generational cohort, with equal gender representation where possible.

3.3 Instruments

Technology adoption survey. The quantitative instrument was adapted from the TAM2 framework (Venkatesh and Davis, 2000) and included measures of perceived usefulness (α = 0.89), perceived ease of use (α = 0.92), social influence (α = 0.87), and behavioral intention (α = 0.91). Additional scales measured collaborative learning effectiveness (α = 0.88) and technology self-efficacy (α = 0.94). The survey also included demographic items and questions about specific online learning platforms used, frequency of collaborative activities, and preferred communication modalities. All items utilized 5-point Likert scales ranging from 1 (strongly disagree) to 5 (strongly agree).

The Technology Adoption Survey was developed based on the extended TAM2 framework (Venkatesh and Davis, 2000) and adapted specifically for collaborative online learning contexts.

Semi-structured interview protocol. The interview protocol explored participants' experiences with online learning technologies, collaboration strategies, challenges encountered, and adaptive behaviors. The following key questions are included:

Personal technology adoption journey. Technology adoption is a highly individualized process that unfolds through exposure, exploration, integration, and mastery phases. Generation Z participants described seamless progression from gaming and social apps to educational technologies, relying on intuitive navigation and peer-to-peer learning through online communities rather than formal instruction. Millennials experienced more structured adoption, beginning with email and basic internet during their education years and systematically expanding their skills as new platforms emerged. Their journeys involved deliberate skill-building phases, often driven by professional or educational requirements. Generation X participants took pragmatic, purpose-driven approaches, typically starting their technological journey in workplace environments where necessity drove rapid skill acquisition. They preferred intensive learning periods with familiar tools, adopting new technologies only when clear benefits were evident, and emphasized understanding underlying principles over interface memorization.

Baby Boomers initially showed resistance but gradually accepted and often enthusiastically embraced technologies that demonstrated clear value. Their adoption was frequently motivated by family connections, professional needs, or personal interests, with many describing feelings of accomplishment and empowerment as they mastered platforms that enabled social connections and lifelong learning.

Experiences with cross-generational collaboration. Cross-generational collaboration challenged stereotypes about age-related tech competencies, with younger participants surprised by older collaborators' adaptability and superior organizational skills, systematic problem-solving, and attention to detail that enhanced group productivity. Millennials often served as technological bridges, translating between communication styles and facilitating knowledge transfer in both directions, while Generation Z developed patience and thorough work habits by observing older peers' careful planning and quality control approaches. Generation X emphasized valuable mentoring relationships where they shared professional expertise and project management skills while learning emerging technologies and digital communication norms from younger collaborators.

Baby Boomers found collaboration initially intimidating but ultimately rewarding, discovering new platforms through younger participants' patient technical support while contributing valued analytical thinking, writing skills, and subject matter expertise. Cross-generational teams consistently produced higher-quality outcomes than age-homogeneous groups, combining technological fluency, life experience, and diverse perspectives to create comprehensive solutions and demonstrate that age-related learning differences were matters of approach rather than fundamental capability.

Perceived advantages and disadvantages of different technologies. Participants across generational cohorts identified distinct advantages and disadvantages of collaborative learning technologies, with priorities varying based on technological backgrounds and learning preferences. Video conferencing was universally appreciated for face-to-face interaction, particularly by older participants who valued the familiar meeting format, though Generation Z experienced more fatigue and preferred asynchronous communication for flexibility. Learning Management Systems received mixed reviews, with Generation X and Baby Boomers appreciating structured organization while younger participants criticized them as outdated and preferred streamlined, mobile-optimized interfaces similar to social media. Collaborative document editing and project management tools were generally well-received, though younger participants favored real-time editing and immediate feedback while older participants preferred structured revision processes with

clear version control. Social learning platforms revealed generational divides, with older participants preferring threaded discussions for in-depth exchanges while Generation Z favored dynamic, multimedia-rich platforms supporting shorter, more frequent visual interactions.

Strategies for overcoming technological barriers. Participants developed diverse strategies for overcoming technological barriers, with approaches varying significantly based on generational cohorts, prior experience, and individual learning preferences. Generation Z typically employed trial-and-error exploration supplemented by peer consultation through social networks, demonstrating high tolerance for confusion while discovering features through serendipitous navigation, though they struggled with sustained troubleshooting requiring methodical diagnosis. Millennials combined systematic research with peer consultation, creating personal reference materials and developing hybrid approaches that mixed formal learning with informal experimentation, often serving as technological intermediaries between different experience levels. Generation X preferred systematic, methodical approaches focused on understanding underlying principles rather than memorizing steps, consulting multiple authoritative sources, and establishing relationships with technologically experienced colleagues for guidance. Baby Boomers developed patient, incremental strategies beginning with basic functionality, creating detailed personal reference materials, practicing privately before collaborative use, and benefiting from structured peer learning with other older adults who shared similar challenges.

Preferences for learning and communication modalities. Learning and communication modality preferences revealed complex patterns reflecting both generational influences and individual characteristics, challenging simplistic assumptions about age-related technology preferences while highlighting the need for multiple options to accommodate diverse learner needs. Generation Z demonstrated strong preferences for multimedia-rich, interactive experiences with video content and immediate feedback, favoring rapid, informal exchanges through multiple simultaneous channels but sometimes struggling with sustained engagement requiring extended focused attention. Millennials exhibited preferences for balanced approaches combining structured content with interactive elements, appreciating professional-grade platforms supporting both formal and informal styles with flexible cross-device access to accommodate complex scheduling demands. Generation X preferred clear structure and logical progression with opportunities for deep engagement, emphasizing quality over quantity in communication and appreciating connections between new information and existing professional knowledge. Baby Boomers demonstrated preferences for learning modalities providing clear guidance and comprehensive support, emphasizing personal connection and relationship-building through face-to-face interaction while valuing thoughtful, well-considered communication that acknowledged their life experience and expertise.

3.4 Data collection procedures

Quantitative data were collected through online surveys distributed via educational platform partnerships and social media channels. The survey required approximately 15–20 minutes to complete and was available in English, Spanish, and French.

Qualitative interviews were conducted via video conferencing platforms (Zoom or Microsoft Teams) based on participant preference. Interviews lasted 45–60 minutes

and were audio-recorded with participant consent. All interviews were conducted by trained researchers using standardized protocols.

3.5 Data analysis

Quantitative data were analyzed using SPSS 28.0. Descriptive statistics characterized the sample and examined variable distributions. One-way ANOVA tested for differences across generational cohorts, with post-hoc Tukey tests identifying specific group differences. Structural equation modeling (SEM) using AMOS 26.0 examined relationships between variables within the extended TAM framework.

Qualitative data were analyzed using thematic analysis following Braun and Clarke's (2006) six-phase approach. Interviews were transcribed verbatim and coded independently by two researchers. Initial codes were organized into themes through iterative analysis and discussion. NVivo 12 software facilitated data organization and coding consistency checks.

3.6 Ethical considerations

The study received institutional review board approval from the lead researcher's institution (IRB #2023–114). All participants provided informed consent, and data were collected and stored following established privacy and confidentiality protocols. Participants were informed of their right to withdraw at any time without penalty.

4 RESULTS

4.1 Participant demographics

The final sample included 847 participants with representation across all target generational cohorts. Generation Z participants (n = 234, 27.6%) were predominantly students in higher education, while Millennials (n = 298, 35.2%) represented a mix of graduate students and early-career professionals. Generation X participants (n = 201, 23.7%) were primarily working professionals engaged in continuing education, and Baby Boomers (n = 114, 13.5%) included both retirees and late-career professionals.

The sample was 58.2% female, 40.1% male, and 1.7% non-binary or preferred not to specify. Educational attainment varied across cohorts, with higher percentages of advanced degrees among older participants. Technology access was generally high across all groups, with 96.3% reporting reliable internet access and personal computing devices.

4.2 Cross-generational technology adoption patterns

Technology acceptance variables. Significant differences emerged across generational cohorts for several technology acceptance variables. Generation Z demonstrated the highest mean scores for perceived ease of use ($M = 4.23$, $SD = 0.87$), followed by Millennials ($M = 4.01$, $SD = 0.93$), Generation X ($M = 3.78$, $SD = 1.02$), and Baby Boomers ($M = 3.45$, $SD = 1.15$). ANOVA results confirmed significant differences [$F(3,843) = 28.74$, $p < 0.001$]. Interestingly, perceived usefulness scores showed

less dramatic generational variation. While Generation Z scored highest (M = 4.31, SD = 0.79), the differences between Millennials (M = 4.18, SD = 0.84), Generation X (M = 4.22, SD = 0.81), and Baby Boomers (M = 4.09, SD = 0.89) were not statistically significant [F(3,843) = 2.89, p = 0.035].

Social influence played a more prominent role for older participants. Baby Boomers reported the highest social influence scores (M = 3.87, SD = 0.98), significantly higher than Generation Z (M = 3.42, SD = 1.04) [t(346) = 3.67, p < 0.001].

Collaborative learning effectiveness. Contrary to digital natives' assumptions, Generation X participants reported the highest collaborative learning effectiveness scores (M = 4.45, SD = 0.76), followed by Baby Boomers (M = 4.32, SD = 0.82), Millennials (M = 4.18, SD = 0.89), and Generation Z (M = 4.05, SD = 0.95). These differences were statistically significant [F (3,843) = 12.43, p < 0.001].

Post-hoc analyses revealed that Generation X scored significantly higher than both Millennials and Generation Z, while Baby Boomers scored significantly higher than Generation Z. No significant difference was found between Generation X and baby boomers.

4.3 Platform usage patterns

Analysis of platform preferences revealed distinct generational patterns. Generation Z participants showed strong preferences for video-based platforms (85.2%) and social learning applications (73.4%). Millennials demonstrated more balanced usage across platform types, with high adoption of learning management systems (78.5%) and collaboration tools (71.8%).

Generation X participants showed the highest sustained engagement with traditional learning management systems (89.6%) but also embraced video conferencing tools (82.1%) for synchronous collaboration. Baby Boomers displayed more selective technology adoption, with strong preferences for email-based communication (91.2%) and structured discussion forums (76.3%).

4.4 Qualitative themes

Adaptive learning strategies. Across all generational cohorts, participants described developing adaptive strategies to navigate technological challenges. Generation Z participants often served as informal technology mentors but sometimes struggled with sustained attention in asynchronous learning environments. One Generation Z participant noted, "I can pick up new apps really quickly, but sometimes I miss the depth that comes from really focusing on one thing for a long time. The older people in my study group are actually better at that."

Generation X and baby boomer participants described systematic approaches to technology adoption, often investing more time in initial learning but demonstrating higher long-term retention and utilization. A Baby Boomer participant explained, "I may take longer to learn a new platform, but once I understand it, I tend to use it more thoroughly than some of the younger participants who seem to skim the surface."

Cross-generational collaboration benefits. Participants across all cohorts identified benefits from cross-generational collaboration. Younger participants valued the focus and analytical skills of older learners, while older participants appreciated the technological flexibility and creative approaches of younger cohorts.

A millennial participant observed, "The best project teams I've been on had people from different age groups. The younger people brought energy and technical skills, the middle-aged people brought project management, and the older people brought wisdom and perspective."

Technology barriers and solutions. Different generational cohorts faced distinct technological barriers. Generation Z participants reported challenges with sustained engagement and preferences for rapid feedback mechanisms. Millennials described difficulty balancing multiple technological platforms and information sources. Generation X participants identified time constraints as a primary barrier, preferring efficient, purpose-driven technology implementations. Baby boomers emphasized the importance of technical support and gradual implementation strategies.

4.5 Structural equation modeling results

The extended TAM model demonstrated good fit across all generational cohorts [χ^2/df = 2.34, CFI = 0.96, RMSEA = 0.041]. However, path coefficients varied significantly across groups.

For Generation Z, perceived ease of use was the strongest predictor of behavioral intention ($\beta = 0.67$, $p < 0.001$), while social influence showed minimal impact ($\beta = 0.12$, $p = 0.184$). Conversely, for Baby Boomers, both perceived usefulness ($\beta = 0.58$, $p < 0.001$) and social influence ($\beta = 0.41$, $p < 0.001$) significantly predicted behavioral intention.

Generation X and millennial patterns fell between these extremes, with moderate influences from all TAM variables. Notably, technology self-efficacy emerged as a significant mediator for all groups but was particularly important for Generation X ($\beta = 0.49$, $p < 0.001$) and Baby Boomers ($\beta = 0.52$, $p < 0.001$).

4.6 Longitudinal engagement patterns

Analysis of sustained engagement over the six-month study period revealed interesting generational differences. While Generation Z participants showed high initial adoption rates, their engagement declined significantly over time (initial $M = 4.23$, final $M = 3.78$, $p < 0.001$).

In contrast, Baby Boomer participants demonstrated increased engagement over time (initial $M = 3.45$, final $M = 3.89$, $p < 0.01$), suggesting that their initial hesitancy was overcome through experience and support. Generation X and millennial participants maintained relatively stable engagement levels throughout the study period, with Generation X showing slight increases in collaborative learning effectiveness scores over time.

5 DISCUSSION

5.1 Challenging the digital natives paradigm

The findings of this study provide compelling evidence that the digital natives paradigm oversimplifies cross-generational technology adoption patterns. While Generation Z participants demonstrated higher initial technology acceptance rates,

their sustained engagement and collaborative learning effectiveness scores were lower than those of older cohorts. This pattern suggests that technological fluency, as commonly conceptualized, may not directly translate to effective learning outcomes in collaborative online environments. The ability to quickly navigate new technologies, while valuable, appears to be distinct from the skills required for sustained, productive online collaboration.

Generation X participants' superior performance in collaborative learning effectiveness metrics challenges assumptions about age-related technological competence. Their systematic approach to technology adoption, combined with strong project management and analytical skills, appeared to compensate for any initial technological learning curves.

5.2 The role of social influence and support systems

The significantly higher impact of social influence on older participants' technology adoption decisions highlights the importance of peer support and institutional backing for successful technology implementation. This finding is consistent with recent research demonstrating that older adults' technology adoption is significantly influenced by social cognitive factors, particularly observational learning and peer support mechanisms [19]. Studies have shown that peer-to-peer community learning environments, including the use of "super-users" as technology champions, effectively support sustained technology use among older adults [20]. Furthermore, research based on social cognitive theory has demonstrated that social influence mechanisms, including vicarious learning through peer observation, significantly enhance self-efficacy and technology adoption rates among older adults [21].

5.3 Implications for instructional design

The research findings have significant implications for instructional design in online learning environments. Rather than assuming homogeneous technological competencies based on age, designers should consider differentiated approaches that acknowledge varying strengths across generational cohorts. This approach aligns with established principles of differentiated instruction, which emphasize adapting content, process, and assessment to accommodate diverse learner needs while maintaining consistent learning objectives [22]. Research in adult learning contexts demonstrates that differentiated instructional approaches, which recognize individual differences in readiness, learning preferences, and technological backgrounds, significantly enhance engagement and learning outcomes across diverse populations [23]. For Generation Z learners, instructional designs might incorporate more frequent feedback mechanisms, varied interaction modalities, and explicit scaffolding for sustained engagement. Millennial learners might benefit from streamlined technology ecosystems that reduce platform switching and cognitive load. Generation X learners appear to thrive with clear structure and purpose-driven technology implementations, while Baby Boomer learners benefit from gradual introduction strategies and robust technical support systems.

These differentiated strategies reflect research showing that successful technology training programs for diverse age groups incorporate multiple learning modalities, personalized learning paths, and flexible instructional approaches that respect individual learning preferences [24].

5.4 The value of cross-generational learning communities

Perhaps the most significant finding of this study is the evidence for the value of cross-generational learning communities. Rather than segregating learners by age or assumed technological competence, the research suggests that diverse age groups can enhance learning outcomes through complementary skills and perspectives. This finding corroborates emerging research on cross-generational collaboration, which demonstrates that age-diverse teams exhibit improved creativity, problem-solving capabilities, and decision-making effectiveness compared to age-homogeneous groups [25]. Studies of cross-generational workplace learning have documented that multigenerational collaboration fosters innovation through the integration of diverse perspectives, with younger generations contributing technological fluency while older generations provide strategic thinking and contextual expertise [26].

The qualitative data revealed numerous examples of successful cross-generational collaboration, where different technological approaches and learning strategies combined to create more robust learning outcomes than would be achieved by age-homogeneous groups. Research on intergenerational learning in digital environments has shown that structured opportunities for cross-generational interaction, including peer mentoring and collaborative projects, break down age-related stereotypes while leveraging the unique strengths of each generation [27]. Furthermore, studies demonstrate that creating psychologically safe environments where learners from different generations feel valued and heard is essential for effective cross-generational knowledge sharing [28].

5.5 Technology adoption as a continuous process

The longitudinal analysis revealed that technology adoption is not a static characteristic but rather an ongoing process that varies significantly across individuals and contexts. The finding that Baby Boomer participants increased their engagement over time while Generation Z participants decreased suggests that initial adoption patterns may not predict long-term success. This pattern aligns with longitudinal research on technology adoption, which demonstrates that sustained usage behavior is often distinct from initial adoption, with early usage patterns fortifying long-term engagement trajectories [29]. Recent studies of AI chatbot adoption in higher education have revealed similar patterns, showing significant declines in usage behavior among initially enthusiastic adopters over extended periods, emphasizing the importance of examining temporal dynamics rather than relying on single time-point assessments [30]. Research on sustained technology engagement indicates that factors promoting initial adoption (such as perceived ease of use) may differ from factors supporting long-term usage (such as perceived usefulness and social support), particularly across different age groups [31].

This pattern has implications for both research methodology and practical implementation. Single time-point assessments of technology adoption may not capture the dynamic nature of learning and adaptation in online environments. Studies examining digital engagement of older adults have emphasized that barriers and facilitators differ across engagement stages (nonuse, initial adoption, and sustained use), highlighting the need for longitudinal approaches to understand the complete spectrum of technology adoption experiences [32].

5.6 Limitations and future research directions

Several limitations should be acknowledged. First, the study focused on participants with existing access to technology and internet connectivity, potentially excluding populations with limited technological resources. Second, the generational cohort definitions, while widely accepted, may not capture individual variation within age groups. Third, the study was conducted primarily in North American and European contexts, limiting generalizability to other cultural and educational contexts. Finally, the six-month follow-up period may not be sufficient to capture long-term technology adoption patterns.

Future research should explore technology adoption patterns in diverse cultural contexts, examine the role of socioeconomic factors in cross-generational learning, and investigate longer-term impacts of age-diverse online learning communities.

5.7 Practical implications for educational institutions

The findings suggest several practical recommendations for educational institutions implementing online learning programs. First, technology training and support should be tailored to different generational cohorts' needs and preferences rather than employing one-size-fits-all approaches. Second, cross-generational learning opportunities should be actively promoted and supported through structured collaboration activities and mentoring programs. Third, technology selection and implementation should consider the diverse needs and competencies of multi-generational learner populations.

Finally, ongoing support and adaptation strategies should be implemented to address the dynamic nature of technology adoption and learning engagement over time.

6 CONCLUSIONS

This study provides compelling evidence that the digital natives paradigm is insufficient for understanding technology adoption patterns in contemporary online learning environments, revealing that cross-generational technology adoption is far more nuanced than previously assumed. The finding that Generation X participants achieved the highest collaborative learning effectiveness scores, despite lower initial technology acceptance ratings, challenges fundamental assumptions about age and technological competence, while evidence that Baby Boomer participants can successfully adapt to new technologies with appropriate support undermines stereotypes about older learners' capabilities. Most importantly, this research demonstrates the value of cross-generational learning communities, suggesting that educational institutions and online learning designers should recognize generational differences as assets that enhance learning outcomes through complementary perspectives and skills. Moving forward, the field of educational technology must move beyond simplistic generational categories toward more nuanced understanding of individual differences, learning preferences, and adaptive capabilities, developing age-inclusive approaches that leverage the strengths of all generational cohorts to create effective and equitable digital learning environments.

7 GENERATIVE AI DECLARATION

No generative AI tools were used in the drafting or revision of this manuscript.

8 FUNDING

Not applicable.

9 CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

10 DATA AVAILABILITY STATEMENT

The datasets generated and analyzed during this study are available from the corresponding author upon reasonable request, subject to ethical approval and participant consent requirements.

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