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Socio-psychological and technological predictors of academic resilience in online graduate programs in STEM and natural sciences

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ABSTRACT

This study developed a conceptual model of academic resilience in online graduate programs in STEM and natural sciences across select Philippine public higher education institutions. Employing a convergent parallel mixed-methods design, the research examined how socio-psychological and technological factors influence the capacity of graduate students to adapt and thrive in virtual learning environments. Quantitative data were collected from 350 STEM-focused graduate students using a correlational design and analyzed via Structural Equation Modeling (SEM) to determine the effects of self-efficacy, social support, satisfaction, and digital adaptability on academic resilience. Complementary qualitative insights were gathered through thematic analysis of semi-structured interviews with 30 purposively selected graduate students actively engaged in online STEM education. Findings revealed that self-efficacy exerted the strongest direct influence on academic resilience (β= 0.65, *p*= 0.001), followed by social support (β= 0.48, *p*= 0.002). Notably, satisfaction partially mediated the impact of self-efficacy (β= 0.55), while digital adaptability fully mediated the link between social support and resilience (β= 0.60). Thematic results reinforced these statistical findings, emphasizing the importance of learner confidence, access to peer and instructor support, and the value of well-structured, engaging online content in science-related disciplines. The study highlights the critical interplay of psychosocial readiness and digital competence in sustaining academic engagement within STEM and natural science programs. Recommendations include developing resilience-centered instructional design, targeted faculty training, and institution-led support systems to enhance graduate students' capacity to persist in technology-mediated scientific education.

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INTRODUCTION

Graduate school education is a cornerstone of national development and global progress (Martins and Faciola, 2025). The advanced training of human resources is directly attributed to the quality of graduate education programs offered by universities worldwide. These programs not only foster academic excellence and specialized expertise but also contribute to addressing global challenges through research, policymaking, and community engagement. In particular, graduate programs in STEM (Science, Technology, Engineering, and Mathematics) and natural sciences play a vital role in driving innovation, ensuring environmental sustainability, enhancing public health, and promoting agricultural resilience.

STEM and natural sciences provide critical insights and practical solutions to complex issues such as climate change, food insecurity, emerging diseases, and technological transformation.

These disciplines empower future scientists, educators, and professionals with the tools to build knowledge-based societies, foster evidence-based decision-making, and strengthen the scientific capacity of nations. Furthermore, by cultivating critical thinking and interdisciplinary collaboration, STEM and natural sciences in graduate education contribute to inclusive social development and community empowerment, especially in developing countries. Thus, investing in robust graduate programs in these fields is essential to building resilient communities and achieving long-term sustainable development goals (Alfalih and Alfalih, 2021; Powers and Kulkarni, 2023).

In developed nations, graduate programs in STEM and biosciences serve as engines of innovation, driving breakthroughs in biotechnology, environmental sustainability, public health, and artificial intelligence (Southworth *et al.*, 2023; Chan, 2023). These programs are supported by advanced research facilities, robust funding mechanisms, and strong collaborations between academia and industry. The result is a dynamic knowledge economy that responds rapidly to global challenges such as climate change, pandemics, food security, and energy transition.

In contrast, developing nations view graduate education in STEM as a vital tool for nation-building. It empowers scholars and researchers to address local and regional challenges such as climate resilience in agriculture, biodiversity loss, emerging infectious diseases, and access to clean water—through scientific inquiry and innovation. Despite the potential, disparities in research infrastructure, digital access, and capacity-building hinder progress in biosciences and related fields. Thus, there is an urgent call for international partnerships, open-access publishing, research fellowships, and technology transfer to bridge the global knowledge gap and strengthen scientific ecosystems in low- and middle-income countries (De Wit and Merkx, 2023; Xu, 2023; Rad *et al.*, 2022).

Globally, the abrupt shift to online education catalyzed by the COVID-19 pandemic exposed significant inequities in digital infrastructure, research continuity, and student preparedness—particularly within graduate-level STEM education (Guppy *et al.*, 2022; Adarkwah, 2021; Heng and Sol, 2021; Shehzadi *et al.*, 2021). For students in biosciences and other laboratory-based disciplines, online transitions created barriers to conducting hands-on research, accessing fieldwork, and collaborating effectively.

This necessitates a model of online resiliency that is specifically attuned to the context of STEM graduate students. Resilient learners in the biosciences must demonstrate high levels of self-efficacy, digital adaptability, academic satisfaction, and social support to maintain their engagement and productivity in virtual environments. Such resilience is not merely personal—it is foundational to sustaining scientific research, thesis work, peer-reviewed publication, and knowledge dissemination in times of crisis.

Moreover, this framework aligns with the United Nations Sustainable Development Goal 4 (Quality

Education) by promoting inclusive and equitable digital learning environments in science education. By fostering digital skills and emotional resilience, this model prepares future researchers, educators, and health professionals to thrive in an increasingly digitized and globalized scientific community. Strengthening online learning readiness and mental health support systems within STEM education will not only improve research outcomes but will also ensure the continued advancement of science that addresses both global and local needs.

In the Asian and ASEAN regions, rapid digitalization is redefining the landscape of higher education. However, this digital transformation also brings forth persistent challenges—particularly unequal internet access, limited digital literacy, and socio-economic disparities.

In the Philippines, these issues are especially pronounced in rural and underserved areas, where reliable connectivity and technological infrastructure remain inadequate (Bustillo and Aguilos, 2022; Letigio and Balijon, 2022). For graduate students in STEM fields, whose learning heavily relies on access to simulations, data modeling, research software, and collaborative platforms, such digital limitations can be even more debilitating.

This proposed model of Online Resiliency for STEM Graduate Students in selected Philippine public higher education institutions (PHEIs) addresses the urgent need for responsive and inclusive educational interventions. It highlights the roles of self-efficacy, social support, satisfaction, and digital adaptability as critical protective factors that empower students to navigate online learning challenges. These elements are particularly relevant for graduate students managing academic rigor alongside professional obligations and family responsibilities, which often lead to heightened stress and burnout (Göldağ, 2022; Concilio *et al.*, 2021).

Aligned with the ASEAN Work Plan on Education 2021–2025 and CHED Memorandum Order No. 15, s. 2019, which advocate for student-centered, flexible, and technology-enhanced learning, this model underscores the integration of digital competencies and emotional support mechanisms to strengthen academic resilience. It also supports the Philippine Development Plan's call for inclusive, accessible, and quality education that fosters innovation and lifelong learning.

Although existing literature has explored individual variables like self-efficacy and social support in promoting resilience (Chew, 2024; Iordan *et al.*, 2022), a noticeable research gap persists in contextualizing how these variables, when combined with satisfaction and digital adaptability, influence the online learning resilience of STEM graduate students. Particularly lacking are studies situated within the unique sociocultural and institutional environments of Philippine public universities.

Furthermore, most existing models do not sufficiently account for the nuanced experiences of STEM learners, who often require higher cognitive engagement, experimental rigor, and synchronous collaboration—all of which can be severely disrupted by poor digital infrastructure and lack of institutional guidance. This study bridges these gaps by proposing a holistic model that integrates psychological, social, and technological dimensions to explain and enhance online resiliency.

By doing so, the model contributes to a deeper understanding of how graduate students in STEM fields can be better supported through evidence-based policies, targeted digital interventions, and responsive institutional programs. It aims to inform future initiatives that seek to improve graduate education equity, digital readiness, and academic outcomes in the Philippine public higher education sector and similar developing country contexts.

MATERIALS AND METHODS

Research design

This study adopted a convergent parallel mixed-methods research design to comprehensively examine the socio-

psychological and technological factors influencing online resiliency among STEM graduate students in Philippine public higher education institutions (Demir and Pismek, 2018). This approach allowed the simultaneous collection, analysis, and integration of quantitative and qualitative data, thereby enabling a robust exploration of the research problem from both statistical and experiential perspectives.

Quantitative component

The quantitative strand employed a correlational design and utilized Structural Equation Modeling (SEM) as the primary analytical framework. SEM was appropriate for this study due to its capacity to examine complex causal relationships among multiple latent variables, such as self-efficacy, social support, satisfaction, digital adaptability, and online resiliency. This method allowed for the testing of both direct and indirect effects, as well as mediating relationships between constructs, providing empirical validation for the proposed conceptual model.

Qualitative component

The qualitative strand employed thematic analysis of data collected through semi-structured interviews. These interviews captured the lived experiences of graduate students navigating online STEM education, particularly their perceptions of self-efficacy, peer and institutional support, satisfaction with digital learning systems, and adaptability to technology-mediated environments. This approach enabled the exploration of students' coping strategies, barriers encountered, and adaptive behaviors in response to the demands of online graduate education.

Integration of quantitative and qualitative data

Integration occurred during the interpretation phase, where findings from SEM were triangulated with emergent themes from qualitative interviews. Quantitative results offered statistical rigor in confirming hypothesized relationships, while qualitative insights added contextual depth and explained the underlying psychological and institutional mechanisms influencing students' online resiliency. This mixed-methods approach ensured a comprehensive, nuanced, and student-centered understanding, generating actionable insights for policy, program development, and instructional design in graduate-level online STEM education.

Respondents and sampling procedure

The study involved a purposive sample of 350 graduate students actively enrolled in online STEM and natural science programs in Philippine public HEIs. This sampling method was appropriate for identifying individuals with direct experience of the phenomena under studybspecifically, the challenges and adaptations involved in pursuing graduate-level education in a virtual environment. The sample size of 350 was determined to be sufficient for SEM, which requires a large dataset for stable parameter estimates and adequate statistical power. Participants were selected based on their active enrollment in online courses during the academic year and their willingness to participate in both the survey and interviews. These demographics reflect a diverse cohort of graduate students in terms of age, gender, academic standing, and levels of digital preparedness. Their varied profiles enrich the study's findings and reinforce the need for tailored institutional support mechanisms to enhance academic resilience in online STEM learning environments (Table 1).

Table 1. Profile characteristics of respondents (n = 350)

Profile **variable**	Category	Frequency (f)	Percentage (%)
Sex	Male	140	40%
	Female	210	60%
Degree program	Master's Students	280	80%
	PhD Students	70	20%
Age group	21–30 years	120	34%
	31–40 years	150	42%
	41–50 years	50	14%
	Above 50 years	30	8%
Certification trainings attended on technology	None	50	14%
	1–2	120	34%
	3–4	110	31%
	5 or more	70	20%

Instrumentation

Data were collected using validated survey instruments that measured the constructs of interest, ensuring both content and construct validity. The

survey included multiple-item scales, which were subjected to reliability testing (e.g., Cronbach's alpha) to confirm internal consistency. The sample of 350 graduate school students was selected using purposive sampling, targeting those actively engaged in online learning environments within a Philippine higher education institution. The sample size was deemed sufficient for SEM, meeting the widely accepted minimum ratio of 10 respondents per parameter to ensure robust parameter estimation and model fit.

Data gathering procedure

Before SEM analysis, preliminary data screening was conducted to test assumptions of normality, linearity, and multicollinearity. Multivariate normality was assessed using Mardia's test, while skewness and kurtosis values were also examined. Outliers were identified and addressed to enhance the reliability of the model. The hypothesized model was tested using maximum likelihood estimation, with indices such as the Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), and Root Mean Square Error of Approximation (RMSEA) used to evaluate overall model fit. This rigorous methodological approach provided a comprehensive framework for understanding the factors influencing online resiliency among graduate students, contributing to both theoretical and practical advancements in the field of online education.

Data analysis

The data analysis for this study followed a multi-stage process to ensure the reliability and validity of the findings. Initially, descriptive statistics were calculated to summarize the demographic and academic profiles of the respondents, including frequencies, percentages, means, and standard deviations. This step provided a foundational understanding of the sample characteristics and contextualized the results within the study's framework. To test the hypothesized relationships among variables, Structural Equation Modeling (SEM) was employed as the primary analytical technique. SEM was chosen for its ability to simultaneously examine complex direct, indirect, and mediating effects among latent variables and their observed indicators. Prior to SEM, confirmatory factor analysis (CFA) was conducted to validate the measurement model, ensuring that the constructs of self-efficacy, social support, satisfaction, digital adaptability, and online resiliency were represented by their respective indicators with acceptable factor loadings (≥ 0.70). Reliability and validity tests, including Cronbach's alpha for internal consistency and composite reliability (CR) and average variance extracted (AVE) for construct validity, were performed. Data screening included assessing assumptions of normality, multicollinearity, and outliers.

Multivariate normality was examined using Mardia's test, while variance inflation factors (VIFs) were used to detect multicollinearity. Any outliers identified through Mahalanobis distance were addressed to enhance model robustness.

The structural model was tested using maximum likelihood estimation. Model fit was evaluated using standard fit indices: Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), and Root Mean Square Error of Approximation (RMSEA). Threshold values of ≥ 0.90 for CFI and TLI, and ≤ 0.08 for RMSEA, were considered indicative of a good model fit. Path coefficients were interpreted to determine the strength and significance of relationships between constructs. Bootstrap resampling was conducted to test the stability of estimates and assess indirect effects. This comprehensive analytical approach allowed for an in-depth examination of the factors influencing online resiliency among graduate students, yielding insights that could inform policy and practice in higher education.

Results of the test of normality, Mardia's test, and model fit indices

The results from the normality tests, Mardia's multivariate normality test, VIFs, and model fit indices suggest that the data meets the necessary assumptions for conducting Structural Equation

Modeling. The model fit is considered good, with all key indicators showing values within the acceptable ranges. These findings ensure the robustness and reliability of the subsequent analyses and the interpretations of the relationships among the latent variables in the study (Table 2).

Table 2. Test of normality, Mardia's test, and model fit indices

Test/Index	Data
Test of normality (Skewness)	Self-Efficacy= (-0.53)
	Social Support= (-0.48)
	Satisfactio= (-0.60)
	Digital Adaptability= (-0.45)
	Online Resiliency= (-0.55)
Test of normality (Kurtosis)	Self-Efficacy= (1.25)
	Social Support= (1.12)
	Satisfaction= (1.35)
	Digital Adaptability= (1.05)
	Online Resiliency= (1.18)
Mardia's multivariate normality test	Mardia's Skewness= (4.50)
	Mardia's Kurtosis= (12.30)
Variance inflation factor (VIF)	Self-Efficacy= (1.25)
	Social Support= (1.18)
	Satisfaction= (1.30)
	Digital Adaptability= (1.22)
	Online Resiliency= (1.40)
Model fit indices	Comparative Fit Index (CFI)= (0.92)
	Tucker-Lewis Index (TLI= (0.91)
	Root Mean Square Error of Approximation (RMSEA)= (0.06)

Test of normality

The skewness and kurtosis values for the constructs, including self-efficacy, social support, satisfaction, digital adaptability, and online resiliency, were all within the acceptable ranges, indicating that the data approximated a normal distribution. Specifically, the skewness values for all constructs ranged from -0.45 to -0.60, which is well below the threshold of ±1, suggesting that the data is not overly skewed. Similarly, the kurtosis values ranged from 1.05 to 1.35, which are within the acceptable range of ±2, indicating that the data distribution is not excessively peaked or flat.

Mardia's multivariate normality test

The results of Mardia's skewness (4.50) and kurtosis (12.30) tests suggest that the data met the criteria for multivariate normality, as the skewness value is below the critical value of 5, and the kurtosis value is below the critical threshold of 20. These results affirm that the data is sufficiently multivariate normal, which is an important assumption for conducting structural equation modeling (SEM).

Variance inflation factor (VIF)

The variance inflation factors (VIF) for all constructs—self-efficacy (1.25), social support (1.18), satisfaction (1.30), digital adaptability (1.22), and online resiliency (1.40)—are well below the threshold of 5, suggesting that multicollinearity is not a concern in the data. These results indicate that the constructs are not highly correlated with one another, which ensures that the parameter estimates in the SEM model are stable and reliable.

Model fit indices

The fit indices for the structural equation model indicate a good fit between the hypothesized model and the data. The Comparative Fit Index (CFI) was 0.92, which exceeds the recommended threshold of 0.90, indicating a good fit. Similarly, the Tucker-Lewis Index (TLI) was 0.91, which also exceeds the threshold of 0.90, further confirming the adequacy of the model. Lastly, the Root Mean Square Error of Approximation (RMSEA) was 0.06, which is below the acceptable threshold of 0.08, indicating a close fit between the model and the data.

Qualitative data analysis and gathering procedure

The qualitative data were gathered through semi-structured interviews with a purposively selected subgroup of 30 graduate students who were actively engaged in online learning across various disciplines. These participants were chosen to ensure diverse perspectives on the key constructs of the study—self-efficacy, social support, satisfaction, digital adaptability, and online resiliency. The interviews were conducted online, audio-recorded with consent, and transcribed verbatim to maintain accuracy and authenticity. Thematic analysis, guided by Braun and Clarke's six-phase framework (Byrne, 2022), was

used to identify, analyze, and report patterns within the data. This process involved familiarization with the transcripts, systematic coding, theme development, and refinement. The final themes offered rich, contextualized insights that complemented the quantitative results, enhancing the study's depth and providing a holistic view of the factors that shape online resiliency among graduate students.

RESULTS AND DISCUSSION

What is the level of self-efficacy, social support, satisfaction, and digital adaptability among graduate school students in online learning environments?

Table 3 shows the results of the study reveal the levels of self-efficacy, social support, satisfaction, and digital adaptability among graduate school students in online learning environments. The self-efficacy of the students was rated as high (M = 4.25, SD = 0.72), indicating that students generally believed in their ability to succeed in online learning tasks.

This result aligns with the expectation that graduate students tend to exhibit a sense of confidence in their academic capabilities, which is crucial for persistence in online education (Bandura, 1997). This finding underscores the importance of fostering a sense of self-efficacy among students to enhance their resilience and academic success.

Table 3. Level of self-efficacy, social support, satisfaction, and digital adaptability

Variable	Mean	Standard deviation	Interpretation
Self-efficacy	4.25	0.72	High
Social Support	3.80	0.65	Moderate
Satisfaction	3.90	0.58	Moderate
Digital Adaptability	4.10	0.60	High

Legend: 4.20-5.00: Very High/ Strongly Agree; 3.40-4.19: High/ Agree; 2.60-3.39: Moderate/ Undecided; 1.80-2.59: Low/ Disagree; 1.79: Very Low/ Strongly Disagree

In terms of social support, the mean score of 3.80 (SD = 0.65) suggests that students perceived a moderate level of support from peers, instructors, and the institution. While students report receiving adequate support, there remains room for improvement in terms of strengthening these networks. Social support is widely recognized as a critical factor for student success in online learning environments, as it can reduce feelings of isolation and stress (Visser *et al.*, 2014). The moderate score indicates that although students are receiving some support, it may not be sufficient or consistent across all aspects of their academic life.

For satisfaction, the students expressed a moderate level (M= 3.90, SD = 0.58) of satisfaction with their online learning experience. This result highlights that while students generally feel positive about their online learning, there are certain aspects that may need attention, such as course design, instructional delivery, and technological support. Satisfaction in online learning is often tied to the perceived quality of the learning environment and the extent to which students feel engaged and supported (Kauffman, 2015, Dziuban, *et al,* 2015).

Therefore, the moderate satisfaction level implies that improvements in the online learning experience are necessary to enhance overall student engagement.

In like manner, the level of digital adaptability was rated high (M = 4.10, SD = 0.60), indicating that students are generally comfortable with using digital tools and adapting to online learning platforms. This is an encouraging result, as digital adaptability is a critical skill for success in modern education (Nataliia et al., 2020; Suseno, 2023). The high level of adaptability reflects students' capability to adjust to the demands of online learning and their readiness to embrace technology as a means of achieving academic success. These findings suggest that while graduate students exhibit strong self-efficacy and digital adaptability, there are moderate levels of social support and satisfaction, which may hinder their full engagement and success in the online learning environment. To improve online resiliency, it is crucial for educational institutions to enhance support systems, both academic and technological, and to tailor online learning experiences to increase student satisfaction.

Strengthening social support through peer mentoring programs, more effective communication from faculty, and increased access to technical assistance could help students overcome challenges and improve their overall learning outcomes. Institutions should also continuously evaluate the usability and accessibility of digital platforms to ensure students' adaptability and engagement are sustained throughout their academic journey. These insights provide a foundation for further research and policy development in the context of online learning in higher education, particularly in the Philippines, where digital resilience is becoming increasingly important for student success.

How do self-efficacy and social support predict graduate school students' online resiliency?

As shown in Table 4, the analysis of the mediating role of satisfaction and digital adaptability in predicting graduate school students' online resiliency revealed significant results regarding the influence of self-efficacy and social support. Self-efficacy exhibited a strong effect (β = 0.65, *p* = 0.001) on students' online resiliency, indicating that students' belief in their ability to succeed in online learning tasks significantly contributed to their overall resilience. The path coefficient suggests that enhancing students' self-efficacy will have a substantial positive impact on their ability to navigate the challenges of online learning. This result underscores the critical role of fostering confidence and competence among graduate students, which is essential for their persistence and success in an online environment (Bandura, 1998). The significant positive impact of self-efficacy suggests that interventions aimed at boosting students' self-confidence—such as providing skill-building workshops and personalized academic support—could be highly effective in strengthening their online resiliency (Table 4).

Table 4. Mediating Role of Satisfaction and Digital Adaptability

Predictor variable	Path coefficient (β)	Interpretation	p-value	Interpretation
Self-Efficacy	0.65	Strong Effect	0.001	Significant positive impact
Social Support	0.48	Moderate Effect	0.002	Significant positive impact

*= significant at 0.05 level; ns= not significant at 0.05 level, Note: all other variables are not significant

Path magnitude coefficient interpretation: 0.70 and above: Very strong effect; 0.50 to 0.69: Strong effect; 0.30 to 0.49: Moderate effect; 0.10 to 0.29: Weak effect; Below 0.10: Very weak or negligible effect.

Table 5. Mediating Role of Satisfaction and Digital Adaptability

Path	Path Coefficient (β)	Interpretation	p-value	Interpretation
Self-Efficacy → Satisfaction → Resiliency	0.55	Strong Effect	0.001	Partial mediation
Social Support → Digital Adaptability → Resiliency	0.60	Strong Effect	0.002	Full mediation

Path magnitude coefficient interpretation: 0.70 and above: Very strong effect; 0.50 to 0.69: Strong effect; 0.30 to 0.49: Moderate effect; 0.10 to 0.29: Weak effect; Below 0.10: Very weak or negligible effect.

In contrast, social support demonstrated a moderate effect (β = 0.48, p = 0.002) on online resiliency. This means that while social support from peers, instructors, and the institution is important, its impact is less pronounced compared to self-efficacy. Nevertheless, the significant positive impact of social support highlights that stronger support networks, including peer mentoring and regular communication from instructors, can help students manage the stresses and challenges of online learning. This finding supports the literature on the importance of social support in enhancing student resilience (Yıldırım and Tanrıverdi, 2021, Malkoç, and Yalçın, 2015, Putri, 2024). While social support is vital, the moderate effect suggests that additional efforts are required to strengthen these support systems, such as creating more opportunities for social

interaction and engagement among students. The results indicate that both self-efficacy and social support are significant predictors of graduate students' online resiliency, with self-efficacy playing a stronger role. To enhance students' online resiliency, it is important for higher education institutions to focus on developing programs and interventions that promote self-efficacy, such as targeted training and skills development. Additionally, while social support plays a moderate role, strengthening the support systems through peer mentoring, faculty-student communication, and technical support can complement efforts to build students' self-efficacy.

What is the mediating role of satisfaction and digital adaptability in the relationship between self-efficacy, social support, and online resiliency?

The results from the analysis of the mediating role of satisfaction and digital adaptability in the relationship between self-efficacy, social support, and online resiliency are summarized in Table 5. The table presents the path coefficients and p-values for the mediating effects. The path from self-efficacy to satisfaction, which subsequently leads to online resiliency, showed a strong effect (β = 0.55) and was found to be statistically significant (p = 0.001), indicating partial mediation. This suggests that while self-efficacy has a direct influence on online resiliency, it also significantly influences satisfaction, which in turn affects resiliency. This finding underscores the importance of fostering self-efficacy in students to enhance their satisfaction with online learning, which further supports their overall resiliency in the online learning environment. The strong effect of self-efficacy on satisfaction aligns with previous research highlighting the critical role of self-confidence in academic achievement (Zimmerman, 2000).

On the other hand, the path from social support to digital adaptability, which then affects online resiliency, showed a strong effect (β = 0.60) and was also statistically significant (p= 0.002), indicating full mediation. This result demonstrates that social support not only directly influences online resiliency but also enhances students' digital adaptability, which further strengthens their resiliency in online learning. The full mediation effect highlights that the role of social support is pivotal in enhancing students' ability to adapt to digital tools and platforms, which is essential for succeeding in online learning environments (Obiena and Tenorio, n.d.; Timotheou *et al.*, 2023; Oh and Syn, 2015). This finding emphasizes the need for educational institutions to invest in peer mentoring, collaborative activities, and technical support to improve students' digital skills, thereby enhancing their resilience. The findings of this study have several important implications for the design and implementation of online learning environments. First, institutions should prioritize the development of students' self-efficacy, as it not only directly impacts their online resiliency but also improves their satisfaction with the online learning experience. Strategies such as personalized learning, fostering growth mindsets, and providing feedback can enhance students' confidence in their abilities. Second, social support plays a crucial role in facilitating students' digital adaptability, which in turn strengthens their online resiliency. Educational institutions should focus on enhancing peer support networks, providing regular technical assistance, and ensuring that students feel supported both academically and socially. Furthermore, efforts should be made to integrate collaborative learning platforms that promote interaction and peer-to-peer learning, which are essential for students' successful adaptation to online learning tools.

Challenges and problems faced by graduate school students in online learning

The thematic analysis of challenges and problems faced by graduate school students in online learning revealed several key themes, as outlined in Table 6. These themes provide insights into the multifaceted issues students encounter in adapting to online learning environments.

Table 6. Thematic analysis of challenges and problems faced by graduate school students in online learning

Theme	Sub-theme	Representative's verbatim quote
Technological challenges	Connectivity issues	"I often face slow internet connections, which disrupt my participation in online classes and delay submission of assignments."
	Lack of digital literacy	"Some of us aren't really tech-savvy, and the constant use of new online tools adds stress."
Psychological challenges	Stress and anxiety	"The pressure of balancing work, study, and family life online makes me anxious and overwhelmed."
	Feelings of isolation	"Without face-to-face interaction, I feel disconnected from my peers and professors, which makes it hard to stay motivated."
Institutional challenges	Lack of supportive resources	"The university does not provide enough support, such as mentoring or technical assistance, which makes it hard to adapt."
	Ineffective communication	"There's a lack of clear communication from the administration regarding course schedules and deadlines. This causes confusion."
Learning experience issues	Inadequate learning platforms	"Some learning platforms are difficult to navigate and are not user-friendly, causing frustration during lectures."
	Limited interaction with instructors	"I miss direct interaction with instructors. The online format doesn't allow for spontaneous question and answer sessions."
Adaptability issues	Adjustment to online learning	"Adapting to online learning has been a struggle; I miss the structure and routine of traditional classes."
	Lack of engagement in online classes	"It's hard to stay engaged with long online lectures. I tend to get distracted easily because there is no in-person connection."
Personal development barriers	Limited peer support	"I don't have much peer support during online courses. I miss group studies and discussions."

Technological Challenges

Connectivity issues and lack of digital literacy emerged as significant obstacles. Students reported facing slow internet connections, which disrupted their participation in online classes and delayed assignment submissions. As one student noted, *"I often face slow internet connections, which disrupt my participation in online classes and delay submission of assignments."* Additionally, the constant use of new online tools added stress, with students indicating that not everyone is tech-savvy. One participant stated, *"Some of us aren't really tech-savvy, and the constant use of new online tools adds stress."* These technological challenges highlight the need for institutions to provide reliable internet infrastructure and comprehensive digital literacy training.

Psychological challenges

Stress, anxiety, and feelings of isolation were prevalent among students. The pressures of balancing work, study, and family life while participating in online classes contributed to stress and anxiety. As one student expressed, *"The pressure of balancing work, study, and family life online makes me anxious and overwhelmed."* Additionally, the lack of face-to-face interaction with peers and professors led to feelings of disconnection and demotivation. One student reflected, *"Without face-to-face interaction, I feel disconnected from my peers and professors, which makes it hard to stay motivated."* These findings underscore the importance of addressing mental health and providing emotional support in online learning environments.

Institutional challenges

A lack of supportive resources and ineffective communication were identified as institutional barriers. Students noted that the university's limited support, including mentoring and technical assistance, hindered their ability to adapt to online learning. As one participant shared, "*The university does not provide enough support, such as mentoring or technical assistance, which makes it hard to adapt.*" Furthermore, unclear communication from the administration regarding course schedules and deadlines caused confusion. One student commented, "There's a lack of clear communication from the administration regarding course schedules and deadlines. This causes confusion." These challenges suggest the need for institutions to improve communication channels and provide more robust academic and technical support.

Learning experience issues

Inadequate learning platforms and limited interaction with instructors were identified as significant problems. Students found some learning platforms difficult to navigate, which caused frustration during lectures. As one student mentioned, "Some learning platforms are difficult to navigate and are not user-friendly, causing frustration during lectures." The lack of spontaneous QandA sessions and direct interaction with instructors also diminished the learning experience. One participant noted, "I miss direct interaction with instructors. The online format doesn't allow for spontaneous question and answer sessions." This highlights the need for user-friendly platforms and more interactive teaching methods.

Adaptability issues

Adjustment to online learning and lack of engagement in online classes were also noted. Several students reported difficulty adjusting to the lack of structure and routine, which they were accustomed to in traditional face-to-face classes. One student shared, "Adapting to online learning has been a struggle; I miss the structure and routine of traditional classes." Additionally, students expressed difficulty staying engaged with long online lectures, especially without in-person connection. As one participant mentioned, "It's hard to stay engaged with long online lectures. I tend to get distracted easily because there is no in-person connection." This emphasizes the importance of creating more engaging and interactive online learning environments.

Personal development barriers

Limited peer support was another barrier identified in the study. Students noted the absence of group studies and discussions, which are crucial for collaborative learning. One student stated, "I don't have much peer support during online courses. I miss group studies and discussions." This highlights the need for institutions to foster peer collaboration through virtual group activities and online discussions to enhance the learning experience.

These findings have several important implications for the future of online education. Institutions must prioritize improving technological infrastructure to address connectivity issues and provide comprehensive digital literacy training to ensure students are equipped with the necessary skills to navigate online platforms effectively. Psychological support systems must also be strengthened to help students cope with stress and feelings of isolation.

Creating more interactive and engaging online learning environments, offering better communication from the administration, and enhancing peer support networks will significantly improve the overall online learning experience. Additionally, institutions should focus on developing user-friendly platforms and offering more opportunities for real-time interaction with instructors and peers to foster a more connected and supportive learning community.

Integration of qualitative and quantitative data

The integration of qualitative and quantitative data highlights the critical factors contributing to online learning resilience. Self-efficacy emerged as a significant theme, with participants expressing confidence in navigating online systems independently, reducing stress, and enhancing learning. This qualitative insight aligns with the quantitative data, where the self-efficacy path coefficient ($\beta = 0.65$) underscores its strong positive impact on online resiliency. Similarly, social support was identified as a crucial predictor, with students valuing peer and mentor assistance, as reflected in the path coefficient ($\beta = 0.48$). This integration suggests the need for fostering collaborative environments and mentorship programs to bolster resilience (Table 7).

Satisfaction with online learning also played a vital role. Qualitative feedback about clear modules and frequent professor check-ins complements the quantitative findings ($\beta = 0.60$), emphasizing that student engagement and support mechanisms are essential for sustained satisfaction and resilience. Digital adaptability, with a path coefficient of $\beta = 0.58$, further demonstrated the importance of

familiarity with online tools, supported by qualitative themes indicating that training and practice enhance confidence and effectiveness. Lastly, technology training and support emerged as pivotal. While only 34.29% of students attended 1–2 sessions, qualitative data indicated that training positively influenced adaptability, highlighting the need for more comprehensive and frequent training programs.

These findings imply that institutions should prioritize enhancing self-efficacy, social support, and satisfaction through targeted interventions like collaborative learning opportunities, robust mentorship programs, and engaging content delivery. Additionally, expanding technology training initiatives and providing consistent support can significantly improve students' adaptability and overall resilience in online learning environments.

Table 7. Integration of qualitative and quantitative data

Qualitative Data	Quantitative Data	Data Integration/Interpretation
Self-Efficacy "I feel more confident when I know I can navigate through the system without needing help." "Knowing how to use the tools and platforms makes learning easier and less stressful."	Self-Efficacy Path Coefficient (β) = 0.65	Strong qualitative theme showing that self-confidence in online learning is crucial. Quantitative data supports the significant positive role of self-efficacy in enhancing online resiliency.
Social Support "Having friends in the class who I can turn to for help makes online learning much more manageable." "Our mentor's guidance through chat and emails really helped me overcome challenges."	Social Support Path Coefficient (β) = 0.48	Positive feedback regarding peer support networks reinforces the quantitative finding that social support is a key predictor of online resiliency.
Satisfaction with Online Learning "I am satisfied because the learning modules are clear, and there is always assistance when needed." "I appreciate the frequent check-ins by our professors, which made me feel supported and engaged."	Satisfaction Path Coefficient (β) = 0.60	The theme of satisfaction aligns with the quantitative data, showing that overall satisfaction with the online learning experience is vital to maintaining resilience.
Digital Adaptability "The more familiar I get with different online tools, the easier it becomes to study effectively." "I still struggle with some tools, but I feel more comfortable adapting over time with the training provided."	Digital Adaptability Path Coefficient (β) = 0.58	The importance of adapting to technology for online learning is evident both qualitatively and quantitatively, highlighting its significance in maintaining online resilience.
Technology Training and Support "The training sessions on Zoom, Google Classroom, and other tools were very helpful in my online learning." "It would be better if there were more sessions focused on using the online tools we encounter in the course."	Technology Training Attendance 34.29% attended 1–2 training sessions	The qualitative feedback emphasizes the importance of training, and the quantitative data supports that regular technology training improves students' adaptability to online learning tools.

Online learning resilience has emerged as a critical area of study, particularly in understanding the factors that enable students to thrive in virtual environments. Self-efficacy is consistently highlighted in the literature as a foundational element of resilience, with studies emphasizing its role in fostering confidence and reducing stress through improved navigational and problem-solving skills in digital platforms (Bandura, 1998; Cassidy, 2015; Yang *et al.*, 2019; Djourova *et al.*, 2020). Social support, encompassing peer networks and mentorship, has also been identified as pivotal, with research showing its contribution to academic persistence and emotional well-being in online settings (Tinto, 2006; Rovai, 2002).

Satisfaction with online learning is another influential factor, often linked to clear instructional design, frequent faculty engagement, and responsive feedback mechanisms, all of which promote student

retention and resilience. Additionally, digital adaptability is gaining attention as a necessary skill for coping with the technological demands of online education, with adaptive expertise being developed through systematic training and hands-on practice. Finally, technology training and support programs have been found to improve students' comfort with and proficiency in online tools, reducing barriers to effective learning and enhancing overall performance. These interconnected factors underscore the need for institutions to implement comprehensive strategies that address self-efficacy, social support, satisfaction, adaptability, and training to build robust online learning ecosystems.

CONCLUSION

This study sought to develop a conceptual model of online resiliency among graduate school students in a Philippine Higher Education Institution through a convergent parallel mixed-methods design. By integrating both quantitative and qualitative data, the study captured a comprehensive understanding of the key factors influencing students' ability to thrive in online learning environments. Results from the Structural Equation Modeling (SEM) revealed that self-efficacy and social support significantly contribute to online resiliency, with self-efficacy demonstrating a stronger direct effect. Students with high self-efficacy exhibited greater confidence in managing online tasks and were better equipped to handle challenges, while social support, though moderately influential on its own, was found to significantly affect resiliency when mediated through digital adaptability.

Satisfaction and digital adaptability emerged as mediating variables that further enhanced students' resiliency. The path from self-efficacy to satisfaction, and from social support to digital adaptability, showed statistically significant effects, indicating that these mediators play a crucial role in shaping students' online learning experiences. Qualitative findings supported these results, revealing that students who felt confident in navigating digital platforms and who received emotional or technical support from peers and faculty reported higher levels of engagement and motivation. However, students also voiced a range of challenges, including technological difficulties, psychological stress, limited peer interaction, and inadequate institutional support. The integration of both data strands confirmed that online resiliency is a multifaceted construct requiring not only individual confidence and competence but also strong support systems and adaptive infrastructures. For institutions to foster resilient online learners, they must provide comprehensive digital training, strengthen mentoring programs, ensure clear communication, and promote interactive and collaborative learning environments. Ultimately, this study emphasizes the importance of a holistic approach in addressing the complexities of online education, ensuring that graduate students are not only able to survive but also succeed and grow in virtual academic settings.

IMPLICATIONS TO PRACTICE, RECOMMENDATIONS, LIMITATIONS, AND FUTURE RESEARCH DIRECTIONS

The findings of this study present critical implications for educational practice and institutional policy in graduate education, particularly within the rapidly evolving landscape of online learning. Notably, the strong influence of self-efficacy on online resiliency underscores the need for universities to embed confidence-building strategies within their academic programs. Orientation sessions, digital skills bootcamps, and workshops that promote self-directed learning can significantly boost students' belief in their capabilities an essential trait for thriving in digital environments. Additionally, the mediating roles of learner satisfaction and digital adaptability emphasize the need for institutions to invest in user-centric learning management systems (LMS), prompt and constructive instructor feedback, and modular course structures. These features enhance students' online engagement and emotional resilience. Support systems such as mental health services, peer mentoring, and strong faculty-student interactions must be institutionalized to foster a nurturing and inclusive learning environment.

Implications for STEM and Biosciences Programs in the Philippines

In the context of STEM and biosciences programs in the Philippines, these findings carry heightened relevance. These disciplines often demand a high level of digital interaction, especially in simulations, lab-based e-learning, and scientific software use. Hence, building digital adaptability among STEM students through targeted training in virtual lab platforms, data analytics, and research software is crucial. Furthermore, biosciences students would benefit from experiential online learning modules that replicate fieldwork and laboratory procedures in virtual settings, enhancing both confidence and practical skill application. The promotion of scientific resiliency defined as the ability to persevere through experimental failures, data errors, or technical limitations in research should be integrated into the academic culture of graduate programs in the natural sciences. Facilitating cross-disciplinary mentorship, encouraging collaborative virtual research, and equipping students with skills in AI-powered bioinformatics tools or remote sensing technologies in environmental science, can empower learners to become adaptive and innovative contributors to their fields. This is particularly vital in the Philippine context where infrastructure limitations and geographic isolation often pose challenges to consistent digital access. Building localized, context-driven strategies for online resiliency will help ensure equitable learning outcomes for science and technology students across the archipelago.

LIMITATIONS

While this mixed-methods study offers comprehensive insights, it is not without limitations. The research was conducted within a single higher education institution, thereby limiting the generalizability of the findings to a broader academic setting. Although the quantitative data included a robust sample of 350 graduate students, the qualitative component relied on only 30 interviews, which may not fully reflect the diversity of student perspectives across disciplines and regions. Additionally, social desirability bias in responses during interviews cannot be ruled out.

RECOMMENDATIONS

Future research should aim to expand the scope by including multiple institutions across various regions of the Philippines to account for educational, cultural, and technological diversity. Longitudinal designs can be employed to examine the evolution of online resiliency throughout the academic journey. Comparative studies involving both undergraduate and graduate learners in biosciences and environmental sciences may reveal stage-specific needs for support and digital skills development. Furthermore, additional mediators or moderators such as intrinsic motivation, institutional culture, socio-technical infrastructure, and quality of instructional design should be explored to refine the conceptual model of online resiliency.

Studies could also investigate the impact of AI-powered learning tools, remote lab technologies, and learning analytics on enhancing adaptive behaviors in science students. Mixed-methods approaches remain valuable for capturing the complexity of digital learning.

Future inquiries are encouraged to leverage learning analytics, AI-based engagement tracking, and virtual ethnography, especially in laboratory-intensive fields like microbiology and agricultural sciences. These tools can yield richer insights into learner behaviors, knowledge acquisition patterns, and technological fluency. Ultimately, these directions will help in crafting evidence-based and responsive interventions to support STEM and biosciences learners in digital education environments across the Philippines and beyond.

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