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Investigating the impact of online learning on mathematical preparedness of first-year engineering students in Eastern Visayas, Philippines

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ABSTRACT

This study investigated the effects of the sudden shift to online education during the COVID-19 pandemic on the mathematical preparedness of first-year engineering students. This study compared the mathematical readiness of students who graduated from Senior High School (SHS) K-12 programs in 2020 (face-to-face education) and graduates of SHS-2021 (online education) using a College Math Readiness Assessment (CMRA), an assessment tool for college level mathematics. This research used a quantitative-comparative design to investigate the 271 participants (156 from the SHS-2020 cohort and 115 from the SHS-2021 cohort). The findings revealed that 55% of the SHS-2021(online) and 48% of the SHS-2020 (face-to-face) based on their CMRA scores were classified as mathematically college-ready (MCR) for engineering programs. Although the online education cohort had a slightly higher percentage of MCR students, the difference in mean scores between the two groups was not statistically significant (t (210) = 1.97, p =0.15). However, the SHS-2021 cohort showed a wider distribution of scores with higher percentages of students in both the 'excellent' and 'poor' categories than the SHS-2020 cohort. The study concludes that while online learning during the pandemic did not significantly hinder overall mathematical preparedness for engineering programs, the variability in performance among online learners highlights the need for targeted support and interventions to ensure equitable learning experiences and outcomes for all students.

Contribution/Originality: The paper's primary contribution is reporting the mathematical readiness of the K-12 2021 online education graduates in Eastern Visayas, Philippines and comparing it with the mathematical readiness of K-12 2020 face-to-face graduates using a College Math Readiness Test. The findings of this study postulate that online education in mathematics is possibly as effective as face-to-face classroom education.

1. INTRODUCTION

The COVID-19 pandemic affected the delivery of education to learners resulting in a rapid shift from traditional classroom instruction to online learning (Calaguas & Consunji, 2022; Tugirinshuti, Mugabo, & Banuza, 2021). The Commission on Higher Education (CHED) of the Philippines addressed the problem of education delivery by recommending online learning to Higher Educational Institutions (HEIs) (Perante & Gomba, 2021). Consequently, the Eastern Visayas State University (EVSU) followed CHED's directive and transitioned to online learning for the 2020-2021 and 2021-2022 academic years. This shift extended to primary and secondary education as well with the Department of Education (DepEd) mandating online instruction for all Filipino students.

Online education is defined as the remote delivery of instruction and knowledge transfer that mirrors traditional course structures that have existed for years (Allen & Seaman, 2010). It leverages the use of the internet and various digital tools like Learning Management Systems (LMS) and video conferencing platforms in facilitating the learning process (O'Donoghue, Singh, & Green, 2004). Online education offers benefits such as flexibility and access to vast online resources (Geith & Vignare, 2008). However, concerns about its effectiveness in STEM fields particularly in engineering have emerged during the pandemic (Dumford & Miller, 2018).

Several studies have questioned whether online learning can fully replicate the benefits of in-person interaction as it potentially can lead to reduced student engagement and performance (Bergstrand & Savage, 2013; Cellini & Grueso, 2021; Kofoed, Gebhart, Gilmore, & Moschitto, 2021; McClendon, Neugebauer, & King, 2017). Additionally, prior research investigated the impact of the K-12 curriculum on Filipino K-12 graduates' mathematical preparedness for college revealed concerning results (Perante, 2022) and the COVID-19 pandemic that resulted in an abrupt shift to online learning may have exacerbated these existing concerns. The goal of this study is to determine the impact of online instruction on the mathematical preparedness of K-12 graduates particularly those pursuing engineering in college. Broadly, the research objective is to investigate the mathematical and analytical preparedness of freshmen engineering students at EVSU who graduated from senior high schools in Samar and Leyte islands during the K-12 programs of 2020 (face-to-face) (SHS-2020) and 2021 (online) (SHS-2021) and specifically, to answer these research questions: a) Are the SHS-2021 graduates from Eastern Visayas who transitioned to online education during COVID-19 adequately prepared mathematically for the demands of engineering programs? b) Is there a significant difference in the CMRA scores between SHS-2020 and SHS-2021 graduates? c) What is the proportion of students classified as MCR for engineering programs in each group? d) Are there any gender-based differences in CMRA performance between the two groups? e) What factors are probably contributing to the variability in mathematical preparedness among online learners? In attempting to answer these questions, the researchers hope to provide learnings and information into the effectiveness of online mathematics education in preparing students for engineering programs and to identify potential areas for improvement, intervention and support. The findings of this study are useful as they could lead to the development of informed educational policies and practices that will help ensure that students receive quality mathematics education regardless of the learning modality and are adequately prepared for the rigors of engineering programs in higher education.

2. REVIEW OF LITERATURE

The COVID-19 pandemic brought unprecedented challenges in the delivery of education, forcing most educational institutions worldwide to rapidly transition from traditional face-to-face teaching to online learning modalities (Adedoyin & Soykan, 2023; Dhawan, 2020). This shift has raised concerns about the effectiveness of online education particularly in STEM fields such as engineering where hands-on learning and practical skills development are crucial (Asgari et al., 2021; Jena, 2020). Several studies have investigated the impact of online learning on student performance and engagement. Stanberry and Payne (2023) reported that STEM students in online calculus courses preferred face-to-face instruction and believed that professors could explain the content better in person during the pandemic. Students in online courses have lower levels of collaborative learning (Dumford & Miller, 2018) and have lower student-faculty interaction and reduced quality interactions with peers compared to those in face-to-face courses. Similarly, Bergstrand and Savage (2013) observed that students in online courses performed poorly than their counterparts in face-to-face classes attributing this difference to reduced student engagement and interaction. These findings suggest that online learning may not fully replicate the benefits of in-person instruction potentially resulting in poor student performance and inadequate student learning outcomes. In the context of the Philippine educational system, the shift to online learning during the pandemic probably worsened the existing concerns about the mathematical preparedness of K-12 graduates for college-level engineering programs. Prior research reported the low percentage of Filipino senior high school graduates who can be considered mathematically college-ready (MCR) for engineering courses (Perante, 2022). This lack of mathematical college readiness was attributed to various factors including curriculum design, poor instructional practices and lack of student engagement and faculty qualifications. Indeed, Massouti (2023) emphasized the need for teacher education programs to capacitate teacher educators with the necessary ICT skills to become competent K-12 teachers for online learning to integrate Information, Communications Technology (ICT) knowledge into the curriculum. Studies have shown that online learning can negatively impact student performance in mathematics (Engzell, Frey, & Verhagen, 2021; Kuhfeld et al., 2020). For instance, Engzell et al. (2021) reported that students in the Netherlands experienced learning losses equivalent to one fifth of a school year due to the shift to online education during the pandemic. Similarly, Kuhfeld et al. (2020) projected that students in the United States could return to school in the fall of 2020 with learning gains in mathematics reduced to approximately 63-68% of what would be expected in a typical school year. On the other hand, some research suggests that online learning can be as effective as traditional face-to-face instruction when designed and implemented properly (Nguyen, 2015; Xu & Jaggars, 2014). Nguyen (2015) in a meta-analysis of 92 studies comparing online and face-to-face learning found that students in online courses performed slightly better on average. This highlights that the success of online learning depends on factors such as course design, student engagement and teacher presence. In a study by Stanberry and Payne (2023) the majority of STEM online students in Historically Black Colleges and Universities in the United States (HBCUs) agreed that multiple means of engagement and structured assignments helped increase their knowledge and comprehension in the online format of education. Additionally, the majority of students reported confidence in online courses in college level mathematics and most students performed well in online calculus courses (Stanberry & Payne, 2023). There is a lack of research on the impact of online education on the mathematical preparedness of K-12 graduates while these studies provide valuable learnings, insights, and understanding into the effectiveness of online learning. This study aims to fill this gap by comparing the mathematical readiness of students who graduated from SHS-2020 and SHS-2021 in the Eastern Visayas region of the Philippines. Statistical analysis of the differences in CMRA scores and the proportion of students classified as MCR between the two cohorts can contribute to the understanding of how online learning during the pandemic has affected students' mathematical preparedness particularly those pursuing engineering education in college.

The findings of this study can lead to the development of informed educational policies and practices in the Philippines particularly in the context of potential future disruptions to traditional face-to-face learning similar to COVID-19. Investigating the strengths and weaknesses of online mathematics education can guide the development of targeted interventions and support mechanisms to ensure that students are adequately prepared for the rigors of engineering programs regardless of the learning modality.

3. METHODOLOGY

3.1. Research Design

A quantitative and comparative research design was used to investigate the mathematical preparedness of first-year engineering students who graduated from SHS-2020 and SHS-2021 in the Eastern Visayas region of the Philippines. The research compared the performance scores of these two cohorts on CMRA to assess the potential impact of online learning on students' mathematical readiness for engineering programs (Creswell & Creswell, 2018).

3.2. Research Population and Sample

The research population was first-year engineering students (respondents) who were enrolled at Eastern Visayas State University (EVSU) and graduated from Senior High Schools (SHS) in Samar and Leyte islands during the K-12 programs of the years 2020 and 2021. There were two hundred and seventy-one (n=271) students that participated in this study with 156 students from the SHS-2020 cohort and 115 students from the SHS-2021 cohort. The researcher used purposive sampling (Etikan, Musa, & Alkassim, 2016) limiting the study participants to (a) first-year engineering students at EVSU and (b) graduating from SHS in either 2020 (face-to-face) or 2021 (online) modalities.

3.3. Research Instrument

The CMRA, developed by Perante (2022) was used to assess the mathematical preparedness of the participants. The CMRA is based on the learning competencies outlined in the Department of Education's (DepEd) Senior High School curriculum. The CMRA covers pre-calculus subjects composed of analytic geometry, trigonometry and series and mathematical induction while basic calculus topics were composed of derivatives, integration, limits and continuity. The CMRA consisted of 60 multiple-choice questions with a time limit of two hours.

3.4. Validity and Reliability

The validity and reliability of the CMRA were established in an earlier study by Perante (2022). Content validity was assessed by a panel of experts composed of mathematics teachers and engineering faculty. The assessment yielded a content validity index (S-CVI/Ave) of 0.92, probably indicating a strong alignment with the requirements of engineering programs (Polit & Beck, 2006). The reliability of the CMRA was determined using the test-retest method and the correlation analysis yielded $r = 0.89$ and $r = 0.91$ values possibly demonstrating consistent results across the CMRA administrations (Weir, 2005).

3.5. Data Collection Procedure

The CMRA was administered online to both the SHS-2020 and SHS-2021 cohorts. The test was administered using Google Forms® between August 3rd and September 30th, 2020 for the face-to-face cohort through this URL: https://forms.gle/fT3uqj87ikb1eG397 and between July 16th and August 18th, 2021, for the online education cohort through this universal resource locator: https://forms.gle/ojj8wVJRTb9tuBvb6 which was provided to first-year engineering students at EVSU during the administration period. The data gathering for this study strictly followed the ethical approval and guidance provided by the research ethics committee of SSU. Thus, before the CMRA properly started, the respondents were informed about the purpose of the study and were assured of the confidentiality of their information and responses. The timify.me add-in was used to enforce the two-hour time limit.

3.6. Data Analysis

The respondents' CMRA scores were interpreted and summarized using descriptive statistics. Measures of central tendency (mean, μ), variation (standard deviation, *s.d.*) and proportion (percentages) were calculated to summarize the CMRA scores and to classify the proportion of students that are MCR in each cohort. To determine the appropriate statistical test for comparing the mean scores between the cohorts, an F- test (Snedecor & Cochran, 1989) was conducted and based on the results, a two-tailed student's T-test (Kim, 2015) was used to determine the differences in mean CMRA scores between the SHS-2020 and SHS-2021 cohorts. Statistical analyses were performed using the Analysis ToolPak add-in Microsoft Excel (Microsoft Corporation) with a significance level of $\alpha = 0.05$. Table 1 shows the scores description and interpretation that determines the mathematical and analytical preparedness of the respondents for college-level engineering studies. F-test ($p \leq 0.05$) was used to examine the variances of the CMRA scores of the two groups; the null and alternative hypotheses are as follows:

- *Null hypothesis (H_0): $\sigma^2_1 = \sigma^2_2$ which indicates that the variances of the CMRA scores of the SHS-2020 and SHS-2021 cohorts are equal.*
- *Alternative hypothesis (H_a): $\sigma^2_1 \neq \sigma^2_2$ signifying that the variances of the scores of the cohorts are not equal.*

The student's t-test ($p \leq 0.05$) was used to calculate the mean score differences between the two cohorts; the null and alternative hypotheses are as follows:

- *Null hypothesis (H_0): $\mu_1 - \mu_2 = 0$ signifying that the mean CMRA score of SHS-2020 graduates is similar to the mean score of SHS-2021 graduates.*
- *Alternative hypothesis (H_a): $\mu_1 - \mu_2 \neq 0$ suggesting that the mean CMRA scores of the two groups are statistically different.*

Table 1. Description and interpretation of the CMRA scores.

CMRT scores	Description	Interpretation
50-60	Excellent	Excellently prepared
40-49	Good well prepared	Good well- prepared
30-39	Satisfactorily prepared	Satisfactorily prepared
20-29	Fair remediation class	Fair remediation class
1-19	Poor remediation class required	Poor remediation class required

4. RESULTS

4.1. Respondents Profile

Table 2 shows the demographic profile characteristics of the CMRA participants. There were one hundred and fifty-six first-year engineering students who graduated from SHS-2020 that participated in this study. These SHS-2020 graduates came from 62 different Senior High Schools (SHS) across the Eastern Visayas region. The SHS-2021 online education group was comprised of 115 students from 48 SHS in Leyte and the Samar Islands. The gender distribution between the two groups was nearly equal (1:1 ratio). The age distribution was also similar with most participants in both groups being 18 years old (65% for SHS-2020 and 64% for SHS-2021).

4.2. CMRA Performance

The F-test for two-sample variances revealed that the variances of the CMRA scores of the SHS-2020 and SHS-2021 groups (F (155, 114) = 4.92, p =0.003) are statistically significantly different.

Table 2. Demographic profile of the SHS-2020 and SHS-2021 graduates that participated in the CMRA.

Demographics	K-12 2020 (face-to-face)	K-12 2021 (Online)
Senior high school	n=62	n=48
Course: BS civil engineering	n=156	n=115
Gender distribution:		
Male	n=77 (49%)	n=59 (50%)
Female	n=79 (51%)	n=56 (50%)
Age distribution:		
17 years old	n=14 (9%)	n=12 (10%)
18 years old	n=101(65%)	n=74 (64%)
19 years old	n=35 (22%)	n=25 (22%)
20 years old	n=3 (2%)	n=2 (2%)
21 years old	n=1 (1%)	n=1 (1%)
>17 or <21 years old	n=2 (2%)	n=1(1%)

Accordingly, a student's t-test indicated that the mean CMRA scores between the two groups (t (269) = 1.97, p =0.15) are not statistically significantly different. This indicates that the SHS-2020 and SHS-2021 graduates probably possess similar levels of mathematical and analytical preparedness for college-level engineering studies.

Further analysis explored gender differences in CMRA scores (see Table 3). For male respondents, the F-test indicated unequal variances between the SHS-2020 and SHS-2021 groups (F (51, 52) = 4.78, p =0.004). A subsequent t-test revealed statistically significantly different mean scores (t (103) = -1.95, p =0.05). The SHS-2021 male graduates achieved a higher mean score (33.63 ± 13.41) compared to the SHS-2020 male graduates (29.5 ± 9.9). In contrast, the f-test for female respondents showed no significant difference in score variances (p =0.19). The t-test confirmed that mean scores between SHS-2020 and SHS-2021 females (t (131) = 1.65, p =0.35) are not statistically significantly different. Additional analysis investigated the CMRA scores categorized by age group (17, 18, and 19 years old) for both SHS-2020 and SHS-2021 graduates. The f- test revealed equal variances in scores for the 17-year-old groups (p =0.05). However, unequal variances were found for the 18-year-old (p =0.095) and 19-year-old groups (p =0.16). Consequently, the t-tests showed no significant differences in mean scores between SHS-2020 and SHS-2021 graduates in the age groups of: 17 years old (t (24) = 1.71, p =0.08), 18 years- old (t (139) = -1.28, p =0.2), and 19 years old (t (40) = 0.76, p =0.44).

Table 3. F- test and student's T-test results on the CMRA scores of SHS-2020 (Face-to-face) and SHS-2021 (Online) for (a)all respondents, (b) male respondents, and (c) female respondents (p=0.05).

Parameters	K-12 2020 (Face-to-face)	K-12 2021 (Online)
All respondents		
Mean (μ); Variance (σ²); Obs (n)	μ = 29.33; σ²= 88.57; n= 156	μ = 31.27; σ²= 142.69; n= 115
F-Test result	The variances of the two samples are not equal p=0.003.	
t-Test: (Unequal variances) result	The means of the two populations are not significantly different (t (210) = 1.97, p = 0.15).	
Male respondents		
Mean (μ); Variance (σ²); Obs (n)	μ = 29.77; σ²= 95.8; n= 77	μ = 33.63; σ²= 183.39; n= 59
F-Test result	The variances of the two samples are not equal p=0.004.	
t-Test: (Unequal variances) result	The means of the two populations are significantly different (t (103) = 1.98, p = 0.05*).	
Female respondents		
Mean (μ); Variance (σ²); Obs (n)	μ = 29.34; σ²= 76.98; n= 79	μ = 28.76; σ²= 95.22; n= 56
F- test result	The variances of the two samples are equal p=0.19.	
t- test: (Equal variances) result	The means of the two populations are not significantly different (t (131) = 1.65, p=0.35.	

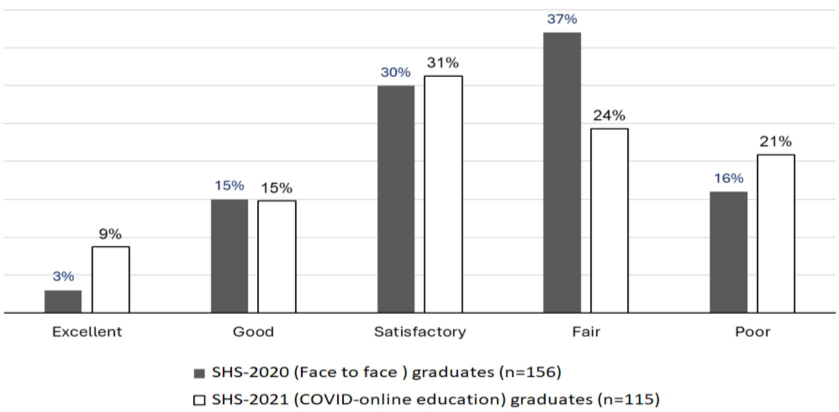

Figure 1. Classification of the CMRA scores of the SHS-2020 and SHS-2021 respondents; notice the SHS-2021 cohort showing a higher proportion of students in 'Excellent' (9%) and 'Poor' (21%) categories compared to the SHS-2020 cohort indicating variability and disparity in performance level in the 2021 cohort.

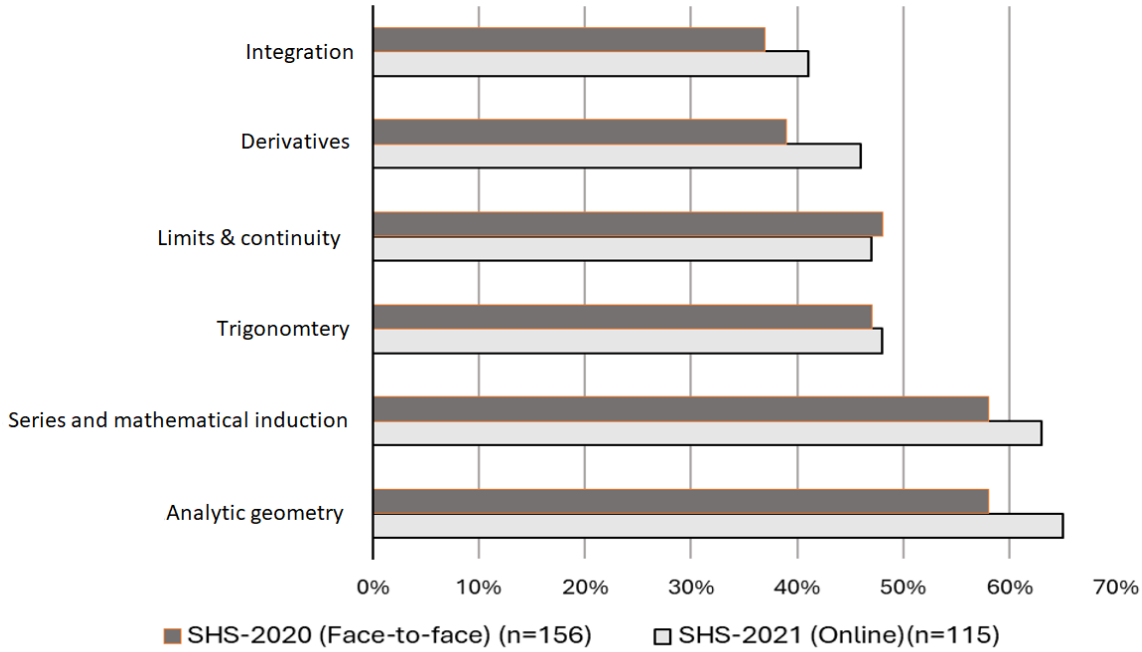

Figure 2. CMRA scores of the SHS-2020 and SHS-2021 respondents based on subject categories.

4.3. Mathematical and Analytical Readiness

Figure 1 presents the distribution of college- level mathematics preparedness of the SHS-2020 (face-to-face) and SHS-2021 (online) graduates as measured by the CMRA instrument. Figure 2 illustrates the breakdown of scores based on subject categories. The results indicate that 48% of the SHS-2020 graduates and 55% of the SHS-2021 graduates fell into the categories of 'excellent,' 'good,' or 'satisfactory,' classifying them as potentially 'mathematically-college-ready' for college engineering programs. Conversely, a higher percentage of SHS-2021 graduates (21%) fell into the 'poor' category compared to the SHS-2020 group. On the other hand, both cohorts obtained good scores in series and mathematical induction and in analytic geometry.

5. DISCUSSION

The effects of the abrupt transition to online education during the COVID-19 pandemic was examined and focused on the mathematical preparedness of first-year engineering students in Eastern Visayas, Philippines. The study compared the CMRA scores of students who graduated from the SHS-2020 programs and SHS-2021, to ascertain whether there were notable differences in mathematical preparedness between these two cohorts.

The results revealed that 55% of the SHS-2021 graduates and 48% of the SHS-2020 graduates were classified as MCR for engineering programs based on their CMRA scores. Although the online education cohort had a slightly higher percentage of MCR students, the difference was not statistically significant ($t\,(210) = 1.97$, p =0.15). The research findings indicate that the transition to distant education imposed by the COVID-19 pandemic did not significantly influence the overall math readiness of students entering engineering programs.

However, the results also revealed a notable difference in the distribution of CMRA scores within the SHS-2021 cohort. A higher proportion of students in this group fell into both the 'excellent' (9%) and 'poor' (21%) categories compared to the SHS-2020 cohort. This finding suggests that while some students thrived in the online learning environment, others may have struggled to adapt to the new modality leading to a wider range of performance levels.

Several factors may have contributed to this variation in performance among the online education cohort. Students from lower-income families may have faced difficulties in using the necessary technology and resources to fully engage in online learning (Aguliera & Nightengale-Lee, 2020). Additionally, individual differences in learning styles, self-regulation skills and adaptability to new learning environments may have played a role in students' success in online mathematics courses (Baloran, 2020; Neroni, Meijs, Gijselaers, Kirschner, & de Groot, 2019).

The research findings are aligned with other research on online learning in mathematics education. For example, Alpert, Couch, and Harmon (2016) found that students in online mathematics courses performed comparably to those in in-person courses suggesting that when online learning is well-structured and executed, it can be as effective as traditional classroom instruction. Similarly, Lockman and Schirmer (2020) conducted a meta-analysis of online learning studies and found no significant difference in student outcomes between online and in-person courses. In a recent study, Stanberry and Payne (2023) surveyed STEM students in urban HBCUs (Historically Black Colleges and Universities) taking online calculus courses and reported that success rates i.e., earning an A, B or C ranged from 69.2% to 80.8% showing that most students performed well in online calculus courses.

Nevertheless, other research yielded inconsistent findings concerning the effect of online learning on mathematics achievement. Xu and Jaggars (2014) found that students in online mathematics courses had lower grades and were more likely to withdraw from classes compared to those in face-to-face courses and the study suggested that the self-directed nature of online learning may be particularly challenging for students in quantitative subjects like mathematics.

The wide range of performance levels of the online education cohort is consistent with research highlighting the variability in student experiences and outcomes in online learning environments; for example, Kuhfeld et al. (2020) reported that students experienced varying degrees of learning loss due to the COVID-19 school closures with some students potentially falling behind while others maintained or even accelerated their learning progress. Li and Lalani (2020) also observed that the rapid shift to online learning during the pandemic revealed and amplified pre-existing disparities in education with students from disadvantaged backgrounds facing greater challenges in accessing and adapting to online learning. The findings of this study have several implications for educational policies and practices. While the study showed that online learning can be as effective as classroom instruction in preparing students for engineering programs, the variation in performance within the online education cohort underscores the need for targeted support and interventions to help all students succeed in online environments. Therefore, the researcher suggests that higher education institutions (HEIs) should prioritize the development of robust online learning systems that are accessible, engaging, and adaptable to the diverse needs of learners (Sanga, 2020). This prioritization should include investing in technology infrastructure providing professional development for faculty to enhance their online teaching skills and offering student support services such as tutoring, mentoring, and counseling to address the academic and socio-emotional challenges students may encounter in online learning. Furthermore, teachers and policymakers should recognize the potential of online education in exacerbating the existing educational inequalities and thus should take proactive steps to mitigate these disparities (Aguliera & Nightengale-Lee, 2020). This may include offering resources and assistance to students from underprivileged backgrounds such as providing access to technology, internet connectivity, and dedicated study areas as well as offering adaptable learning options and accommodations to cater to the diverse needs of students (Li & Lalani, 2020). The researcher suggests that research should continue to investigate the factors that contribute to student success in online mathematics education in preparation for potential future disruptions to traditional face-to-face instruction similar to COVID-19. Studies that examine the specific challenges faced by students from disadvantaged backgrounds and explore effective interventions to support their learning in online environments will be especially valuable in informing educational policy and practice.

6. CONCLUSION AND RECOMMENDATIONS

The results of this study revealed a picture of comparable overall mathematical readiness between the two cohorts suggesting that the shift to online learning did not significantly hinder the development of essential skills for engineering programs. However, upon closer inspection, the study exposes a more nuanced narrative within the online education cohort, where a wider spectrum of performance emerged, with some students soaring to new heights of excellence while others grappled with the challenges of this new learning paradigm.

The findings of this study can serve as a guide to teachers and policymakers towards a deeper understanding of the factors that shape student success in the face of adversity. This study emphasizes the need for targeted support and interventions to bridge the gaps exposed by the pandemic ensuring that every student regardless of their background or circumstances has the opportunity to thrive in the digital learning landscape. Furthermore, this study offers valuable insights into the potential of online learning to transform the way society cultivates the minds of future engineers. This study showed that the internet and online education can be more accessible, engaging, and can provide equitable learning experiences to students of diverse backgrounds, and that teachers should remain vigilant in the pursuit of educational excellence in the face of unprecedented challenges.

To address the achievement gap observed among online learners, this study recommends (a) determining the practicality of adopting hybrid educational approaches that integrate remote teaching with in-person classroom experiences, particularly during difficult times like a pandemic. (b) Explore the development of targeted online or in-person math tutoring programs to support students with weaker foundational math skills. (c) Consider providing financial aid or establishing accessible computer labs to address potential disparities in student access to technology and internet resources.

To improve overall MCR rates, this study recommends (a) conducting further research to identify the specific factors influencing student preparedness in senior high school mathematics education (e.g., curriculum design, instructional practices, student self-efficacy) and (b) Based on the research findings, develop and implement professional development programs for SHS mathematics teachers to enhance their skills in online or blended learning environments.

Furthermore, this study recommends encouraging further research on the impact of online education across various subjects and student demographics employing larger sample sizes and broader geographical coverage to expand the knowledge base on online education.

7. POLICY SUGGESTIONS

The findings of this study have significant implications for educational policies and practices, particularly for potential future disruptions to traditional classroom instruction. The following policy suggestions aim to address the issues, challenges, and opportunities identified in this research: 1) Investment in Technology Infrastructure. Educational institutions and policymakers should prioritize investments in robust technology infrastructure to support effective online learning. These may include ensuring access to reliable internet connectivity, providing students and faculty with adequate devices, and establishing secure and user-friendly learning management systems; these investments can enhance the quality and accessibility of online education particularly for students from underprivileged backgrounds who may face barriers to accessing necessary resources. 2) Professional Development for Faculty. Educational institutions should set policies to better prepare teachers for the demands of distance learning (Massouti, 2023) to ensure the success and effective delivery of online learning initiatives by the faculty. Providing comprehensive professional development opportunities to faculty including training in online pedagogical strategies, effective use of educational technologies, and best practices for engaging and supporting students in virtual environments are essential as these skills and knowledge are necessary so that faculty can design and deliver high-quality online instruction, thus enabling institutions to foster a culture of excellence in online education and promote student success. 3) Student Support Services. Educational institutions should recognize the unique challenges that students may face in online learning environments; thus, educational institutions should prioritize the development and expansion of student support services including offering virtual tutoring and mentoring programs, providing access to online mental health resources, and establishing mechanisms for regular check-ins and feedback between students and teachers. This network of support services can help students navigate the academic and socio-emotional challenges of online learning, promoting their well-being and academic success. 4) Flexible Learning Options. Educational institutions should accommodate the diverse needs and circumstances of learners and should consider implementing flexible learning options within their online education programs. These may include offering asynchronous course components, providing alternative assessment methods, and allowing for personalized learning pathways offering flexibility and adaptability in online course design and delivery enabling institutions to foster more inclusive and equitable learning environments that accommodate the distinct needs of students. 5) Collaboration and Knowledge Sharing. By promoting collaboration and knowledge sharing among stakeholders involved in online education such as facilitating partnerships between schools, universities, and industry partners to share best practices, resources, and expertise in online learning through this culture of collaboration and continuous improvement, the educational community can collectively address the challenges and embrace the opportunities associated with online learning, ultimately improving the quality and effectiveness of online education for all students. 6) Research and Evaluation. Decision-making and policy development should be evidence-based; thus, educational institutions and policymakers should support ongoing investigation and evaluation efforts focused on online learning particularly on research about factors that contribute to student success in online learning environments, evaluating the effectiveness of specific online teaching strategies and technologies, and exploring the long-term impacts of online education on student outcomes. Research and data-driven analysis can help the educational community to continually refine and improve online learning practices, ensuring that policies and initiatives are grounded in empirical evidence.

8. LIMITATIONS

This study has two primary limitations: (1) Due to the online administration of the CMRA, it was not possible to directly observe participant engagement or response behaviors during the test. This limits our ability to assess factors that might have influenced test performance beyond the content knowledge measured by the CMRA. (2) The study's focus on a single subject (college-level mathematics) and a specific student population (incoming engineering freshmen) restricts the generalizability of the findings. Future research should explore the effectiveness of online education on mathematical preparedness in a wider range of subjects and student demographics.

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Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: Both authors contributed equally to the conception and design of the study. Both authors have read and agreed to the published version of the manuscript.

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