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Arduino Programming Education Using Tinkercad: A Mixed-Method Study on Usability and Student Engagement During the COVID-19 Pandemic

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Abstract: The COVID-19 pandemic necessitated rapid transitions from traditional face-to-face instruction to emergency remote teaching, particularly challenging hands-on technical education. This mixed-methods study evaluates the usability and effectiveness of Tinkercad, a web-based Arduino simulation platform, for programming education during the pandemic. Using a convergent parallel design, the research examined 42 first-year Computer Technology students at a Philippine state university who transitioned from physical laboratory work to online simulation-based learning. Data collection employed the standardized System Usability Scale (SUS) survey, open-ended questions, and academic performance comparisons with pre-pandemic cohorts. Results revealed a below-average overall SUS score of 58, with notable gender differences (female students: 62, male students: 54). Despite suboptimal usability ratings, 74% of students expressed willingness to use Tinkercad frequently, and 67% found it easy to use. However, academic performance declined from pre-pandemic averages (2.4 to 3.3), indicating learning challenges. Key barriers included pandemic-induced mental health impacts, inadequate internet infrastructure in the Philippines, and the inherent limitations of simulation-based learning compared to hands-on experiences. The study demonstrates that while Tinkercad can maintain educational continuity during crisis situations, successful implementation requires addressing infrastructure constraints, providing enhanced technical support, and incorporating mental health considerations. Findings suggest simulation platforms serve as viable emergency alternatives but highlight the continued importance of hands-on experiences in technical education and the need for hybrid learning approaches.

Keywords: Arduino Programming, System Usability Scale (SUS), Online Education, Tinkercad, COVID-19 Education

INTRODUCTION

Arduino is an open-source electronics platform based on easy-to-use hardware and software. Because of its simple and accessible user experience, Arduino has been used in thousands of different projects and applications. The Arduino IDE (Integrated Development Environment) is easy to use for beginners, yet flexible enough for advanced users. It is cross-platform as it runs on Mac, Windows, and Linux. (Arduino, 2023).

To use any of the Arduino microcontroller boards, programming specifically for this platform is an essential skill for electronics enthusiasts and developers and for students who would like to design their prototypes using this technology. Prototyping, robotics, and Internet of Things (IoT) projects widely use Arduino due to its cost-effectiveness. However, learning Arduino programming can be challenging, especially for beginners who lack the necessary hardware or have limited access to physical components.

The COVID-19 pandemic has forced many educational institutions to shift their teaching and learning methods from in-person to online and distance learning (UNESCO, 2020a). In particular, the Higher Education Institutions (HEIs) in the Philippines have been greatly impacted, as hands-on laboratory activities, such as programming and circuit building, are more difficult to facilitate remotely. Tinkercad, a free web application for simulation from Autodesk, has emerged as a potential solution for teaching Arduino programming remotely.

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REVIEW OF RELATED LITERATURE

The intersection of Arduino programming education, simulation-based learning platforms, and educational technology implementation during crisis situations represents a critical yet underexplored area of educational research. This comprehensive literature review synthesizes recent academic findings across 10 interconnected research domains to establish theoretical foundations, empirical evidence, and research gaps in technology-enhanced programming education, particularly focusing on developing country contexts and crisis-responsive educational systems.

Educational Technology Adoption During COVID-19

COVID-19 increased educational technology usage, showing unprecedented prospects and continuing inequities in programming instruction. The COVID-19 epidemic forced emergency remote teaching worldwide, changing educational technology uptake and highlighting infrastructure and fairness issues. A meta-analysis of 42 research studies in 15 countries revealed significant learning impairments (Cohen's d = -0.14, corresponding to 35% of a typical school year), with arithmetic deficits being greater than reading deficiencies (Betthäuser et al., 2023). Technical education and laboratory-based courses have distinct issues that require comprehensive revamping of programming and electronics education's hands-on learning experiences.

Simulation platforms like Tinkercad showed equivalent learning outcomes to hands-on methods while being more accessible during lockdowns, spurring fast adoption during this crisis (Abburi, 2021). However, infrastructure capacity greatly affected implementation success, with 50% of low-income families and 42% of families of color lacking technology access, highlighting persistent digital divides in developing countries where Arduino programming education could provide STEM opportunities.

Arduino Programming Education Effectiveness and Simulation Platform Integration

Recent systematic assessments of Arduino programming education show that Problem-Based Learning (PBL) dominates, with implementations in interdisciplinary STEAM projects (Acevedo-Borrega et al., 2023; Leoste et al., 2024). Arduino-based education routinely outperforms traditional techniques in peer-reviewed studies, with educators claiming deeper comprehension through actual projects (Leoste et al., 2024). Breadboard-based physical interfaces, modular boards, and Tinkercad simulation performed similarly for microcontroller knowledge and coding skills in experiments. Tinkercad simulation outperformed modular boards for circuit comprehension (Abburi, 2021), demonstrating simulation platforms can improve learning results in specific fields.

The curriculum emphasizes computational thinking, problem-solving, and 21st-century skills, with "learning to program" and "tackling science subjects" as the pedagogical objectives (Leoste et al., 2024). Studies show gains of up to 75% in retention compared to lecture-based methods. Pandemic-era remote learning research in 2020–2021 investigated Tinkercad's effectiveness. Most students like Tinkercad and understand their assignments, with perceived usability positively affecting student performance (Juanda et al., 2021). Comprehensive usability evaluations with Information Technology teachers indicated that they completed authentic Circuits tasks and preferred Arduino circuit simulation over physical components (Abburi, 2021).

Especially in primary school, Tinkercad impacts creativity, algorithmic thinking, teamwork, critical thinking, and problem-solving (Juanda et al., 2021). Studies reveal that Scratch and Tinkercad improve programming and computational-electronic skills, with pupils interested in online Tinkercad workshops.

Educational Technology Usability Assessment and System Usability Scale Applications

Educational technology platforms have a mean SUS score of 70.09 (SD = 12.98) in a systematic analysis of 104 research publications with 170 SUS scores, indicating "excellent usability but with significant difficulties." Mobile applications score highest (M = 73.62), while university websites score lowest (63.82) (Vlachogianni & Tselios, 2022). With mean ratings of 76.43, multimedia platforms are usable. Statistics suggest that SUS scores are connected to subject content learned, but not to participant age or education stage. Participants adversely correlate with SUS scores (r = -0.259, p = 0.001), suggesting educational technology platforms may have scaling issues (Vlachogianni & Tselios, 2022).

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Complementary PSSUQ/CSUQ investigations from 42 research papers reinforce these findings, with mobile applications scoring 81.53 and overall usability mean 72.75 (SD = 15.12) (Vlachogianni & Tselios, 2023). For educational simulation platforms like Tinkercad, these criteria are essential.

Meta-analysis of 124 studies (N = 34,357 teachers) confirms the Technology Acceptance Model's academic applicability, with perceived utility and simplicity of use predicting technology uptake (Scherer et al., 2019). Self-efficacy, subjective norms, and supportive conditions influence fundamental dimensions in extended TAM applications. We just introduced AI-powered usability evaluation using machine learning indicators and learning analytics for automated, continuous educational technology efficacy assessment.

Online Education Transformation and Mental Health Impacts During COVID-19

Laboratory-based courses with hands-on training were especially vulnerable to the pandemic. American Society for Biochemistry and Molecular Biology guidelines revealed severe disruptions in hands-on laboratory learning, with professors encountering special obstacles in transitioning equipment-dependent courses online. UK studies found mental health issues increased from 24.3% pre-pandemic to 37.8% during lockdowns. 85.8% of university students expressed worry during the epidemic, and academic worries correlated with mental health results. Virtual students have more mental health issues and less social connection than in-person classmates.

Critical infrastructure issues prevented 826 million kids from using household computers and 17% from completing homework owing to internet connectivity (UNESCO, 2021). With 89% of learners in Sub-Saharan Africa lacking household computers and 82% without internet access, the situation was dire. Mobile-first therapies for SMS-based numeracy issues with phone calls (Botswana) and motivating text messages (Brazil) showed promise in resource-constrained situations. Marginalized communities still lack high-speed broadband, and rural places are less likely to obtain needed technology.

Gender Differences in Programming Education and Technology Acceptance

A comprehensive research shows complicated gender differences that start early and persist in higher education. Longitudinal research of 109 first-graders demonstrated gender disparities after coding instruction: boys had higher accuracy, while girls planned more but had worse accuracy. It appears that social factors, not cognitive aptitude, explain these discrepancies. Meta-analysis of 30 research studies (N=9,181) indicated small but significant gender differences in computational thinking favoring boys (Hedges's g = 0.091), becoming more evident in high school. However, 2-hour robotics workshop interventions removed initial gender inequalities in programming self-efficacy, proving early interventions work.

Technological Acceptance Model studies show females value programming technology more but find them harder to utilize. Though cultural and contextual factors modify these associations, female pre-service teachers have lower technology confidence.

Science museum programming workshops eliminate initial self-efficacy discrepancies and diminish gender gaps in robotics programming. Collaborative learning environments help girls more than competing individual tasks. Interdisciplinarity and problem-based learning engage girls, with 41% exhibiting interest in programming when taught alongside other disciplines. Girls' self-efficacy development depends on mastery experiences and female role models, and early intervention before grade 3 can prevent stereotypes.

Virtual Versus Hands-On Learning Effectiveness in Technical Education

Meta-analysis of 46 studies indicated virtual laboratories have a moderate to large educational impact with Hedges' g = 0.686 (Wu et al., 2024). Learning motivation (3.571) and engagement (2.888) had the strongest benefits, while knowledge acquisition (0.865). In experiments comparing virtual, hands-on, and blended approaches, hybrid models consistently perform well. Compared to 48% in traditional settings, 73% of students say blended learning improves learning experiences, compared to 38% in traditional settings.

Effective sequential model implementation (virtual preparation followed by hands-on application) reduces lab time and boosts efficiency. Virtual laboratories are great for conceptual understanding and pattern identification, but manual dexterity and professional laboratory procedures require hands-on experiences.

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Scaled properly, virtual laboratories reduce student costs by 3-5x and offer 24/7 access, no geographical limitations, and infinite repetition without resource constraints. Startup costs include software licenses, hardware infrastructure, and faculty training. Technical limitations include software authenticity and simplistic models neglecting real-world complications. Simulations cannot fully replace hands-on experience because they cannot reproduce haptic feedback or improve manual skills.

Infrastructure Challenges in Developing Countries Affecting Educational Access

According to research, the digital gap has three levels: access (devices and connectivity), competence (digital literacy and training), and result (unequal learning outcomes despite technology access). Developing countries have 25% internet connectivity, while developed countries have 93%, and Least Developed Countries have 6%. The Sto-Rox district in Pittsburgh has only 30-60 laptops for 1,300 pupils, causing major issues. Devices and internet connections cost over 100% of average monthly pay in 17 countries (UNESCO, 2021). In developing countries, mobile broadband is the main connectivity option, with 78% growth, yet it's typically insufficient for schooling.

Women access mobile internet 20% less than men, worsening gender inequality. Female technology access is limited by culture and society, limiting programming education chances.

With Pakistan's mobile literacy promotion and Uganda's Harmonizer Programme using mobile technology for youth education, mobile-first and offline implementations show the most promise. In locations with poor internet connectivity, SMS-based education works. World Bank programs connecting 600 public institutions in Malawi and Connected Schools for All targeting 3.5 million Latin American and Caribbean students show scaling potential. Radio, television, and digital multi-modal delivery systems allow crisis-responsive education redundancy.

Universal internet service obligations and public-private partnerships can promote sustainable infrastructure development. Competition policies lower telecom costs in Bangladesh, Bhutan, Cambodia, and Nepal.

Learning Theory Frameworks and Educational Technology Foundations

The Community of Inquiry framework remains highly influential with over 7,000 citations, providing a theoretical foundation for online learning design through social presence, cognitive presence, and teaching presence components (Garrison et al., 2000). Recent meta-analyses confirm effectiveness across diverse educational contexts, with peer-led teaching presence enhancing cognitive development through multiple pathways. Social constructivism applications to e-learning emphasize collaborative knowledge construction through Zone of Proximal Development principles and scaffolding approaches. E-Social Constructivism theory accounts for electronic communication environments, updating traditional constructivist approaches for digital contexts.

Constructivist learning environments significantly enhance both intrinsic and extrinsic motivation, with students demonstrating improved learning strategies, critical thinking, and problem-solving skills. Virtual reality and simulation applications successfully transfer constructivist principles to digital environments while maintaining emphasis on social presence and collaborative learning.

Zimmerman's Self-Regulated Learning model proves critical for online learning success, involving forethought, performance, and self-reflection phases (Zimmerman, 2000; Panadero & Alonso-Tapia, 2014). SRL significantly predicts academic performance in online contexts, with students demonstrating better engagement and completion rates. AI-supported SRL interventions show increasing promise for personalized learning support.

Learning analytics frameworks provide systematic approaches to educational data analysis, with Greller and Drachsler's six-dimensional framework addressing stakeholders, objectives, data, instruments, and limitations (Greller & Drachsler, 2012). Context-specific implementation needs require theoretical grounding and stakeholder involvement for successful deployment.

Objectives of the Study

This study aims to explore the effectiveness of online Arduino programming education using Tinkercad during the COVID-19 pandemic to identify the learning outcomes, challenges, and opportunities of this approach.

Having mentioned all the premises, the objectives of the study are the following:

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1. To determine the usability of using Tinkercad as an online platform for teaching Arduino programming during the pandemic;
2. To identify the challenges and opportunities associated with online Arduino programming education during the pandemic; and
3. To provide recommendations for educators and institutions seeking to implement or improve their online Arduino programming education offerings during the pandemic and beyond.

RESEARCH DESIGN & METHODS

Research Design, Setting, and Context

This study employed a convergent parallel mixed-methods design to comprehensively evaluate Tinkercad's usability and effectiveness as an online Arduino programming education platform during the COVID-19 pandemic, allowing simultaneous collection and analysis of quantitative and qualitative data with equal priority (Creswell & Plano Clark, 2017). The research was conducted at a state university in the Philippines during the height of the pandemic when traditional face-to-face laboratory instruction was suspended, focusing on first-year Computer Technology students who transitioned from hands-on laboratory work to online simulation-based learning using Tinkercad. This natural experimental setting provided an authentic context for evaluating emergency remote teaching effectiveness in technical education while addressing the complexity inherent in educational technology evaluation during crisis situations.

Participants and Sampling

The study used census sampling to include all 42 first-year Computer Technology students in Arduino programming courses during the study period. We adopted this extensive sampling technique because of the small population size and the necessity to capture the full experience of students affected by the pandemic-induced switch to online schooling. The participant demographics were balanced, with 22 female (52.4%) and 20 male (47.6%) students, which improved generalizability and lowered technology adoption bias. All participants were 18–20-year-old college students with similar computer technology backgrounds.

Data Collection Methods

The primary quantitative instrument was a post-evaluation survey based on Brooke's (1996) standardized System Usability Scale (SUS), consisting of **10 statements** measured on a 5-point Likert scale (1 = Strongly Agree, 5 = Strongly Disagree) to evaluate effectiveness, efficiency, and user satisfaction. The survey was administered via Google Forms two weeks after course completion, with SUS statements adapted to specifically reference Tinkercad while maintaining original psychometric properties and ensuring sufficient platform exposure for accurate assessment.

To complement the quantitative usability assessment, two open-ended questions (number 11 and 12) were integrated into the survey instrument:

1. I think that I would like to use this app frequently.
2. I find the app unnecessarily complex.
3. I think the app was easy to use.
4. I think that I would need the support of a technical person to be able to use this app.
5. I find the various functions of this app were well-integrated.
6. I think there was too much inconsistency in this app.
7. I would imagine that most people would learn to use this app very quickly.
8. I find the app very cumbersome to use.
9. I feel very confident using the app.
10. I needed to learn a lot of things before I could get going with this app.
11. What aspect of the app did you find most valuable/useful?
12. What aspect of the app did you find least valuable/useful?

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Data Collection Procedures

Data collection was three-phased. First, students used Tinkercad to finish Arduino programming courses in six weeks with instructor supervision and guided exercises. Second, after course completion, participants answered the online SUS survey and open-ended questions within two weeks. Third, academic performance data were anonymized and retrieved from institutional records. All participants gave informed consent, emphasizing voluntary involvement, confidentiality, and the right to leave the study. This longitudinal comparison revealed the educational efficacy of simulation-based versus hands-on learning. The institutional ethics committee approved the research protocol before data collection.

Data Analysis Methods

SUS scores were calculated using Brooke's (1996) standardized methodology with positively worded items scored as 5 minus scale position and negatively worded items as scale position minus 1, yielding final scores from 0-100, while descriptive statistics and independent t-tests analyzed usability scores and gender differences. Open-ended responses underwent thematic analysis following Braun and Clarke's (2006) six-phase approach, with two researchers independently coding responses to ensure reliability through inter-rater agreement and consensus-building. The convergent parallel design culminated in integrated analysis comparing quantitative and qualitative findings to provide comprehensive insights into Tinkercad's usability and educational effectiveness during the pandemic.

Validity and Reliability Considerations

Several measures enhanced the study's validity and reliability, including the use of the standardized SUS instrument for established psychometric properties, mixed-methods design for methodological triangulation, census sampling to eliminate selection bias, and transparent reporting of methodological choices and contextual factors. The quasi-experimental comparison with pre-pandemic data strengthened causal inferences about the impact of transitioning from traditional to online instructional modalities during the crisis period.

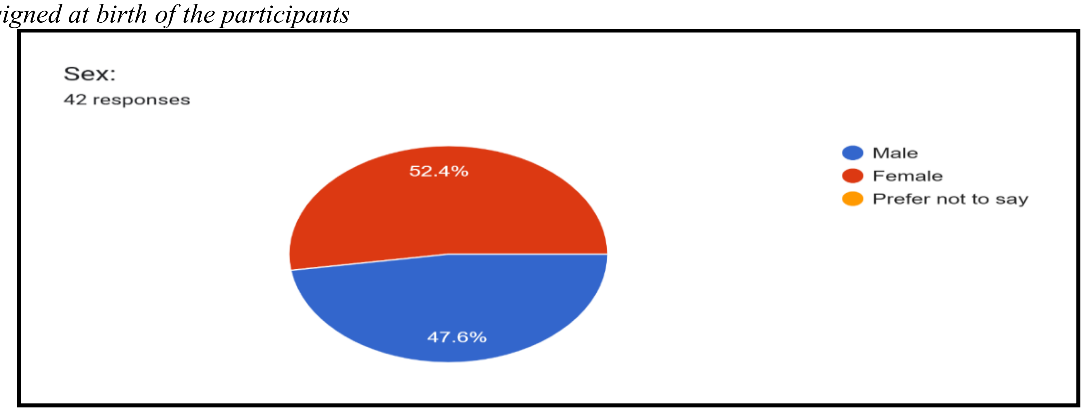
RESULTS

The participants are 42 First-Year Computer Technology students, which is the sample size of the student population taking up the Arduino programming classes at a state university. A five-point Likert Scale is used: 1 – Strongly Agree, 2 – Agree, 3 – Neutral, 4 – Disagree, and 5 – Strongly Disagree.

Figure 1 presents the demographic composition of study participants, displaying a pie chart that illustrates the gender distribution among the 42 first-year Computer Technology students. The chart shows that there is a nearly equal number of female participants (22 students, or 52.4%) and male participants (20 students, or 47.6%), which helps ensure fair comparisons and reduces any bias from gender differences in the study results.

Figure 1

Sex assigned at birth of the participants



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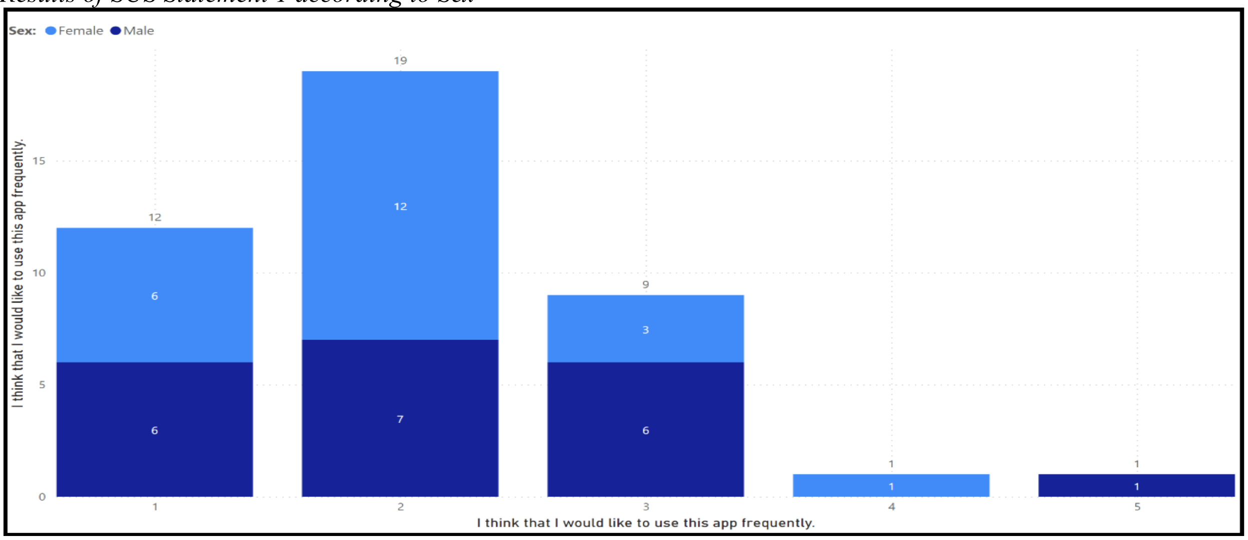
As shown in Figure 2, 31 (74%) out of 42 participants agreed that they would like to use the Tinkercad web application frequently. At the time we conducted this survey, online Arduino programming required the use of Tinkercad. Additionally, among the 31 participants who agreed to participate, 18 (58%) were female. The study by Hassan and Hassan (2016) suggests that female students tend to be more diligent than their male counterparts. They would like to use the application frequently because it is a requirement of the learning outcomes of the course.

Figure 2

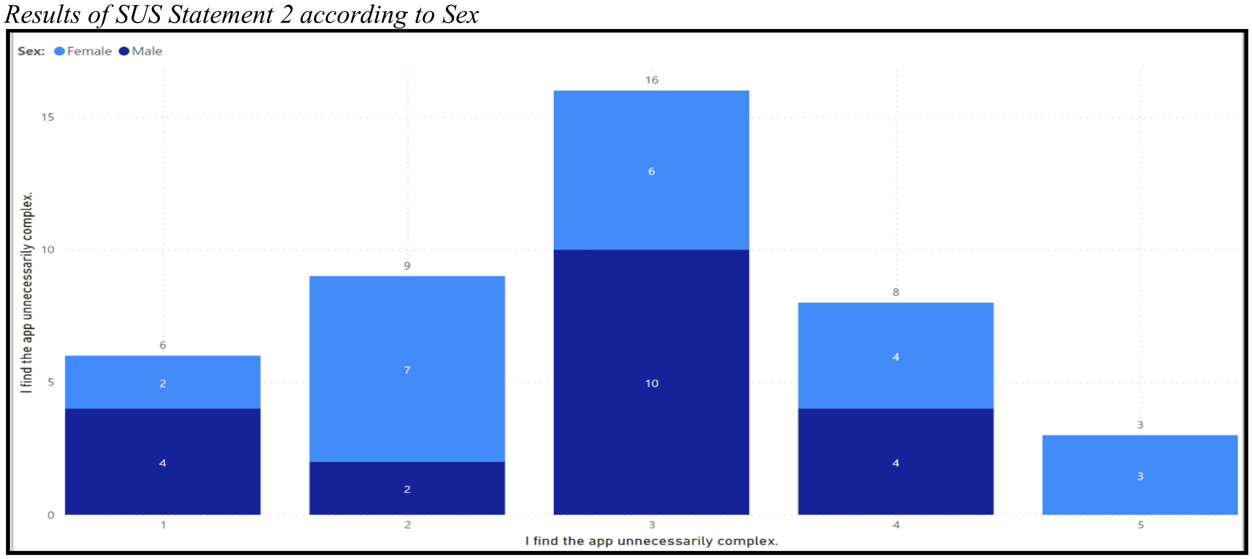
Results of SUS Statement 1 according to Sex



Based on Figure 3, 15 (37%) participants generally agreed that they find the Tinkercad web application unnecessarily complex. Moreover, of the 15 participants, nine (60%) were female. Based on the study of Rubio et al. (2015), male and female students have different perceptions and learning outcomes: male students find programming easier, have a higher intention to program in the future, and show higher learning outcomes than female students.

Figure 3

Results of SUS Statement 2 according to Sex



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Also, 16 (38%) of the participants have neither a strong favorable nor a strong negative view regarding the difficulty of the Tinkercad web application. They may have some level of experience with the program, but they may not feel strongly enough about it to voice a definite view. Of the 42 participants, 28 (67%) agreed that the Tinkercad web application was easy to use. Out of these individuals who agreed, 16 (57%) were female students, as indicated in Figure 4. Students can utilize the online application to better their grasp of Arduino programming through its simulation (Juanda et al., 2021). Female students see the web application as easier to use.

Figure 4

Results of SUS Statement 3 according to Sex

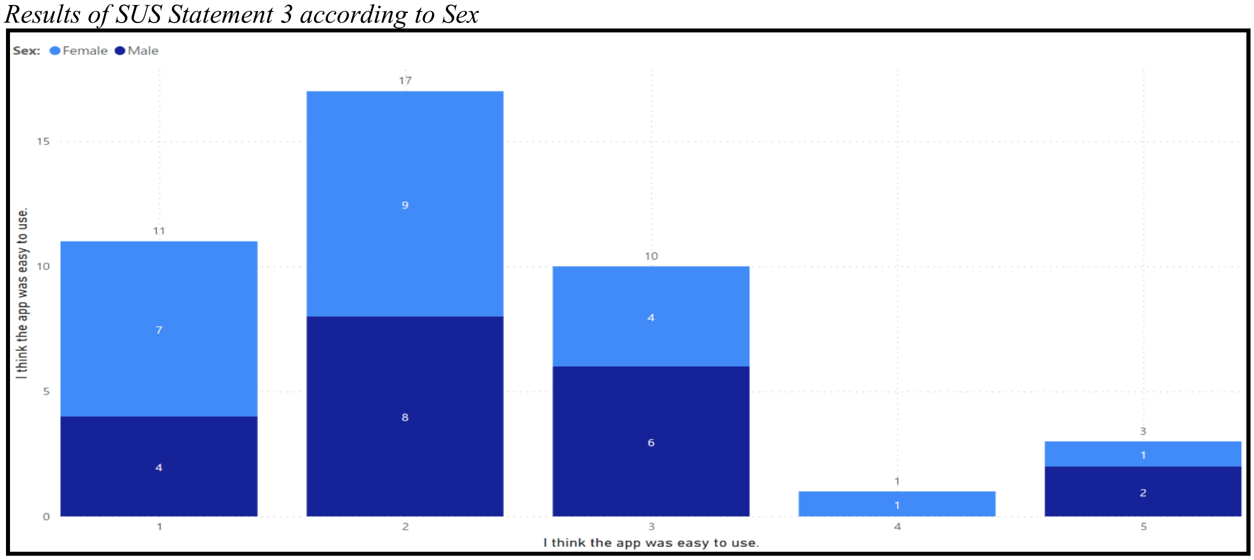
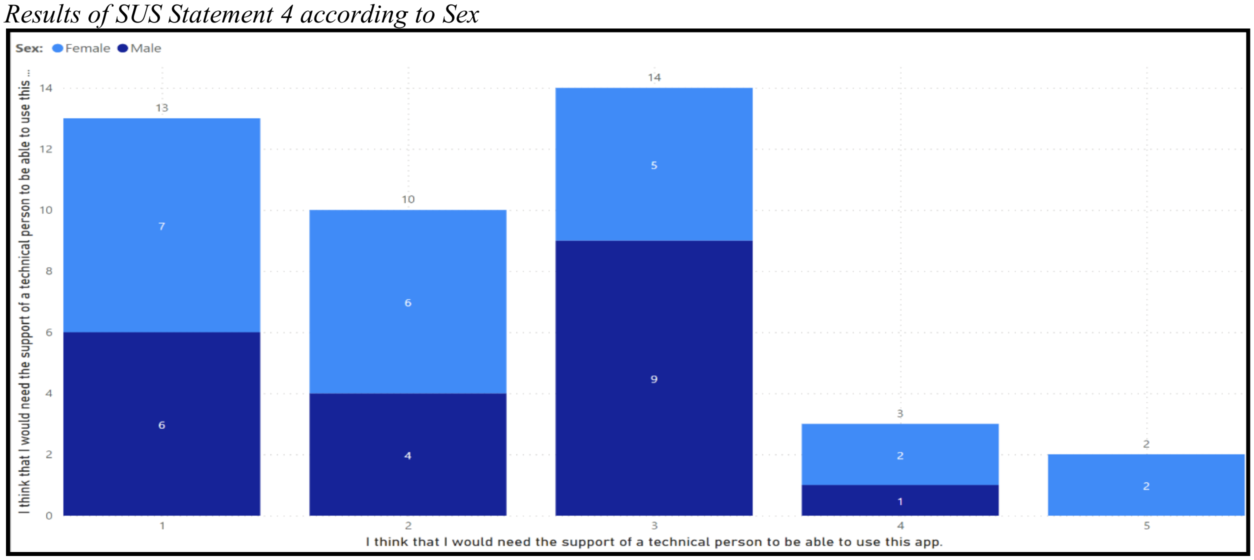


Figure 5

Results of SUS Statement 4 according to Sex



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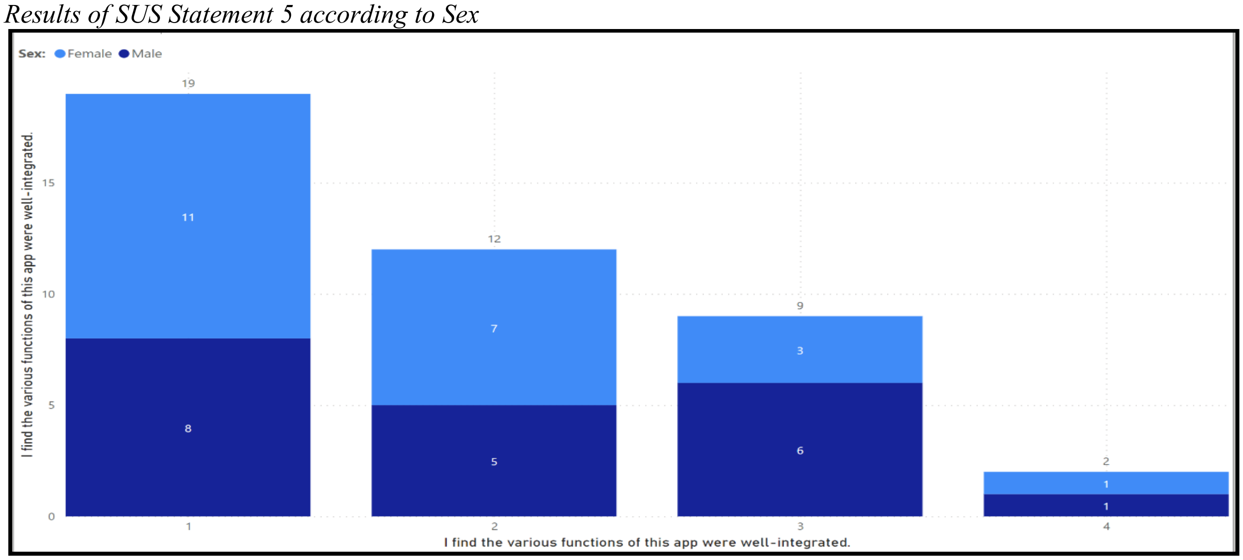
As depicted in Figure 5, though the Tinkercad web application is perceived as easy to use by 67% of the students, as based on Figure 4, and has an intuitive interface, 23 (55%) of the participants generally agreed that they would still need the support of a technical person to be able to use the application. Of those who agreed, 13 (57%) participants were female students. There was still a need for an expert or teacher intervention (Dong et al., 2021) for students, disregarding sex, to fully understand Arduino programming by using Tinkercad.

Moreover, 14 (60%) were neither agreeing nor disagreeing with the technical person's support for the use of the web application. Similarly, with Statement 2, they may have some level of familiarity with the application, but they may not feel strongly enough about it to express a clear opinion of needing a technical person's support.

As shown in Figure 6, 31 (74%) of the participants generally agreed that they found the various functions of the Tinkercad web application to be well integrated. Moreover, of the 31 participants, 18 (58%) were females. As evidence of the Tinkercad web user interface, it is complete with the integrated development environment (IDE) for coding the Arduino sketch, the electronic components inventory needed for setting up the microcontroller, and simulation to check the correctness of the Arduino sketch and the electronic components in the Arduino board. Female students were more aware of the integration of the application's functions.

Figure 6

Results of SUS Statement 5 according to Sex



According to Figure 7, 12 participants (29%) generally agreed that the Tinkercad web application has too many inconsistencies. 12 out of 42 participants, however, disagreed with those inconsistencies in general. Of those who disagreed, 10 of them (83%) were female participants. Also, 18 (42%) of the participants have neither a strong positive nor a strong negative opinion about the inconsistencies of the Tinkercad web application. They may be content with the Tinkercad web application interface and features, but they may not feel strongly enough about it to express a clear opinion.

Of the 42 participants, 27 (64%) agreed that they would imagine that most people would learn to use the Tinkercad web application very quickly. Out of these participants who agreed, 18 (67%) were females, as seen in Figure 8. Based on the study of Eryilmaz and Deniz (2021), Tinkercad is easy to learn and use. As mentioned in the results of Statement 2, male students find programming easier (Rubio et al., 2015), and female students are more studious than male students (Hassan and Hassan, 2016), so they found that learning Tinkercad more quickly as it is a requirement in their Arduino programming course.

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Figure 7

Results of SUS Statement 6 according to Sex

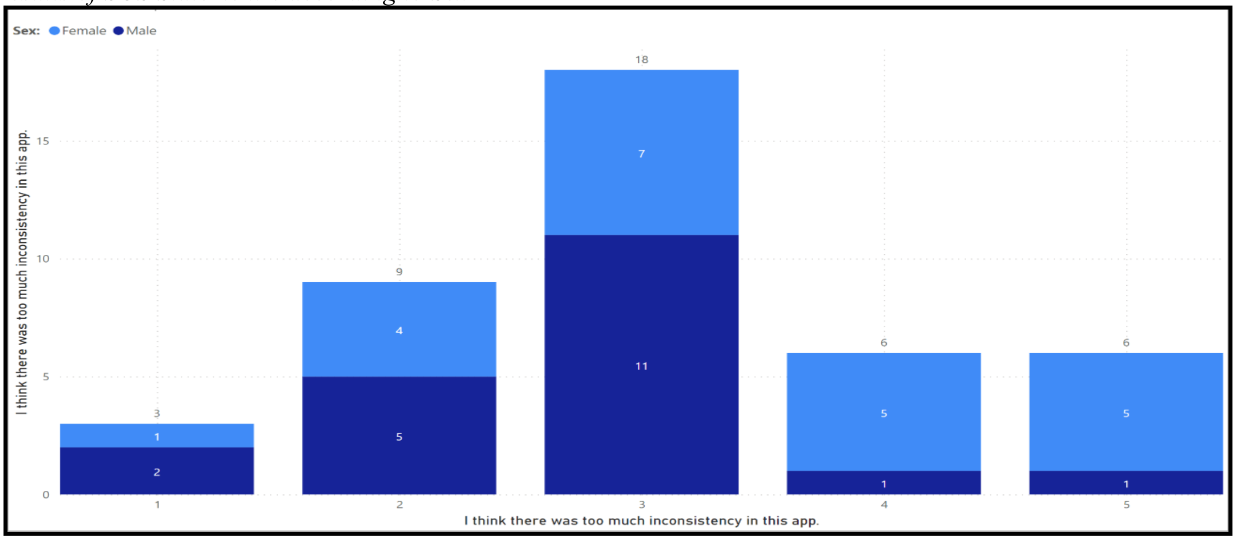
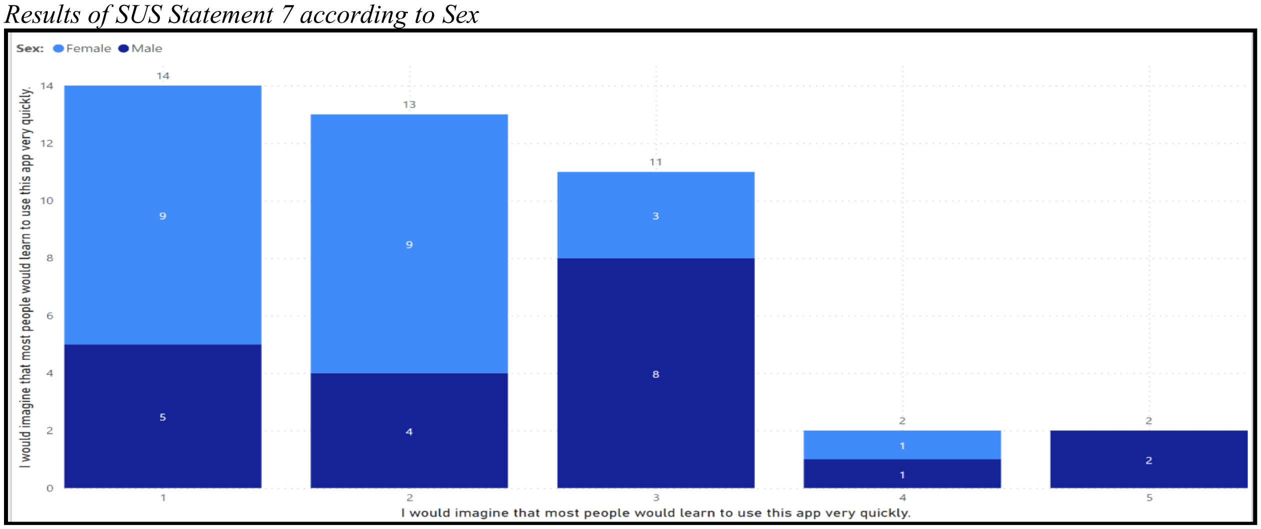


Figure 8

Results of SUS Statement 7 according to Sex



As depicted in Figure 9, 16 (38%) of the participants generally disagreed that the Tinkercad web application was very cumbersome to use. Of those who disagreed, 11 (69%) participants were female students. The results support Statement 3's claim that the web application was user-friendly.

Moreover, 17 (40%) were neither agreeing nor disagreeing that the Tinkercad web application was very cumbersome to use. Likewise, with Statements 2 and 4, they may know the application but not feel strongly enough to express a clear opinion.

As shown in Figure 10, 24 (57%) of the participants generally agreed that they felt very confident using the Tinkercad web application. Moreover, of the 24 participants, 14 (58%) were females. According to Hassan and Hassan (2016), female students are more studious than male students. Because of this, they felt confident using Tinkercad.

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In addition, 16 (38%) of the participants have neither a strong positive nor a strong negative opinion about their confidence while using the web application. Similarly, with Statements 2, 4, and 8, they may have some level of familiarity with the application, but they may not feel strongly enough about it to express a clear opinion. Also, there are no participants who answered that they strongly disagreed about their confidence while using Tinkercad.

Figure 9

Results of SUS Statement 8 according to Sex

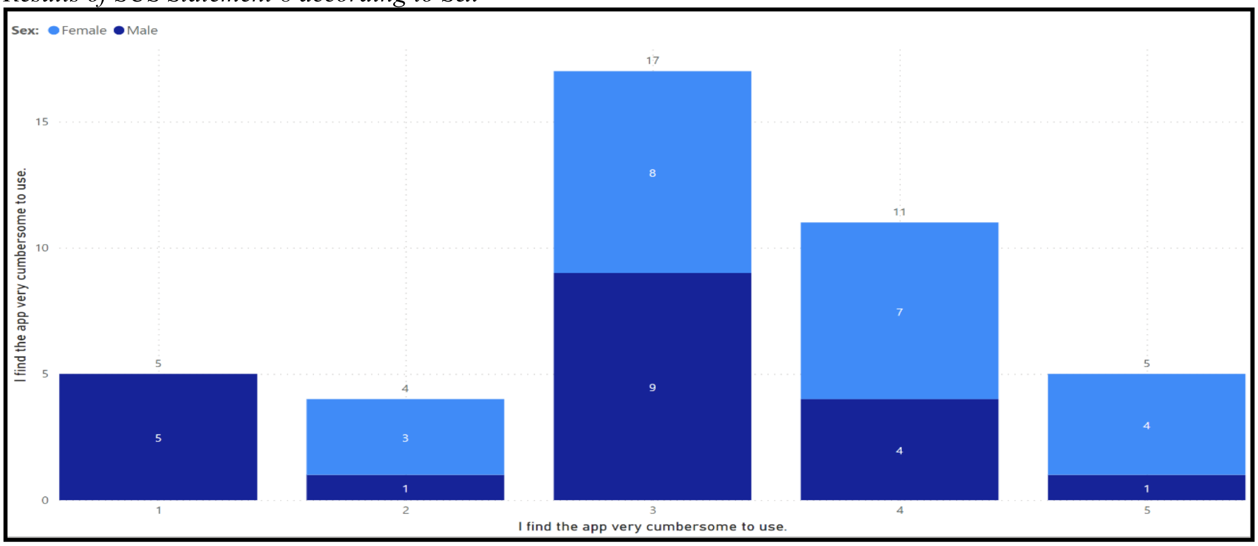
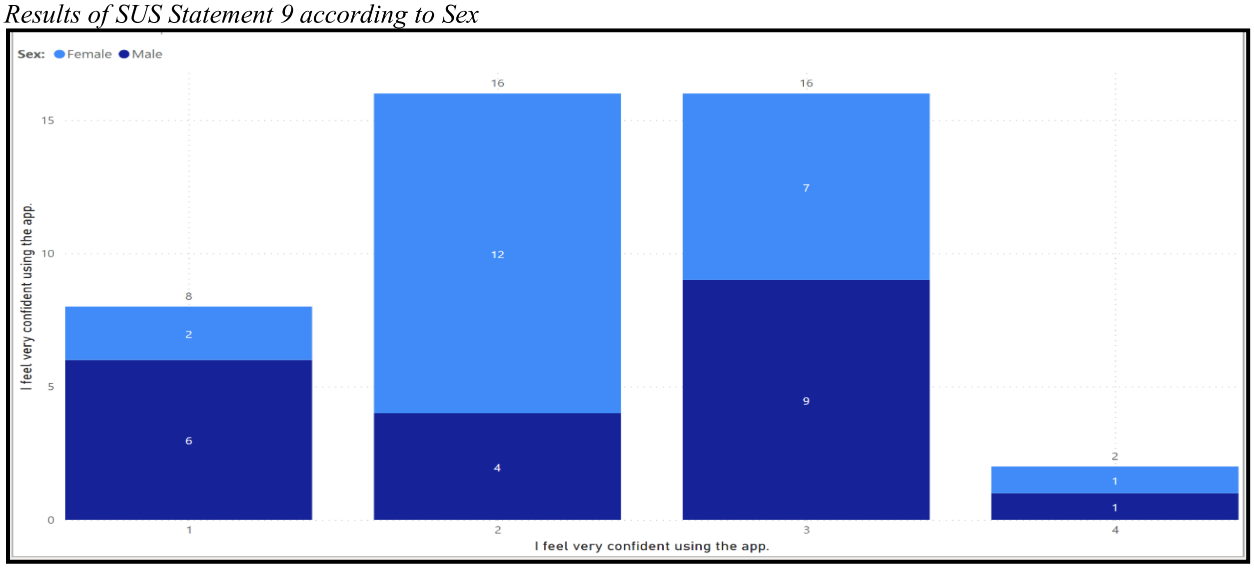


Figure 10

Results of SUS Statement 9 according to Sex



Based on Figure 11, 24 (57%) participants generally agreed that they needed to learn a lot of things before they could get going with the application. Of those who agreed, 14 of them (58%) were female participants. Just like learning any programming language, it is imperative to learn about concepts (Hassinen and Mäyrä 2006) related to Arduino programming and electronic components.

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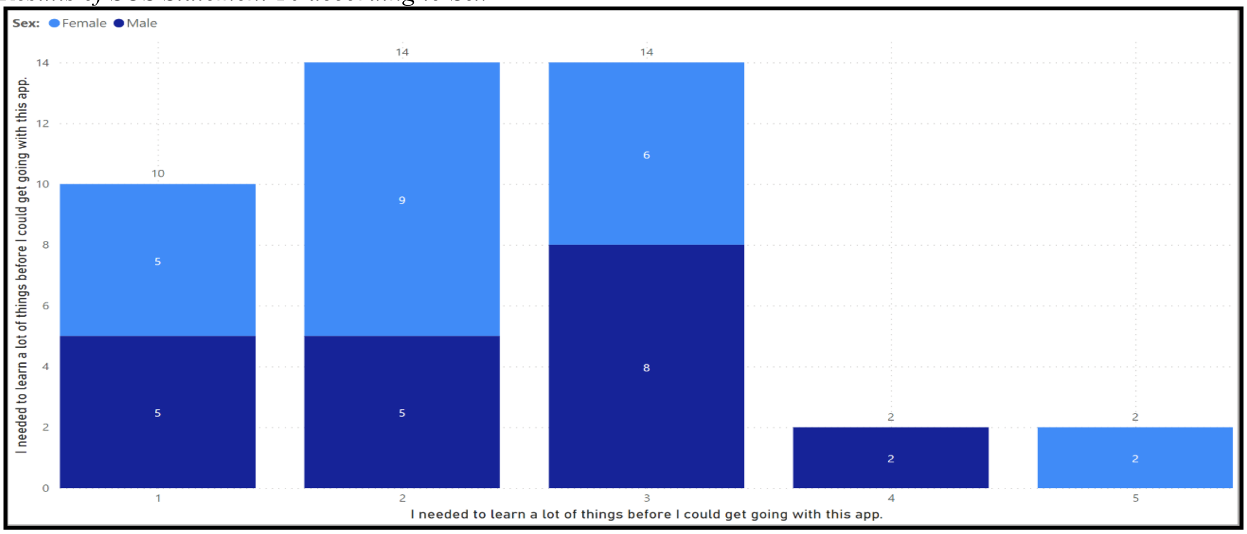
Figure 11

Results of SUS Statement 10 according to Sex



Also, 14 (33%) of the participants have neither a strong positive nor a strong negative opinion about the need to learn a lot of things before students can use the Tinkercad web application. Similarly, with Statements 2, 4, 8, and 9, they may have some level of familiarity with the Arduino programming and electronic component concepts, but they may not feel strongly enough about it to express a clear opinion.

DISCUSSION

The comprehensive study on Tinkercad's usability for Arduino programming education during the COVID-19 pandemic yields significant findings that warrant discussion across multiple dimensions of educational technology implementation during crises.

The study's findings nuance all three research goals. The first objective of analyzing Tinkercad's usability as an online Arduino programming platform brought complex findings that tested usability thresholds. The System Usability Scale (SUS) score of 58 is below the satisfactory usability criteria of 68, however pandemic-induced emergency remote teaching must be considered. Demographics and learning styles affect usability perspectives, as female students scored 62 on average compared to male students' 54. This is important because the platform helped education during a crisis despite poor usability. The comprehensive SUS comments show that students considered Tinkercad easy to use (67% agreement) and well-integrated (74% agreement), but they needed technical guidance (55% agreement) and extensive preliminary learning (57% agreement). Despite the appealing UI, Arduino programming principles were tough regardless of delivery platform.

Quantitative and qualitative findings addressed the second focus on impediments and possibilities. The study found three key issues: pandemic-related mental health issues, insufficient internet infrastructure in the Philippines, and simulation-based learning's limitations compared to hands-on experiences. SUS ratings and academic achievement data showed these concerns, with participants average 3.3 compared to 2.4 for pre-pandemic youngsters who got hands-on teaching. The analysis also revealed substantial prospects, such as the platform's ability to maintain educational continuity during crises and build 24/7 global educational environments. Despite usability issues, 74% of students use Tinkercad regularly, proving that it meets a crucial remote learning requirement.

The findings match and differ from educational technology and simulation-based learning research. Abburi (2021) noted that simulation platforms like Tinkercad can improve lockdown accessibility and provide hands-on

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learning goals. The current study's SUS scores differ significantly from Vlachogianni and Tselios' (2022) meta-analysis, which found a mean SUS score of 70.09 for educational technology platforms. Crisis-driven technology adoption may differ from planned, consensual integration in usability. Abburi (2021) expected Tinkercad would surpass established circuit comprehension approaches, but it did not. After the outbreak, academic performance fell.

The gender inequalities in programming education are slightly similar to this study. Female pupils study more methodically, say Hassan and Hassan (2016). They had higher SUS and usability ratings. These findings contradict Rubio et al. (2015), who found male students program better. By eliminating hardware manipulation's intimidation, simulation-based learning may level the playing field. Tinkercad was too complex for 60% of female respondents, supporting evidence that females may initially find programming tools harder despite academic success.

The findings confirm Betthäuser et al.'s (2023) meta-analysis of COVID-19-related learning deficits and educational technology uptake. Academic achievement dropped from 2.4 to 3.3 average grades, reflecting global learning loss, with hands-on technical education particularly vulnerable. The study's focus on mental health, infrastructure, and conventional schools' hands-on advantage complements UNESCO's (2021) pandemic-induced educational disruptions and digital gap in underdeveloped nations.

This study supports Community of Inquiry by showing how emergency remote teaching changes teaching, social, and cognitive presence. Even though the platform was easy to use, students needed technical support, demonstrating that teaching presence is vital in simulation-based learning environments, where the teacher must connect virtual and real-world applications. Peer engagement and scaffolded learning can teach Arduino programming basics in virtual environments, extending Social Constructivism theory.

This revelation affects education directly. Despite low usability scores, Tinkercad can teach organizations to adopt simulation tools in emergencies. Instead, they should adopt hybrid learning models with virtual simulation and hands-on experiences and boost technical support. The gender-differentiated results suggest instructional design should enable varied learning styles and achievement trajectories. More component libraries in Wokwi can boost remote Arduino education for institutions.

The analysis demonstrates huge infrastructure needs that require government intervention as policy. disadvantaged internet access hinders online learning, supporting broadband infrastructure strategy in disadvantaged nations. Crisis-driven remote learning's mental health implications suggest educational technology guidelines should incorporate psychological aid. Simulations can't substitute hands-on experiences, affecting technical and professional certification. Policy frameworks must encourage hybrid learning and quality education.

Several novel educational technology research contributions distinguish this study. During an educational crisis, the convergent parallel mixed-methods design provides honest emergency remote teaching efficacy insights that controlled studies cannot reproduce. A census sample of 42 first-year Computer Technology students eliminates selection bias and covers the affected population, improving generalizability within similar institutions. Qualitative theme analysis and standardized SUS rating convey usability perceptions better than quantitative methods.

The temporal comparison methodology, which uses comparable curriculum and assessment methodologies to compare pandemic-era student performance to pre-pandemic cohorts, is its strength. A quasi-experimental study shows simulation-based training's effects. Educational technology research lacks gender-disaggregated technology acceptability and learning outcomes insights. Material normally comes from wealthier nations with more technology, therefore focusing on a developing country fills a gap.

It employs the Technology Acceptance Model, Community of Inquiry framework, and Social Constructivism theory to describe the complex relationships between technology, pedagogy, and student learning. Methodological transparency and demographic data improve reproducibility and future study comparisons.

This study acknowledges considerable limitations and potential biases to properly evaluate the study's findings and consequences. Due to COVID-19's stress, the study's chronological constraint may not reflect educational technology use. According to research and this study, the pandemic's psychological effects on kids make it hard to credit learning results to Tinkercad vs. stress and disturbance. The study's regional and institutional peculiarities limit generalizability. The Philippine state university research of 42 first-year Computer Technology students may not apply to different educational contexts, demography, or national infrastructure. Salac and Kim (2016) say Philippine internet

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infrastructure issues are unique technically. This infrastructure may hinder usability and learning compared to better internet connectivity.

Self-reported SUS survey measures may bias results, especially in settings where students feel pressured to give socially desirable or instructor-expected answers. Two weeks after course completion, a survey may have skewed students' memories with final grades or course satisfaction. No control group getting regular schooling during the same timeframe makes Tinkercad outcomes difficult to assign. Despite two independent coders, qualitative theme analysis lacks inter-rater reliability. The qualitative analysts' training and background may affect thematic categorization consistency and validity, however the study does not report them. Standards-based and well-tested SUS for generic software applications may not capture technical skill development educational simulation platforms.

The study sample was all Arduino programming course graduates during the outbreak, which may have introduced selection bias despite census sampling. Dismissing pupils who couldn't participate in online learning due to technology may misrepresent Tinkercad's success. Natural rather than stratified gender distribution may reduce gender-related findings' generalizability.

In Philippine English-medium instruction, students' comfort with English interfaces and technical jargon may impair usability. Southeast Asian educational usability and learning preferences may not match Western SUS.

We must recognize numerous important limitations and biases to properly evaluate the study's findings and consequences. The study's temporal limitation may not reflect regular educational technology acceptance due to the COVID-19 pandemic's stress. Research suggests that the pandemic's psychological effects on children make it difficult to attribute learning results to Tinkercad vs stress and disturbance.

Regional and institutional variables limit study generalizability. The Philippine public university's 42 first-year Computer Technology students' research may not apply to different educational contexts, demography, or national infrastructure. Salac and Kim (2016) say the Philippines' internet infrastructure issues are unique. Infrastructure limitations may hinder usefulness and learning compared to internet-connected settings.

SUS survey self-reported metrics may bias answers, especially in cultures where students feel pressured to give socially desirable or instructor-expected answers. Surveys two weeks following course completion may have altered students' memories of final grades or course satisfaction. No control group receiving regular schooling at the same period, therefore I can't credit outcomes to Tinkercad.

Despite two independent coders, qualitative topic analysis lacks inter-rater reliability. The study does not report qualitative analysts' training and background, which may affect thematic categorization consistency and validity. For technical skill development educational simulation platforms, the standards-based and well-tested SUS instrument may not operate. Despite census sampling, the study sample was all Arduino programming course graduates during the outbreak, which may introduce selection bias. Excluding pupils who couldn't learn online due to technology may improve Tinkercad. Natural, not stratified, gender distribution may reduce gender-related findings' generalizability.

Filipino students' English-language interface and technical jargon skills may impair English-medium training usability views. Southeast Asian schools' usefulness and learning styles may differ from Western SUS.

CONCLUSION

This study enhances our understanding of crisis-related educational technology adoption and provides digital technical education insights. Simulation-based Arduino programming instruction using Tinkercad may maintain instructional continuity during crises and educate students technical skills despite poor usability, according to studies. The mixed-methods methodology and authentic crisis setting give educational institutions and policymakers evidence-based emergency remote teaching recommendations that controlled experimental designs cannot.

Documenting gender differences in technology acceptability and learning outcomes promotes inclusivity and equity in underrepresented technical education fields. Simulation-based learning settings may remove some barriers to female technical involvement, but all students need focused support and instructional design improvements to maximize learning outcomes.

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This research informs educational policy by showing the infrastructure, support systems, and pedagogical methods needed to provide technical education in developing nations. Study findings on internet connectivity, mental health support, and hands-on learning can help educational planners and policymakers increase technical education availability and quality in resource-constrained contexts.

Crisis settings affect usability, satisfaction, and learning results, increasing educational technology adoption and efficacy theories. The study's multiple theoretical methods prepare for future research on technology, pedagogy, and contextual factors' complex implications on educational effectiveness.

Most importantly, this research shows educational systems and stakeholders can adjust to unexpected issues. Students and instructors made progress despite technological and contextual constraints, suggesting that innovative instructional methods can improve technical education availability and quality. The study's comprehensive successes and shortcomings aid educational technology implementation and crisis-responsive planning.

This research affects more than Arduino programming education at COVID-19. As schools globally implement blended and online learning models, this study's findings on simulation-based technical education, gender inequalities in technology acceptability, and infrastructure and support systems are relevant for sustainable educational innovation. The study addresses fundamental global educational system challenges by maintaining educational quality while expanding access through technological innovation, making it relevant for diverse educational contexts and stakeholder communities seeking to optimize technical education delivery in an evolving technological landscape.

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