

Revolutionizing Online STEM Education: Strategies for Enhancing Learning Design, Digital Tool Utilization, and Student Engagement in Pre- to Post-Pandemic Contexts

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Abstract. The rapid shift to online learning, accelerated by the global pandemic, has profoundly impacted STEM education, this paper critically examines this transformation. This paper also aims to explore effective strategies in online STEM education, focusing on optimizing learning design, leveraging digital tools, and enhancing student engagement in both pre- and post-pandemic scenarios. It delves into how these elements can be integrated to improve the quality and effectiveness of online STEM learning, providing valuable insights for educators, institutions, and policymakers navigating this evolving educational landscape.

Keywords: Global Pandemic, STEM Education, Learning Design, Student Engagement, Online Learning Experiences, Higher Education.

1. Introduction

This paper explores the transformative strategies in online STEM education from pre- to post-pandemic contexts, focusing on enhancing learning design, digital tool utilization, and student engagement. It employs a mixed-methods approach, integrating survey data, case studies, and literature reviews to assess the effectiveness of online learning environments in STEM fields. The research question of this paper is to assess and investigate potential solutions and developments in digital platforms, educational software, and engagement structures by analyzing the online learning experiences of Chinese higher education students during the pandemic period. Key findings highlight the importance of tailored learning designs, interactive digital tools, and engagement strategies in improving online learning outcomes. Challenges such as providing hands-on experiences and maintaining student motivation are also addressed. The study concludes with recommendations for educators and policymakers, emphasizing the need for innovative and adaptable approaches in the evolving landscape of STEM education.

2. Organization of the Text

2.1. Literature Review

The educational landscape has undergone a seismic transformation with the advent of the COVID-19 pandemic, propelling institutions into an era of unprecedented reliance on online learning. Many educational institutions faced challenges in fully embracing online learning due to concerns about its effectiveness, accessibility, and the potential lack of engagement compared to in-person instruction. Online learning often existed as an alternative or supplementary option rather than a core component of the educational landscape. Further, not all students had equal access to online resources and technology. The digital divide was a significant concern, with disparities in access to devices, reliable internet connections, and necessary software. This posed a significant barrier to ensuring that all students could benefit from online learning opportunities.

Then came the COVID-19 pandemic, which can be seen as a major, emergency event that accelerated the shift to online learning. Educational institutions were forced to pivot rapidly to remote learning to protect the health and safety of students, teachers, and staff. The pandemic essentially catalyzed the widespread adoption of online learning, propelling institutions into an era of unprecedented reliance on this mode of education. It forced both educators and students to adapt

quickly to the new reality of remote learning, highlighting the need for technological infrastructure and support. It is irrefutable that online learning was evolving gradually with technology, but the COVID-19 pandemic was a transformative event that accelerated this change, making it a central component of the educational landscape and revealing the urgent need for infrastructure and support to ensure its success.

One central research question emerges from this context: How can we enhance online STEM education, from pre-pandemic to post-pandemic, through redesigning learning, improving digital tools, and fostering engagement, while addressing challenges in technical and hands-on training? This question will guide our exploration of the challenges and opportunities in online STEM education during and after the COVID-19 pandemic, and the forthcoming literature review will provide the evidence needed to address it comprehensively. This literature review navigates through key insights from various studies, with a focal point on strategies to elevate online STEM education from the pre-pandemic era to the post-pandemic reality, including the importance of course design, the student-centric teaching approach, the importance of technology and digital tools, the emotional dimensions of online education and the challenges in the online shift. This transition not only underscores the challenges posed by the sudden shift but also opens a realm of unprecedented opportunities for redefining and optimizing online educational experiences.

Research by Abouhashem et al (2021), Tahani (2022), and SRI International (2022) highlights the pivotal role of course design, program layouts, and learning approach redesign in enhancing online STEM education, particularly in the context of the pre- to post-pandemic transition, emphasizing the significance of incorporating digital tools, simulations, and a student-centered approach. The incorporation of digital tools, simulations, and a student-centered approach is therefore a catalyst for a successful shift to online STEM education. Digital tools encompass interactive resources like video lectures and 3D modeling software, allowing students to visualize complex concepts and conduct virtual experiments. Simulations offer safe and accessible virtual labs where students can experiment with real-world scenarios.

Adopting a student-centered approach encourages active engagement, empowering learners to set goals, explore their interests, and collaborate with peers. These strategies not only enhance understanding but also cultivate critical thinking and collaboration skills, preparing students for success in STEM fields. Qualitative data can be effectively categorized under 'learning design' for these aspects to provide insights into their impact on online STEM education. This classification facilitates a more granular examination of the educational landscape and allows for a nuanced analysis of the effectiveness of adaptive course design, the influence of a student-centric approach, the utilization of technology, the recognition of emotional dimensions, and the resolution of challenges in the online STEM learning environment. By categorizing data in this manner, it becomes possible to uncover specific insights into the holistic impact of these strategies, thus offering a comprehensive perspective on their role in optimizing online STEM education. Positive perception by the faculty members as per the study emphasizes the adaptability of STEM courses and the continuous refinement based on invaluable student feedback. These findings underscore the importance of adaptive and student-centric course design in the comprehensive redesign of learning for online STEM education.

Abouhashem et al (2021) and Ariella Levenberg (2023) emphasize the importance of considering students' perspectives, particularly regarding emotional support. Ariella Levenberg's (2023) study underscores the importance of the student experience, and their perception of kindness, within the context of online education. Wester (2021) contributes a nuanced understanding of changes in student engagement during the shift to online biology education. Identifying behavioral, cognitive, and emotional changes, the research emphasizes the decline in emotional engagement and the need for strategies to improve overall engagement. This understanding of student engagement is crucial for fostering active participation and effective learning in online STEM education. As such, emotional support is important in fostering a positive and supportive online STEM education experience. Recognition of challenges that may occur in transition to or during online learning such as situational

difficulties, and finding means of solving them, that is from an educator/facilitator goes a long way in offering a supportive online system. This in turn will improve the students' perception of online classes and will lead to overall improved results. Teachers must build genuine relationships with their pupils in addition to imparting knowledge. Effective teaching and learning depend on developing close bonds with students and creating a feeling of community in the classroom. These relationships have the potential to improve student motivation, engagement, and general school satisfaction. When educators prioritize relationships and community, they create a supportive and inclusive environment where students feel valued and are more likely to succeed. This pivotal role of educators will help provide crucial insights for the redesign of learning methods to create a nurturing and supportive virtual learning environment.

In addition, it is crucial to underscore the iterative nature of online STEM education, emphasizing the importance of feedback and continuous refinement. Across the studies examined, a consistent thread emerges regarding the significance of gathering feedback from both educators and students. This feedback loop becomes instrumental in the process of refining course designs, teaching methodologies, and the integration of digital tools. Abouhashem et al (2021) exemplify this in their study, showcasing how faculty members adapted their STEM courses based on invaluable student feedback during the transition from in-person to online learning. Commitment to continuous improvement is a hallmark of effective online STEM education, ensuring that strategies evolve in response to the evolving needs and challenges posed by the dynamic educational landscape. In this research, acknowledging and harnessing the power of feedback loops for refinement will be pivotal in enhancing the overall quality and effectiveness of online STEM education. This commitment to adaptability and continuous improvement will form a cornerstone for building resilient and responsive online educational experiences.

Rebecca Nesson (2023) places a significant emphasis on the importance of technology and digital tools in the context of online education. Specifically, the primary focus of her article centers around the creation and maintenance of inclusive online spaces. As seen earlier, in the realm of education, inclusivity is a paramount concern. It encompasses the objective of providing all students with equitable access to educational opportunities and making them feel appreciated within the learning setting, regardless of their diverse backgrounds, capabilities, or situations. In the context of online education, inclusivity takes on unique challenges and opportunities. Nesson's work underscores that technology and digital tools can be instrumental in fostering inclusivity in online learning environments. As an illustration, employing easily usable digital materials like screen readers for students with visual impairments or closed captioning for those experiencing hearing challenges can enhance the accessibility of educational content for a broad spectrum of learners. Moreover, this article explores strategies for creating a sense of community and belonging in online spaces. This may involve using collaborative online platforms, discussion forums, or virtual office hours to facilitate interaction among students and between students and instructors. These methods can help combat feelings of isolation that some online learners may experience and contribute to a more inclusive learning experience.

Further, Tahani (2022) amplifies the discussion with an institutional perspective on online STEM education, highlighting the successful transition to online programs. However, advocating for enhanced program layouts, qualified instructors, and supportive guidelines is appropriate. Effective program design plays a critical role in both redesigning online STEM learning as well as fostering a conducive learning environment. Institutional support is integral in facilitating this and providing instructor training to ensure students' needs are properly addressed. As previously discussed, a conducive learning environment will also help improve learners' attitudes toward online learning.

The nuanced challenges faced by students in the transition to online learning are scrutinized in research by SRI International (2022), and Wester (2021) emphasizing disruptions to academic paths and the specific concerns of STEM students such as changes in student engagement. It is therefore important to address challenges in technical and hands-on training and to provide essential insights for redesigning learning approaches. Strategies should be set up to mitigate identified challenges

faced by STEM students such as failure to complete their educational requirements. It should become paramount to ensure effective delivery of online STEM education, and this should be taken up by the institution involved, instructors as well as the students themselves. Rebecca Nesson (2023) takes a technological standpoint, and it is agreeable that technology should be aligned with pedagogical goals, that provide valuable guidance for the improvement of digital tools in STEM education. This alignment becomes a step closer to addressing these challenges.

Collectively, the synthesis of insights from these authors offers a comprehensive understanding of the multifaceted landscape of online STEM education. The strategies highlighted in these studies, encompassing adaptive course design, a student-centric approach, effective use of technology, recognition of emotional dimensions, and addressing challenges, collectively provide a roadmap for optimizing online STEM education in the post-pandemic era. These insights will guide the exploration of additional dimensions and the formulation of evidence-based recommendations for enhancing online STEM education.

2.2. Method

In response to the global surge in online STEM education during the pandemic, this study aims to critically assess students' perspectives, encompassing both the challenges and perceived benefits of this educational shift. Our research employs a mixed-methods approach, integrating both quantitative and qualitative analyses to offer a comprehensive evaluation of the student experience in online learning environments. The primary instrument for data collection is a structured questionnaire, designed to elicit detailed insights into students' subjective experiences, learning obstacles, and advantages recognized in the online format. This approach facilitates a nuanced understanding of the quality of online education and informs post-pandemic preferences in course selection. The quantitative component of the study emphasizes systematic data collection and rigorous analysis, aiming to yield empirical insights into the effectiveness of online STEM education. By entering student perspectives, the research seeks to provide evidence-based evaluations and draw informed conclusions about the developmental trajectory and efficacy of online educational modalities.

2.3. Data Collection & Data Findings

The questionnaire was developed through several important steps. The first step involved conducting a comprehensive analysis of the body of research and literature on online STEM education to pinpoint pertinent themes and elements. After that, a series of inquiries was developed that tackled the themes that were found, including difficulties, benefits, evaluation of quality, and preferences. A crucial stage in improving the questionnaire was pilot testing. A portion of the student body not included in the main study was asked to complete the questionnaire and provide feedback on its clarity, comprehensiveness, and applicability. To make sure the questions were clear and collected the desired data, changes were made in response to their feedback.

Surveys were the main technique of data collection used in this investigation. There are no time or location restrictions on the questionnaire methodology. The questionnaire is a common scientific research tool that can be used in exploratory, explanatory, and descriptive research. Because the survey was meant to be completed online, it was successful in reaching a large number of students. A thorough questionnaire was created to obtain in-depth information from students regarding their experiences with online STEM education. One of the most important steps in guaranteeing the accuracy of the data gathered was designing the questionnaire. Carefully considered questions covering the main areas of the research—difficulties, benefits, evaluation of quality, and preferences—were used. Multiple-choice and Likert-scale questions were among the formats of the questions, which were used to collect both categorical and ordinal data. This research received 36 responses in total, most of the participants are from the City University of HongKong (30 of 36), 3 participants are from US universities (UC Davis and JHU), 1 student is from a UK university (Cambridge University), 2 participants are from Chinese universities (Fuzhou University and Chongqing University), all of these participants are Chinese students. For the school year, most

students are undergraduate students (21 of 30), 6 of them are graduate students, and 3 of them are postgraduate students. They have a variety of majors, including liberal arts, business, and STEM majors, this research will focus on the 21 STEM major students.

The questionnaire's design was significantly influenced by the Likert scale. Participants were able to indicate whether they agreed or disagreed with a range of statements using Likert-type questions. Typically, the scale had a range of 1 to 5, with 1 denoting strong disagreement, 3 neutrality, and 5 strong agreement. To reliably assess the degree of agreement or disagreement with the statements, the Likert scale was essential. Based on their ratings, students' attitudes toward online versus in-person education can be discerned from the Likert scale this time. For the quality of online education Likert scale question, the mean of the rating is 3.2 and the medium of ranking is 2.5, which means participants are generally satisfied with the quality of online education. For the engagement question, the mean of the rating is 2.9 and the medium is 2, which means participants perceived low engagement in online education. For the learning one, the mean of the rating is 3.1 and the medium of ranking is 2, so same as engagement, the participants believe they don't learn much from online education. Then, by a set of questions, the participants are asked to compare their experience between online and in-person learning using elements such as relationship building, collaboration, hands-on, time management, access to resources and materials, quality of teaching and learning, computer technology issues, asking questions and seeking answers, active participants in discussions, areas of unmet learning needs. All of the ratings of these elements are below 2.5, which means the participants' experiences with online education are quite negative.

Sections 5 and 6 of the survey provided insights into online education's evolution post-pandemic, highlighting diverse experiences and perceptions. Section 5 focused on "Innovation - Best Practices and Future Recommendations." Participants reflected on changes since the pandemic, with opinions ranging from no significant change to increased convenience and efficiency. They noted the similar effectiveness of hybrid and fully online classes. Best practices identified include prompt feedback, intuitive interfaces, hybrid models, and MOOCs, catering to varied learning styles. For enhancing online learning, suggestions included innovative tools and strategies like online forums, Zoom, and VR technologies for interactive learning. The final question in Section 5 gathered recommendations for specific technologies like Tencent Meeting, YouTube, and AR, emphasizing the need for interactive platforms in virtual learning environments.

Using surveys as the main technique for data collection can collect a large amount of information from different student samples. This approach helps to view the challenges, advantages, quality assessment, and post-pandemic preferences in online STEM education from a holistic perspective. The use of a stratified sampling method further enhances the representativeness of the sample, indicating differences in disciplines, age groups, and educational levels. In the analysis phase, strict statistical techniques were used, including the calculation of mean values, to quantitatively evaluate the data. The average value is crucial in providing a central measure of respondents' opinions on relevant aspects, thereby generating valuable insights into various aspects of online STEM education. The analysis section of this survey has already implemented privacy protection. In addition, the ethics committee of the institution where the researchers are located has approved the current study, and the respondents have provided appropriate informed consent forms. The limited number of data samples is a major limitation of this study. In the future, investigations will be conducted on a larger scale to increase the quantity of data and improve its credibility. The overall effectiveness of this survey has achieved the preset goals. Through analyzing the data, we can understand that even after the pandemic, a considerable number of students still choose to continue online education. However, a considerable number of students chose not to seek further online learning opportunities (15 students chose to continue online education after the pandemic, and 21 students decided not to continue). These choices indicate the lasting impact of online learning experiences on students' educational preferences.

2.4. Findings & Discussion

The survey conducted on online STEM education revealed a dichotomy in student preferences post-pandemic. While a significant number of students expressed a willingness to continue with online learning, highlighting its convenience and flexibility, a notable proportion showed a preference for returning to traditional, in-person educational settings. This split underscores the need for educational institutions to adopt a more hybrid approach to learning, accommodating both online and in-person preferences. The findings for qualitative data also suggest that improvements in the design and delivery of online courses could further enhance their appeal, particularly in addressing the challenges and maximizing the benefits identified by the students. Such as for these Chinese students, almost use Zoom and Tencent Meeting. Their experience with online education was forced on them because of the pandemic, they can't have in-person classes. Almost 85% of the students believe the disadvantage of online education is the lack of student engagement, few of them also think the adaptation and technical issues influenced their online learning experiences. For their suggestions for online learning, they all give different ideas about how to improve the participation between students and teachers such as adding games, using recordings, AI assistance, online Q&A, pedagogical improvements, etc. One interesting and significant finding from these qualitative data is that although the ratings of online education are low, these Chinese students still think online education is better than in-person education as it can save time and money, it can be paused and played back, it is more flexible, etc.

Key insights from the study emphasize the importance of understanding and catering to diverse student needs in the evolving landscape of education. The mixed reactions to online STEM education during the pandemic highlight an opportunity for educational policymakers and institutions to reevaluate and innovate their instructional methods. Future research should focus on exploring the specific elements that make online learning more engaging and effective for students. Additionally, there's a need to investigate the long-term impact of blended learning models, combining the best practices of both online and traditional education, on student success and satisfaction.

2.5. Conclusion

In summary, this paper has highlighted key strategies for enhancing online STEM education, drawing insights from the experiences of Chinese higher education students during the pandemic. Utilizing a mixed-methods approach, the study emphasizes the importance of customized learning designs, interactive digital tools, and effective engagement strategies to improve online learning outcomes. It identifies challenges such as providing practical experiences and sustaining student motivation in a virtual environment. Conclusively, the paper recommends that educators and policymakers focus on innovative and adaptable methods to continually refine online STEM education. This research contributes to the broader understanding of evolving educational practices, underlining the need for ongoing innovation in the field of online learning.

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