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Museum Education in the Post-Pandemic Era: Hybrid Models and Learning Outcomes

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ABSTRACT

The COVID-19 pandemic has fundamentally reshaped museum education, accelerating the adoption of hybrid learning models that integrate onsite and virtual experiences. This study examines the evolution of museum education in the post-pandemic era, focusing on hybrid models and their implications for learning outcomes. It explores how synchronous and asynchronous delivery modes, combined with onsite–online complementarity, enhance accessibility, inclusivity, and audience engagement. The paper further analyzes key learning outcomes, including knowledge acquisition, skill development, critical thinking, and attitudinal change, while situating these within established pedagogical frameworks such as constructivism, experiential learning, and communities of practice. Additionally, it highlights the importance of assessment strategies, including formative, summative, and data-informed approaches, in evaluating hybrid programs. Despite the opportunities presented by hybrid education, challenges related to equity, digital access, and resource disparities persist. Through case studies and practical implementation strategies, the study underscores the need for intentional design, stakeholder collaboration, and sustainable evaluation frameworks. Ultimately, hybrid museum education emerges as a transformative approach that expands access, deepens learning, and redefines the role of museums as inclusive, adaptive, and participatory learning environments.

Keywords: Hybrid Museum Education, Learning Outcomes, Digital and Onsite Integration, Accessibility and Inclusion and Experiential Learning.

INTRODUCTION

The COVID-19 pandemic has generated unprecedented challenges for museums and other learning institutions, requiring rapid adaptation to limited onsite access [1]. Teaching and learning, central activities in museums have shifted significantly 1 yet remain largely unexamined. To guide museum professionals and researchers in this critical moment, the following outlines a systematic overview of the post-pandemic educational landscape, operationalizes the hybrid continuum to describe models and options, articulates relevant learning outcomes, and characterizes key pedagogical approaches and evaluation strategies [2]. Placing these hybrid adaptations within the overarching goal of maximizing visitor learning outcomes brings renewed clarity to institutional strategies, helping to determine how, when, where, and what to teach in hybrid environments[1]. Such ongoing museum adaptations have given rise to new educational models and format that merit further investigation following the abrupt pandemic shift to remote learning. Consequently, considerable unpacking of the hybrid framework and articulation of potential benefits, alongside more systematic exploration of learning outcomes, remain critically needed [2].

The Post-Pandemic Educational Landscape

The Covid-19 pandemic has had a profound impact on education and training throughout the world. In higher education sectors, for instance, many governments have adopted alternative modes of education delivery to ensure the continuity of the learning process despite the pandemic and lockdown restrictions [2]. Technology-mediated teaching and learning has become an integral part of modern teaching and learning. A new teaching and learning model has subsequently emerged in the post-pandemic scenario and academic institutions are being compelled to

embrace a hybrid education model for effective learning outcomes [3]. The Hybrid-Flexible Teaching and Learning model, also termed as HyFlex Tuned for Technology and Conscious Learning process or HyFlex + Tec, encapsulates both the physical mode of learning for a fixed geographical location and internet-mediated online mode for learners who are globally scattered[4]. This model provides an enormous opportunity to engage learners in both the physical and online spheres, with the option to switch between spheres whenever suitable and it can be utilized to assess the educational status of students in the physical or online sphere. This model was predominantly initiated during the pandemic period but remained to play an important role in learning and pedagogy even in the post-pandemic era [5]. The pandemic has forced individuals, firms and institutions to adopt an unprecedented level of digital technology for professional; social and personal activities, thus taking the whole world even closer to digital transformation. The former pedagogical approach is no longer effective after the pandemic during the post-Covid-19 era; the hybrid learning model offers an alternative solution for course instructors in higher education therefore several scholars have started proposing different customized hybrid models that suit the contemporary societal and education environments and address the sustainability priorities [6]. These hybrid models can be employed to study various learning experiences related to, metacognition, emotional wellbeing, e-learning engagement and motivation, learning clarity and understanding, learning effectiveness, mood tracking and emotional state, focus time, time allocation, educational technology grief, and waste of learning time[7]. Universities worldwide are spontaneous modifying the pedagogy to address the post-pandemic experiential change. The hybrid education and cycle learning approach of education thereafter reflects on both the digital aspect and on the historical pedagogy [7]. The pandemic has offered both a fearsome and priceless lesson to humanity across all societal sectors. On the one hand, it has given rise to the ever-minute knowledge and educational demand, and on the other hand, it has changed the conventional learning mode. Interestingly, many traditional education sectors, corporate learning education, cultural education, training institutions and multiple initiative universities on near-campus have relinquished formal teaching and learning yet new technology-supported educational method and measures for alternative education are rapidly emerging [8].

Hybrid Models in Museum Education

In an effort to expand reach, several museums began experimenting with virtual, off-site programming [1]. The goal was to complement existing, primarily on-site educational activities. Institutions drew on decision-making frameworks developed before the pandemic that identified a continuum of activity types, ranging from fully digital to fully physical [2]. The pandemic created urgency to use these frameworks and principles to establish programming in entirely new areas. As interest in hybrid programming continues, outlining key dimensions reflects conditions museums are likely to encounter in hybrid approaches [3]. Hybrid models incorporate onsite and virtual learning experiences that augment one another. Educational programming can take place at museums or virtually, with people in either location able to participate simultaneously or engage separately. Several museums also catalogue hybrid offerings in which activities are onsite and online, and people at both sites engage synchronously[4]. Alongside a continuum from fully physical to fully digital, a basic distinction separates synchronous and asynchronous activities. Conclusion of programming had traditionally been focused on concepts and ideas learned; hybrid programming broadens and deepens planning to include skills, attitudes, and behaviours. Constituents with different backgrounds and interests can assemble different, complementary elements into a distinctive offering and contribute equally to program development [5].

Onsite and Virtual Complementarity

Onsite and virtual museum education experiences are complementary, not in competition [3]. A blend of onsite and virtual program offerings enables a wider reach without sacrificing learning outcomes. While some institutions and practitioners potentially view onsite and virtual programs as alternatives to one another, museum education that optimizes the affordances of both modalities positions onsite and virtual learning experiences as mutually reinforcing rather than mutually exclusive[4]. In a hybrid studio at a children's museum, in-person and virtual family programming occur simultaneously, allowing on-site families to interact with a wider audience and off-site families to engage in hands-on art-making experiences [5]. Such dual delivery enhances conceptual understanding for either learning context alone. Hybrid programs that engage with both virtual and onsite groups are thus likely to have greater educational potential than those addressing just one [6]. Similarly, virtual guided tours connecting a museum, a community college, and a regional library district provide introductory content through an online platform, followed by collaborative, interactive large-group sessions, and culminate with smaller in-person tours [2]. For participants unable to attend, a recorded, self-paced version remains accessible, ensuring equitable access. Such hybrid delivery thus retains flexibility while broadening partnerships, deepening learning outcomes, and increasing participation. The integration of both formats is therefore a potent driver of educational benefit [1].

Synchronous and Asynchronous Learning Experiences

Increasing the quantity of information simultaneously communicated to learners is generally seen as a way of enhancing learning [1]. Appropriately scaling up the number of things communicated while maintaining learner

engagement, understanding, and retention is consequent, but much less straightforward. Constructing engagement and retention-supportive integration and segmentation principles enabling multilayered communication of large amounts of information across diverse ages and abilities is among several grand challenges necessary to achieve this goal [2]. Balancing synchronous and asynchronous elements also supports different ways of knowing through different activities. Asynchronous activities fostering personal reflection, self-direction, generation of observations, and internal dialogue complement the social aspects of synchronous activities. Synchronous activities further promote social behavior and understanding and support individuals developing into group members [3]. Senior learners tend to enter groups already having acquired these skills, while younger learners benefit from additional assistance and hence from a greater proportion of synchronous activities and interaction [4].

Accessibility and Inclusivity Considerations

In the post-pandemic context, accessibility considerations increasingly move beyond physical barriers and the digital divide towards broader notions of equity and inclusion [5]. While complementary onsite–online models are emerging in museums, there are concerns that this extra layer of pedagogy may reinforce existing disparities in access and equity [4]. The pandemic has prompted a reassessment of definitions of access that encompass barriers of language, culture, and safety, and highlights the importance of learning opportunities for major target groups such as children and youth, immigrant populations, and the elderly [5]. Socioeconomic deficiencies have been exacerbated by the pandemic, and collaborative co-creation experiences that foster partnerships with schools and community organisations can address urgent needs for youngsters, minorities, and people from new residents families [6]. Such partnerships also promote acquisition of alternative skills for the changing job market and provide opportunities to participate in democracy-building processes in voting, neighborhood participation, and general citizenship [6].

Learning Outcomes in Hybrid Museum Education

The essential learning outcomes for museum education delineate the objectives of museum programs. They are unsurprisingly aligned with learning outcomes stated by other educational organizations worldwide. Enabling relevant skill development provides another key learning outcome [7]. Museums help facilitate the development of cognitive, psychomotor and intra- and inter-personal skills. Cognitive skills include critical, creative and logical thinking, the capacity to draw conclusions from objects and artifacts and reading skills such as interpreting texts or images. Psychomotor skills encompass manual activities and dexterity [8]. Museums are also conducive to the development of social skills such as teamwork, communication and sharing [1]. Learning can be approached from a more holistic perspective as the acquisition of knowledge through a sense of dialogue involving cultural mediation through such activities as listening to a story, interpreting visual information or asking questions. Rather than simply offering information, knowledge should be presented in ways that allow audiences to experience reality and cultivate a personal sense of meaning [6]. Finally, museums engage audiences' attitudes either directly through specific themes or indirectly through the learning process itself. Learning environments and events can inspire feelings of respect, affection or contemplation of bygone eras [7].

Knowledge Acquisition and Conceptual Understanding

The study of museum educational practices in various countries indicates that learning outcomes can be categorized into the following dimensions: knowledge acquisition and conceptual understanding; skill development and critical thinking; and attitude change, engagement with cultural artifacts, and cultural competence [1]. The impact of hybrid models on these dimensions is explored in the sections below, focusing on how knowledge, skills, and attitudes are affected when museum learning occurs in a mix of physical and digital formats. Significant evidence suggests that hybrid educational experiences help participants acquire knowledge and develop conceptual understanding [2]. Programs which emphasize both onsite and online components allow museum educators to convey people's identities, connections to belonging, and even wider community engagement and issues [3]. When educators intentionally adopt an integrated model, hybrid approaches support cohesive learning relying on prior museum knowledge. Accordingly, museum educators noted the importance of cultivating conceptual understandings of hybrid learning solutions, complementing the previously understood onsite dimensions [4].

Skill Development and Critical Thinking

The ability to communicate ideas effectively, work with others, and think critically has never been more urgent than today as citizens are called to make sense of and respond to complex problems and a rapidly changing world. Today's education must prepare learners to comprehend the challenges, opportunities, and new realities unfolding in ways unlike previous generations [5]. Critical Thinking is a crucial twenty-first century skill that permeates throughout subject areas [6]. Thinking critically involves asking questions, engaging in argument, discerning trustworthy information, making connections across domains, assessing sources, and working with competing interpretations to develop informed opinions [7]. Critical thinking is seen by many as an essential literacy in today's highly interconnected world and can be enhanced with museums' encouragement of open questioning and

critique among learners. Museums can develop skill sets that further critical thinking and thinking outside the box [2]. Critical thinking is especially important as human existence is threatened by disruptive innovation. Critical thinking skills on how to sort through and make sense of vast quantities of information without complete dependence on predetermined formulas, given the inevitability of roles changing whether a job exists in the future at all[8]. In a world of transcending now being a definite, it is a fundamental capability to interrogate how former, slower perceptions gained multi-modalities or other dimensions and how previously only tangible becomes currently possible as the parallel or free move or activity was witnessed through machine, extending that creative and critical fluency from there ultimately to human sense(deprivation)[9].

Attitudes, Engagement, and Cultural Competence

Educational programming in museums is designed to stimulate interest in and engagement with museum collections while providing opportunities for developing broader sets of skills [1]. As the audiences and the societal roles of museums have evolved, so too have the desired learning outcomes. Current programming is directed not only toward the acquisition of knowledge and skills but also toward the development of attitudes, the promotion of cultural competence, and the encouragement of lifelong learning[2]. Understanding cultural heritage in a multicultural context is particularly relevant to museum learning and engagement. Such understanding can contribute to enhanced appreciation and respect for cultural differences and the values of the diverse members of society [3].

Pedagogical Approaches and Theoretical Foundations

To meet visitors' needs for a diverse range of onsite and online experiences museum education has evolved into hybrid learning delivery, which requires developing complementary educational practices that embrace onsite and online spaces [1]. As museum educators have become increasingly concerned with how people learn visiting museums as building knowledge understanding and skills; engaging with the arts; experiencing authenticity; promoting personal meaning and facilitating online communication museum learning is gradually shifting from a focus on what is provided to how learning is created and constructed between the museum and audience[10]. Young people from diverse cultural contexts are engaged in filtering and curating online information to suit their purposes hybrid education presents as an opportunity for museums to embrace these out-of-the-classroom learning practices [11]. The design of any learning experience determines whether a visitor can get what they need from the learning.

Constructivism and Experiential Learning

The experiential learning theory of Kolb develops a framework for understanding the learning process, offering concepts such as subjectivity, reflection, and development of the self, expressed in the paradigms of individual learning and social learning [12]. Constructivist Lewis incorporates Dewey and Piaget to describe learning as a building process of meaning through interaction with the outside world. Factors influencing this development include prior knowledge, active and social interaction, and cultural context, all connecting in a dynamic process of adaptation and assimilation. Like many planners in the museum field, explorers recognize the need for long-lasting, acquired knowledge relevant to everyday life [13]. Constructivist rules for planning include using visitor experience as the basis for building new meanings and remaining in proximity to familiar knowledge [14]. Builders build on their own action and intervene depending upon visitor experimentations. Knowledge sharing and social interaction become decisive aspects to tap in an interconnected and collective construction of meaning [1, 8].

Communities of Practice and Co-Creation

Communities of Practice (CoP) and collective learning appear more than ever relevant to museum education. Working collaboratively with locals for community-oriented projects enables mutual cultural exchange, aspirations of empowerment and growth [9]. Museums initiate co-creational dialogues, giving voice to underrepresented groups in the articulation of narratives and cultural expressions [10]. Individuals engage in participatory, shared and interdependent learning whilst acquiring knowledge and expertise in community matters. Artefacts of collective learning originate from intercultural discussions, brainstorming and problem-solving of cultural issues. Participants become ever more self-directed and autonomous [11]. In sharing views and matters of concern, individuals strive to foster strong community bonds and sustain learning. Adopting knowledge gathered in museums empowers personal, educational and professional improvements. Engaging in these exchanges with pedagogy rooted in CoP can help to deepen and enhance the learning process [9]. Aiming at bridging learning and space designing developing a CoP pedagogy appears appropriate. Museum engagement extends learners' social fabric, whilst a focus on community-wide matters of concern may allow all those attending to feel included in the flow of exchange [10, 11].

Universal Design for Learning in Museum Contexts

The principles of Universal Design for Learning (UDL) offer significant opportunities for enhancing museum learning [11]. UDL provides a framework to ensure that diversity in museum audiences, and their individual variability and potential barriers to learning, are fully considered in program design and planning [11]. Museums

regularly aim to reach audiences that have lower attendance and participation rates, and diverse visitors, such as individuals with disabilities, can be better engaged through the thoughtful application of UDL principles [12]. A UDL approach addresses three primary principles for program design: multiple means of engagement, presentation, and action and expression. The central idea behind UDL is to develop flexible programs that proceed along pathways allowing individual options within each of the three categories [13]. Consequently, any museum learning program can be designed to accommodate a wider diversity of audiences without the need for specialized programs directed toward individual attributes such as age or ability [14].

Assessment Strategies in Hybrid Settings

Hybrid teaching and learning modalities have gained widespread popularity across diverse learning environments, including K–12 and university systems, workplaces, and museums [15]. Detailed studies on K–12 and higher education systems during the pandemic have explored stakeholder feedback concerning the relevance, applicability, and effectiveness of these new formats [2]. Practical, research-based models have been developed for hybrid teaching and learning in schools. Museum educators have not yet had the same opportunity to share insights on the effectiveness of hybrid programming or to establish models specific to museums [16]. As a result, educational programs in museums, galleries, and science centres, in tandem with stakeholder feedback and engagement, have continued to shift toward hybrid formats. The effective use of hybrid programming requires a better understanding of how the format supports learning within museum education, so as to identify the most appropriate hybrid model in any given context [1].Both formative and summative assessments support stakeholder evaluation of hybrid museum educational experiences. Formative assessment addresses program process and pedagogy, helping to shape ongoing program development and delivery based on participant feedback. Summative assessment addresses participant learning and engagement, gathering data from participants, educators, and community partners to evaluate overall program effectiveness [17]. The development of assessment instruments depends on whether answers are expected to emerge from ongoing engagement in the program, and whether learning is documentable in a specific format that participants feel comfortable sharing. Summative assessment is typically conducted after the hybrid program concludes, yet a sufficient duration can be secured to evaluate participants' satisfaction with the program, skills subsequently applied, and foundational concepts still in use [18]. Longitudinal studies track participants' full spectrum of engagement over a longer period.

Formative and Summative Assessment

Many assessments in museum education remain fundamentally formative. Museums strive to provide meaningful experiences to visitors without the incentive or ability to award credentials [17]. Unlike the many hours of practice required before advancing to a higher level in a music or martial arts class, learning in museums occurs episodically. Visitors may return to observe behaviours and continue ongoing pursuits, or they may engage in a quest and come once or never again, thus making summative assessments almost irrelevant [1]. Museums are ultimately trying to discover and improve the experiences they give to visitors: help visitors engage meaningfully, for learning occurs naturally when individuals engage meaningfully [18]. Agencies assemble actual learners' responses to approved questions as value adding information. Agencies have moved away from indirect pointers of outcomes such as attendance or expense toward tracking in-house indicators reflective of engagement, such as the number of completed game levels, the length of time between visits by an individual, and the time elapsed at a location, and style of queries posed [19]. By building hands-on displays, agencies anticipated how many individuals would interact more. Data suggest conventional museums are successful at widespread cultural engagement [19].

Authentic Assessment and multimedia Evidence

A formative assessment of the virtual and hybrid offer aims to identify the impact of the experience on the interested public [6]. Indicators such as number of visitors, duration of interaction, and number of returns are collected for each session. Regardless of the education scenario, follow-up micro-surveys are sent to participants within 48 hours of the activity. The initiative aims to understand if participants acquired knowledge, developed any skills, or changed their attitudes after the activity [3], as well as to improve future iterations. The current virtual offer is designed for an informal audience, and how it may be adapted to schools is under investigation. There are also questions regarding how a museum might transition from a predominantly virtual offer back to a more conventional one [5]. Participatory action research would involve six collaborative iterations with partners from the community or educational domain. A summer co-design project with a newly recruited digital advisor could be a first exploratory step to deepen the understanding of potential hybrid offers [2].

Data-Informed Program Improvement

Hybrid programs create new models of participation that reach broader communities and enhance the impact of individual programs. Participation in off-site museum-led programs has historically been used as a measure of outreach, yet hybrid programs can enable participation without leaving one's home [5]. Many museums and other organizations offered hybrid programs at the beginning of the COVID-19 pandemic and continue to do so as they

emerge from it. As in-person gatherings resume, the question of how to offer engaging hybrid participation remains. Museum educators articulated a range of program goals intended to encourage different types of participation and informed choices among potential programs that could be hybridized [6]. One of the hybrid goals broadening audience reach by providing a virtual attendance option to evenings and other programs that are already widely reached onsite, should warrant both attention and caution. For wider communities to engage with local cultural events, place-based richness needs to be maintained [5]. Engagement and enthusiasm was reported by participants in hybrid articulation programs, indicating that hybrid program development, offering complementary content at different times, remains relevant [6]. Common registration systems for hybrid programs allow but do not require implementation of these broader goals as part of hybrid programming. Hybridized programs offering sharing or amplification of articulations from onsite programs and evening programs aimed at broadening reach of locality-based, vernacular art-making opportunities, while framed in already familiar structures for a hybrid audience pinpoint some of the possibilities hybrid articulation still holds[7]. Other forms of extension from sessions on gallery activities unfolded when articulations were transcribed. The interleaving of different onsite gallery discussions connected to the same content but offering different perspectives across individuals and times further suggests additional fruitful directions for development within this evolving space [1, 12].

Equity, Access, and Global Perspectives

The immediate transition to hybrid formats, however, has revealed limits, inequities, and unintended consequences. Hybrid approaches to education do not automatically carry the advantages of their full-scale analogue or digital counterparts [8, 9]. Learning and engagement outcomes fostered by on-site interaction with peers and educators during sessions in the museum or gallery can often go missing in recorded formats or presentations that do not effectively fulfil the educational mission [10, 11, 12, 13]. Experience may be widened or enriched but, without wise planning or adequate staffing, it can propose lessened opportunities for learning altogether 14. Moreover, reliance on processes, products, platforms, and applications that favour some languages or alphabets over others further exacerbates inequity in learning access [10]. High-quality translation of required texts and materials into a range of national languages, however widely spoken is seldom an economical option, yet considerable global knowledge and data go unseen by populations sharing diverse vernaculars across any continent [13].

Resource Disparities and Digital Divide

The acute need for remote educational activities and resources raised awareness of disparities among students, schools, and educational systems in their respective readiness to offer online learning [14, 15]. Specific issues emerged in parts of the world that experienced extreme lockdown measures, leaving students entirely at home for lengthy periods; students from schools that had not yet developed such capacity were placed at an extreme disadvantage [16]. In certain contexts, educational inequalities were augmented further due to lack of access to technology and the internet, as well as lack of parental support for home schooling [16]. Widespread impoverished access to essential digital hardware was especially problematic during the early phase of the pandemic, combined with additional factors such as absence of dish televisions, phones, or even books that improved general knowledge. These developments indicated that simply having access to education was not sufficient if a "digital disconnect" characterized school systems [17]. Material conditions for hybrid museum learning were similarly unequally distributed before the pandemic, and their impact on learning outcomes at museums and similar places remained to be further investigated [18].

Multilingual and Cross-Cultural Learning

Language and culture are crucial in fostering social cohesion in multicultural societies. Museum education can promote multilingualism and cross-cultural understanding through a hybrid model that combines onsite and virtual experiences [19]. Some museums have launched streaming pilot projects to encourage media exchanges between youth from different cultural backgrounds in various countries, supporting collective storytelling through music and informal conversations [20]. This approach enables young mediators to facilitate cross-cultural dialogue by sharing their own media productions with peers abroad. Moreover, formats such as pre-recorded video clips, audiovisual slides, and audio podcasts extend the reach of messages about identity, community, and cultural perceptions, thereby enhancing empathy and consideration for others' perspectives [2, 22]. Reflecting on the importance of multilingualism in intercultural education, the arts support learners who experience constructive unease and ideological conflicts due to diverse cultural backgrounds or ethnic identities [23]. A community-oriented online museum platform employing an interactive hybrid model enables users from different countries and languages to participate in multilingual co-creation by sharing artistic inputs on four themes: emotions, attitudes toward COVID-19, life habits, and imaginary spaces. Such a cross-cultural platform inspires collection-based storytelling practices that consider local and global interconnectedness and address the social expectation of a circular economy [17].

Partnerships with Schools and Community Organizations

Collaborative partnerships with elementary and secondary schools and community organizations remain effective strategies for reaching diverse audiences [23, 24]. Museums must understand their community's educational and cultural needs, and then demonstrate how they can support community interests before building partnerships 18. Each potential partner should be invited to discuss shared goals and make specific contributions. Lessons learned should inform further development of virtual and hybrid museum education models [19]. Partnering with local organizations is also critical within multicultural communities. For example, museums serving mixed-language populations can collaborate with community translators to develop bilingual programs [25, 26].

Case Studies and Best Practices

Museums were eager to resume their programming and to welcome visitors back onsite, equipped with newly installed health protocols and a hybrid mindset [6]. This allowed the delivery of new in-person experiences while continuing to offer virtual-only programs that had attracted many participants [7]. A case study from a science museum illustrates how the institution's hybrid studio runs synchronous, co-designed sessions on making and tinkering onsite and from afar, fostering playful, hands-on, and collaborative engagement across distances [1, 2]. Another case study describes how a visual arts museum embraced the virtual realm by offering guided tours of co-exhibits, paired with hyperinclusivity strategies that assured connection in many languages, and interactive art-making sessions that allow mixed media experimentation and dialogue [4]. Participants are encouraged to share their works with fellow creators 19. This service to the community continues alongside an ambitious endeavour to co-create fuller exhibitions with artists and different groups from the neighbourhood[3].

Case Study A: Hybrid Studio in a Science Museum

Museum education in the post-pandemic era requires a formal, evidence-based exploration of hybrid models and learning outcomes [12]. In the past year resources have drawn attention to the significant physical and economic constraints facing museums following this extended period of closure. Understandably, programs that emerged during this period of confinement were primarily viewed through a lens of equity, diversity, accessibility, and inclusion [13]. The National Museum of Mathematics (MoMath), located in New York, is dedicated to promoting a broader, more inclusive, and more accessible vision of mathematics. This is accomplished through engaging exhibits, creative programs, and innovative outreach [13]. MoMath, guided by a commitment to diversity, equity, and inclusion, sought for the first time a deeper understanding of the mathematics conceptual framework preserved in mathematical interactions [14]. Consequently, while equity-centered "community partnerships" are critically important, mathematical co-designs should explicitly reflect the mathematical understanding associated with such partnership work. It is essential for museums, the constituents of mathematics themselves; to navigate expert community partnerships that further broaden the definition of mathematics through hybrid co-designs [20]

Case Study B: Virtual Guided Tours and Interactive Learning

The COVID-19 pandemic has caused the interruption of onsite, face-to-face learning activities in museums, resulting in modified teaching strategies [13]. Some museums developed virtual guided tours with a subsequent interactive session, while others adopted an asynchronous mode enabling solo explorations with various resources. Participants' experiences during these guided tours illustrate the advantages of synchronous online programs hosted by museums. Observers indicated that their learning increased to a higher level after joining post-tour Q&A sessions in association with online guided tours [14]. Through these collaborative discussions, learners deepened their understanding, refined their thoughts, and acquired more engagement. Such virtual learning environments enable students to reconstruct knowledge actively and shift learning responsibility toward museum educators, thus meeting hybrid delivery criteria [15]. Participants indicated that onsite similar collaborative activities would foster better knowledge construction together with communication and interaction experiences. The added value of the interactive session also illustrated that sharing knowledge collectively leads to deeper learning [16]. Museums that seek to develop in-depth museum education programs should focus on assessment and enhancement instead of simply providing pedagogical opportunities. An educational program should not just transmit knowledge but also create deeper routes through continued learning. Hybrid delivery offers increased flexibility for educational programs delivered in museums, yet assessment is vital to track the impact and further improve such valuable educational opportunities [17]. Hybrid education provides instruction in both physical and virtual environments, enabling participants to develop knowledge in their own learning spaces, drawing links with what they learn during guided sessions. Program enhancement requires understanding the current popularity and improvements in such learning environments [17]. Participants attending hybrid programs within a specific duration represent at most one-fifth of total attendees; hence, it is crucial to grasp the impact of hybrid education on learners and program enhancement towards a broader audience [18]. To fulfil hybrid museum education aspirations and operational efficiency, a knowledge framework is established outlining potential knowledge links between distance and onsite teaching forms [6].

Case Study C: Co-Created Exhibits with Community Groups

In November 2020, a local children's museum collaborated with a university lab on a community-engaged research project involving informal STEM learning during childhood [19]. Both organizations remained committed during the pandemic, supporting efforts to transfer the project to other informal settings [20]. A hybrid graduate service-learning course included a 20-hour project analyzing museum exhibits for STEM learning and improvement opportunities. Student teams four long-standing exhibits through the museum's online learning platform. An in-person visit permitted hands-on data collection and further exhibit analysis. Museum staff provided critical input and guidance, enriching students' understanding of STEM engagement and the role of children's museums [21]. University students collaborated with a local community-based museum and a public school district to create oral-history-based exhibits of the region's history, tying together stories drawn from personal interviews with members of the community and artifacts from the museum's collection [21]. The project was undertaken at the invitation of the museum's director and regional history educator, who sought to strengthen the community's ties to the museum by involving local residents and to encourage student participation in the institution. In framing the project, museum staff articulated key attributes that would bring value to the partnership: respect for timelines and resources; clearly defined roles and areas of expertise; consideration of how proposed designs might enhance the museum's mission; and student involvement in a way that would avoid fully derailing ongoing operations [22].

Practical Implementation: Strategic Planning for Institutions

New strategies merging on-site and online activities have gained prominence in museum education since the COVID-19 pandemic began [23]. Hybrid programming is increasingly seen as a way of extending the museum's reach, engaging diverse audiences, and providing both a form of equity and a rationale for retaining digital components of museum education developed during pandemic lockdowns [24]. Hybrid offerings remain scarce, however, and models of extension beyond the sites and modes of formal schooling are still evolving, as institutions adapt to a landscape transformed by the pandemic. Specialist literature is now beginning to emerge [25]. Hybrid programming extends learning opportunities beyond the walls of formal schooling to audiences unable or disinclined to travel to a museum [26]. Museums are now increasingly seen as out-of-school learning and other informal opportunities complementing formal schooling, rather than as replacing schools [18]. Hybrid formats have been formalized in response to evidence that COVID-19-related constraints on out-of-school, museum-related time have persisted even as other restrictions have eased [19]. Program leaders have often noted changes in pre- and post-program engagement, along with the emergence and rising engagement with programs geared towards broader themes and collective art-making viewed as hip-hop education but attaching them to and asserting ownership of the themes in relation to a programme focusing attention on works of art by artists in those communities despite lighthouse facilities and evacuation notices [19]. To critically assess the role and operation of hybrid museum education developed a hybrid museum education pedagogical framework that incorporates the interplay among learning outcomes, pedagogical approaches, assessment strategies, equity and access issues, and global perspectives [20]. The framework centres on three learning outcome domains knowledge and conceptual understanding, skills and critical thinking, and attitudes and engagement and is aligned with the emphasis that museum education plays in the policies of museums worldwide [20].

Stakeholder Engagement and Governance

Museum education in the post-pandemic era requires a formal, evidence-based exploration of hybrid models and learning outcomes [21]. Post-pandemic realities compel museums to re-examine educational offerings and rethink fundamental service delivery modes. The rationale lies in the accelerated shift to hybrid programming fomented by the COVID-19 pandemic and sustained interest in such educational models [22]. It therefore remains crucial to catalogue, analyse, and articulate hybrid offerings in ways supportive of post-implementation improvement as leadership seeks to stabilise operations within new, lower-user baselines. Such analysis may also facilitate replication of successful strategies across evolving pandemic and non-pandemic circumstances [23]. Several characteristics of hybrid offerings distinguish museums, warrant attention, and facilitate organisation into four principal categories, bringing multi-faceted benefits to user experiences. Onsite and virtual models, in which participants select either face-to-face or online attendance, constitute the first category. Sessions delivered via both synchronous virtual instruction and on-site delivery represents a second hybrid category [24]. Third, the availability of a recorded virtual component after live instruction is conducted complements existing offerings. Finally, the fourth grouping encompasses entirely self-directed, pre-produced virtual resources, including videos, webinars, and activities, developed by the institution or third parties with museum affiliation [25]. Hybrid museum education enables delivery of deeper and broader user outcomes across knowledge-acquisition, skill-development, and attitude domains [24]. Within knowledge acquisition and conceptual understanding, the breadth of optional thematic and curriculum-area combinations emerging from new partnerships promoted by two-pronged hybrid education interest including science, literacy, sustainability, and social-emotional topics has

expanded at both local and international levels. Recognition of connections between optional-topic selection and user conceptions further reinforces dual offering advantages [25].

Technology Infrastructure and Content Design

Successful implementation of hybrid models in museum education relies upon three interrelated aspects: investment in the necessary technological infrastructure; proactive design or curation of engaging, purposeful content for delivery across the chosen modes; and clearly defined objectives that ensure each learning experience, regardless of modality, remains meaningful, relevant, and supportive of visitor agency [2].

Evaluation Frameworks and Sustainability

Formal evaluation frameworks measure the value of educational activities to learners, organizations, and society, guiding program improvement and sustainability [26]. Museums face a persistent challenge to demonstrate the impact of educational activities, even in a post-COVID-19 world. Institutions on low budgets might therefore avoid adopting hybrids on the false assumption that they cannot implement an evaluation framework. An alternative approach defines broad institutional goals and then decides whether to apply a hybrid approach, taking into account the institution's specific context [25].

Policy Implications and Future Directions

In the wake of seismic shifts in both the educational landscape and visitor needs and expectations brought about by the pandemic, museums and other informal learning institutions must adapt to rapidly shifting attitudes and behaviors in the areas of hybrid in-person and online experiences [23]. The rise of technology, social media, and the shift of Information and Resources into the cloud has fractured learning adventures and made experiences much more accessible, necessitating a more comprehensive approach to learning that supports integrated on-site and off-site experiences [24]. Haphazard online extensions of on-site programming will not fulfill the emerging visitor needs, and museum educators, broadly defined to include educators, program developers, curators, exhibit designers, interpretation specialists, and others, must design and implement thoughtful, fully integrated hybrid programs that explicitly engage with both the existing literature and the enabling technologies [1]. The three case studies a hybrid studio in a science museum, virtual guided tours supported by interactive learning experiences in an art museum, and the co-creation of exhibits with local community groups in a natural history museum illustrate innovative approaches to hybrid programming and offer frameworks for further development and implementation[25]. Each of the cases engages explicitly with hybrid program development and is designed to be either fully online or fully on-site, allowing for authentic formative and summative assessment based on the complete program experience. The observations and lessons learned from these instances are intended to inform the wider community of practice of educators and program developers at museums and other informal learning institutions [26].

CONCLUSION

Museum education in the post-pandemic era has undergone a significant transformation, with hybrid models emerging as a central strategy for delivering meaningful and inclusive learning experiences. By integrating onsite and virtual modalities, museums are no longer confined by physical boundaries but are able to reach broader and more diverse audiences. This dual approach enhances learning outcomes by combining the strengths of physical engagement, such as tactile interaction and social learning with the flexibility and accessibility of digital platforms. The study demonstrates that hybrid museum education supports a multidimensional framework of learning, encompassing knowledge acquisition, critical thinking, skill development, and attitudinal change. Pedagogical approaches grounded in constructivism, experiential learning, and community collaboration further strengthen these outcomes by emphasizing active participation, reflection, and co-creation. At the same time, effective assessment strategies remain essential to ensure that hybrid programs are responsive, impactful, and continuously improved. However, the transition to hybrid education also reveals persistent challenges, particularly in relation to equity, digital access, and resource availability. Without careful planning, hybrid models risk reinforcing existing inequalities rather than mitigating them. Addressing these challenges requires intentional design, investment in infrastructure, multilingual and culturally responsive programming, and strong partnerships with schools and community organizations. Looking ahead, the sustainability and success of hybrid museum education will depend on institutions' ability to balance innovation with inclusivity, and flexibility with pedagogical rigor. Museums must continue to evolve as dynamic learning environments that not only disseminate knowledge but also foster dialogue, creativity, and social connection. In doing so, they can play a vital role in shaping a more accessible, participatory, and resilient educational landscape in the post-pandemic world.

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