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The Confluence of Digital Literacy and Eco-Consciousness: Harmonizing Digital Skills with Sustainable Practices in Education

Noble Po-Kan Lo ^{1,2} 

¹ College of Professional and Continuing Education, The Hong Kong Polytechnic University, Hong Kong, China; noble.lo@cpce-polyu.edu.hk or p.k.lo@lancaster.ac.uk

² Department of Educational Research, Lancaster University, Lancaster LA1 4YL, UK

Abstract: This study investigates the implementation and impact of maker culture—viewed as a tool for developing green digital skills—in higher education institutions in Hong Kong. Maker culture, a collaborative educational approach, embraces students' capacity for self-paced, autonomous learning and applies this knowledge to creative problem-solving and innovation, key aspects of sustainability education. An empirical study was conducted, focusing on the experiences of teachers in the higher education sector in Hong Kong. Eight individuals were interviewed to gain insights into their perceptions and experiences with maker education within sustainability contexts. The sample was limited to ensure cross-sectional comparability and direct weighting of teachers' experiences within a singular, complementary educational setting. The findings provide valuable insights into the benefits and challenges of integrating maker education into traditional educational systems to foster green digital skills. It became evident that adequate resources, effective teachers, and improved administrative systems play significant roles in the successful implementation of this approach. Maker education, as a tool for developing green digital skills, offers a promising alternative to traditional performance-based studies. It has the potential to lead to a future of education that is creative, innovative, and student-directed, fostering sustainability competencies. Therefore, despite the challenges, with the right support and resources, the integration of maker culture into educational systems could significantly transform teaching and learning processes, advancing sustainable education.



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1. Introduction

In the critical discourse on maker culture, Ayivor [1] posits the existence of three distinct personas within the societal framework: the wanters, the wishers, and the makers. At the heart of maker education lies the philosophy of experiential learning—a paradigmatic shift from the conventional didactic transmission of knowledge to an active engagement with pertinent concepts [2]. Despite the pervasiveness of innovation within our digital epoch, the valorization of the creator often remains muted, eclipsed by the tangible allure of the end product and its pragmatic utilities. Yet, the ethos of maker culture harbors an intrinsic inspirational value, exemplified by figures such as Kamkwamba [3], known as 'the Boy Who Harnessed the Wind'. His narrative transcends the mere acknowledgment of a challenge (a lack of access to a drill) and encapsulates the ingenuity of conceiving and actualizing a bespoke solution (thus, crafting his own drill). From the perspective of educational theory, maker culture presents a juxtaposition to the structured and prescriptive norms that dominate curricula, assessments, and standardized metrics of knowledge [4]. While it is conceivable that a multitude of students will make significant contributions to society—potentially spearheading the next wave of disruptive innovations—the rigidity and prescriptivism endemic to traditional educational frameworks often marginalize the

nascent maker movement. This movement is nonetheless orchestrating a silent revolution, gradually reshaping educational tenets and methodologies.

In the evolving landscape of education, where institutions are actively adapting to shifting learner needs and expectations, maker education emerges as a transformative force redefining the dynamics of classroom engagement and curriculum development. Lundberg and Rasmussen [4] articulate a formal definition of maker education as a variant of project-based learning wherein learners materialize their understanding through the creation of tangible artifacts that embody newly acquired concepts and skillsets. This pedagogical approach, rooted in expansionary learning, empowers educators and students to harness critical problem-solving skills and apply them to real-world scenarios that demand innovative and adaptable solutions. Embracing a spectrum of disciplinary practices, maker culture is delineated as both a burgeoning movement and a multifaceted educational instrument, encapsulating (1) the ethos of experimental play, (2) the collaborative dynamics of maker space communities, and (3) technologically oriented activities designed to foster learning [5]. Within the social context of education, Morado et al. [6] have observed that maker-centric pedagogies engender a participatory learning environment in STEM education, where students achieve innovative literacy as they navigate and create within immersive, non-traditional learning spaces. The present study delves into the pragmatic and pedagogical merits of the discourse on maker culture, examining its integration and efficacy within educational paradigms. Amidst the aftermath of the COVID-19 pandemic, maker education has surged in prominence as an adaptable educational strategy. It facilitates students' abilities to assimilate and disseminate knowledge amongst their peers through versatile online platforms, exemplified by spatial visualization tools employed in machine drawing courses [7]. This inquiry seeks to unpack the transformative potential of maker education and its capacity to meet contemporary educational challenges.

This investigation offers an examination of the influence exerted by maker education within contemporary educational contexts, scrutinizing the intricate relationship between the architectural underpinnings of inventive pedagogical approaches and the resultant student learning trajectories and opportunities. The research pursued several interlinked objectives to achieve its overarching goal:

- A comprehensive critical appraisal of existing scholarship pertaining to the nexus of maker culture and educational environments.
- The formulation of a theoretical construct delineating the objectives and focal points of maker education initiatives.
- The execution of an empirical inquiry into educators' experiences with the integration of maker culture in pedagogical settings.

By integrating insights from each phase of the study, the research facilitated a nuanced discourse surrounding the impact of maker culture on educational reform and instructional strategies. The subsequent section of this article elucidates the pivotal literature that informs the study and delineates the conceptual framework derived from previous research findings.

2. Literature Review

Notwithstanding its departure from conventional modes of educational assessment, maker education can indeed be evaluated to ascertain student proficiency across essential competencies such as concentration, engagement, and problem-solving acuity. Lundberg and Rasmussen [4] advocate for a pedagogical shift that diverts from traditional performance metrics—such as scores, precision, and uniformity—towards a process-oriented approach. This realignment can be operationalized through the adoption of several strategies:

1. Inculcating a design cycle that emphasizes iterative development and refinement of ideas.
2. Valuing the educational journey and the strategies employed over the final artifacts produced.

3. Embedding real-world problem-solving activities that necessitate the application of classroom learning in practical contexts.
4. Fostering an iterative approach to learning that embraces the cyclical nature of trial, error, and improvement.
5. Transitioning the educator's role from an authoritative instructor to a facilitator and motivator of student exploration.
6. Offering students autonomy in their learning pathways to promote ownership and intrinsic motivation.
7. Recognizing the educational potency of play and experimentation as vehicles for discovery and innovation.

This reconceptualization is grounded in the theoretical framework of 'expansive learning', which posits an explorative approach to grasping novel concepts, practices, and technologies by scrutinizing and addressing the present challenges and tensions within a given context [8]. While traditional education systems have often emphasized the acquisition or assimilation of established knowledge, maker culture champions the extension of established boundaries of understanding into realms either wholly uncharted or only partially explored, thereby stimulating students to engage in critical thinking and inventive problem solving that pushes the envelope of their current capabilities [8–10].

The efficacy of maker education in enhancing student learning outcomes is contingent upon the integration of certain core practices within each instructional activity. A structured approach to problem solving, which typically includes a clearly defined problem, the creation of a solution, and subsequent reflection, serves to foster a culture of iterative thinking and the practical application of knowledge to challenges with tangible relevance [4,11]. Research conducted by scholars such as Krummeck and Rouse [12], Chou [13], and Zhan et al. [14] underscores the necessity for students to be actively engaged in problem-solving processes. It is crucial that learners navigate these exercises autonomously, rather than being unduly steered by their peers or educators. This approach encourages students to independently interpret challenges and potential resolutions. The implication being that the value of creative ideation, construction, experimentation, and critical reflection is maximized when students internalize and self-direct their engagement with the task or project at hand [13,14]. This self-directed engagement is instrumental in ensuring that students not only absorb theoretical knowledge but also develop the capacity to apply such knowledge in practical, often complex, problem-solving scenarios. Maker education, therefore, hinges on the ability of students to assimilate these experiences and manifest their understanding through tangible innovation and reflective practice.

The practical application of iterative problem-solving exercises, as evidenced through empirical research, substantiates their value in reinforcing maker education methodologies. Lock et al. [15] detail an illustrative case where Arduino-based modular computing platforms were utilized in the collaborative design of robotics projects. This longitudinal approach, spanning several months, afforded students the opportunity to engage in intensive group work, fostering an environment conducive to open discourse and collective problem solving. Each participant, within this framework, was tasked with contributing to the resolution of central challenges, a process that not only solidifies foundational engineering principles but also encourages the emergence of novel solutions that might ultimately be integrated into the final product [16–18]. In the realm of collaborative maker ventures, Shin et al. [18] explored how structured brainstorming sessions, coupled with the 3D drafting of models, enabled students to engage in a methodical process of design and prototyping. Such collaborative efforts resulted in the creation of scaled models and prototypes for community enhancement projects anchored in sustainability objectives and quantifiable network outcomes. These pedagogical practices leverage the diverse skill sets and knowledge bases of participating students, prompting them to question and move beyond traditional paradigms in community problem-solving. In doing so, they convert individual tacit knowledge into collective, actionable strategies that transcend the sum of their parts [18–20]. These instances exemplify how maker education, through its embrace

of collaborative and iterative problem solving, serves to catalyze the transition from theoretical learning to the application of skills in relevant and impactful community projects. By valuing the contribution of each student and fostering a culture of collective intelligence, maker education practices challenge and expand conventional educational methodologies, leading to a rich tapestry of innovation and shared expertise.

The institutional embrace of maker culture and its incorporation into educational frameworks necessitates a strategic commitment to nurturing an ecosystem supportive of maker-centric pedagogies. This commitment hinges on the establishment of a network or collective that actively learns from both the triumphs and setbacks encountered in the implementation of maker programs [8,21]. Hsu et al. [5] contend that for students to reap the full spectrum of benefits that maker education promises, a robust provision of resources is indispensable. This includes access to well-equipped makerspaces, a diverse range of materials, and guidance from experienced mentors. While certain educational systems, particularly within the STEM disciplines, have begun to weave maker-oriented activities into their curricula, there remains a tension between progressive pedagogies and conservative educational traditions. The latter often undermine the liberating and empowering ethos of maker culture, thus impeding the potency of these innovative learning models [5]. Webb [21] characterizes makerspaces as transformative agents, reliant on a suite of modern technologies—ranging from immersive software applications like virtual reality (VR), to expansive networking solutions such as cloud computing and artificial intelligence (AI), to tangible tools like Arduino kits and 3D printers. Nevertheless, the successful integration of such technologies into educational practices calls for a cadre of educators who are not only adept in current technological trends but are also equipped with the skills and theoretical knowledge to adapt to the evolving demands of student populations [5,22]. The realization of this educational standard mandates a concerted effort to provide continuous professional development for teachers, ensuring that they are prepared to facilitate and guide the experiential learning experiences that are central to maker education.

The incorporation of maker education within academic environments has garnered empirical support, demonstrating its capacity to facilitate the enrichment of student knowledge bases and the refinement of practical skills [13]. De Backer et al. [22] have further illuminated the psychological dimensions of maker education, noting that group dynamics and complex problem-solving tasks within these settings can foster the development of collective metacognitive strategies. Within such collaborative frameworks, students' reliance on the collective achievements of their team can serve as a significant motivator, spurring individual members towards heightened levels of engagement and fostering a robust belief in their collective capacity to succeed in subsequent endeavors [23]. Rambe [23] posits that the pedagogical application of team-based approaches traditionally aims to democratize the learning process within educational institutions. Maker culture, however, transcends this objective by cultivating a sense of empowered cooperation among participants. This empowered cooperation is not merely a byproduct of the maker ethos but is regarded by Clapp et al. [24] as a driving force that underpins the reinforcement and expansion of knowledge. It is this empowered state that imbues learners with the confidence and competence to confront and navigate future challenges with greater autonomy and efficacy. The implications of these findings are twofold: first, they suggest that maker education intrinsically promotes a participatory and democratic form of learning that values and leverages the unique contributions of each student. Second, they indicate that the collaborative empowerment characteristic of maker culture serves as an impetus for ongoing learning and skill development, with the potential to transform the traditional educational landscape into one that is more dynamic, inclusive, and attuned to the practical realities of the 21st century.

To crystallize the principles that foster maker culture within educational contexts, researchers including Setiাপutra and Yoas [25] and Morado et al. [6] have proffered guidelines for implementing a learning-by-making (LBM) methodology in classroom design

and curricular delivery. Rooted in the ‘constructionist’ paradigm—akin to the ‘learning by doing’ philosophy—this pedagogical shift redirects the educational experience from a traditional classroom environment to one characterized by hands-on engagement. This transition facilitates a dynamic interplay between the learner and physical objects, engendering a platform for knowledge exchange and the reconstitution of roles predicated upon constructive activities [6]. In this reimagined learning landscape, the externalization of educational processes calls upon learners to activate higher-order cognitive functions. This includes the adaptation of skills, the recognition of patterns across diverse media, and the cultivation of deliberate intentions. Morado et al. [6] argue that such engagement enables students to interact with the material in a manner that is both more active and intentional. While the allure of creative freedom within the LBM framework may initially stimulate students to explore idiosyncratic solutions, Cohen et al. [26] and Setiaputra and Yoas [25] have empirically substantiated the notion that, to effectively bridge the gap between experimentation and academic insight, a more empirical approach to problem-solving is requisite. This methodology leverages existing knowledge and tangible prototypes as foundational elements to guide the inception and refinement of solutions that are not only creative but also grounded in practicality. For instance, when designing a soapbox car, the application of scientific reasoning would lead to the selection of oversized wheels—a functional and innovative choice—over square pegs, which would impede the vehicle’s movement [26,27]. The synthesis of these research findings suggests that for maker education to flourish, it must be scaffolded by an educational framework that encourages scientific inquiry and critical thinking, allowing students to navigate the balance between imaginative exploration and the constraints of real-world functionality.

As the educational paradigm shifts towards digital-centric learning modalities, the concept of constructive functionality assumes an even greater significance, particularly within the domain of maker education. This pertinence is amplified by the potential for digital and virtual resources to simulate real-world challenges and foster innovation within a virtual makerspace environment [28]. Hall et al. [29] and Shu and Huang [30] have elucidated the potential of virtualization, positioning it as an immersive conduit through which collective experiences and narratives can be explored by student populations. This virtual engagement facilitates a ‘learning by doing’ experience that transcends passive consumption of information and actively involves students in the knowledge creation process. Interactive virtual domains offer students the autonomy to make choices and pursue various outcomes, thereby influencing the narrative trajectory and fostering a critical examination of the circumstances (How and Why), the action (What), and the context (Where) of a given storyline or historical event [30]. In a related venture, An et al. [31] underscored the utility of asynchronous learning platforms, such as digital discussion boards, in the post-pandemic educational landscape. They propose a ‘thinking’ model that blends contemplation with hands-on experimentation (‘think and tinkering’), applied to the digital and tangible fabrication of artifacts that respond to specific problem-based prompts. By designing virtual experiments and orchestrating student engagement through collaborative discussions, the sharing of solutions, and iterative revisions, the reflective dimension of learning is expanded. The virtual landscape becomes a crucible for collective intellectual endeavors, transcending individual reflection to encompass a broader creative and collaborative milieu. This environment is characterized by a continuous feedback loop and the exchange of ideas, where the group collectively refines and evolves their understanding and creative output [32,33]. In sum, the integration of virtual makerspaces within maker education harnesses the power of digital tools to extend the reach of constructive functionality. It enables students to engage in a critical and collaborative process of design, experimentation, and reflection, thus preparing them to address and solve complex problems in an increasingly digital world.

3. Conceptual Framework

The preceding literature review delineates the evolving aspirations of integrating maker culture within academic settings, a dynamic underscored by a spectrum of both facilitative and inhibitory factors. The conceptual framework depicted in Figure 1 encapsulates these elements, presenting a structured model that underpins a progressive and adaptive system where student learning thrives on hands-on experimentation and problem solving. The GEARS acronym encapsulates the framework's primary components, signifying the Goals, Enablers, Activators, Recognition, and Solutions that are critical to the cultivation of a robust maker culture. Below is an encapsulation of the key variables and constructs embodied in this conceptual framework:

- **Goal:** The bedrock of sustained maker activity implementation is the establishment of a sustainable maker culture. This encompasses comprehensive institutional support, the engagement of adept and driven mentors, and the development of the requisite skills and tenacity necessary for the regular curation of maker tasks or experimental ventures [5,8].
- **Enablers:** Two pivotal enablers underpin a thriving maker culture, namely foundational resources (including mentors, technological tools, and knowledge repositories) and the formation of communities of practice, characterized by collaborative small groups, accessible online databases, and supportive team structures [5,8,16,19].
- **Activators:** Activating the learning process necessitates a series of sufficiently challenging components: (1) iterative problem-solving exercises that (2) stimulate creative and innovative outcomes and are (3) supported by contemporary technological advancements [8,13].
- **Recognition:** A nuanced assessment framework is essential for the validation of student learning, which can be achieved through traditional evaluative measures or through practical, conceptually driven methods [4,13].
- **Solution:** The culmination of the learning process is represented by the solutions generated. Whether these solutions are marked by success or failure, they serve as a testament to the students' capacity to assimilate and apply new knowledge within the context of their learning journey [8].

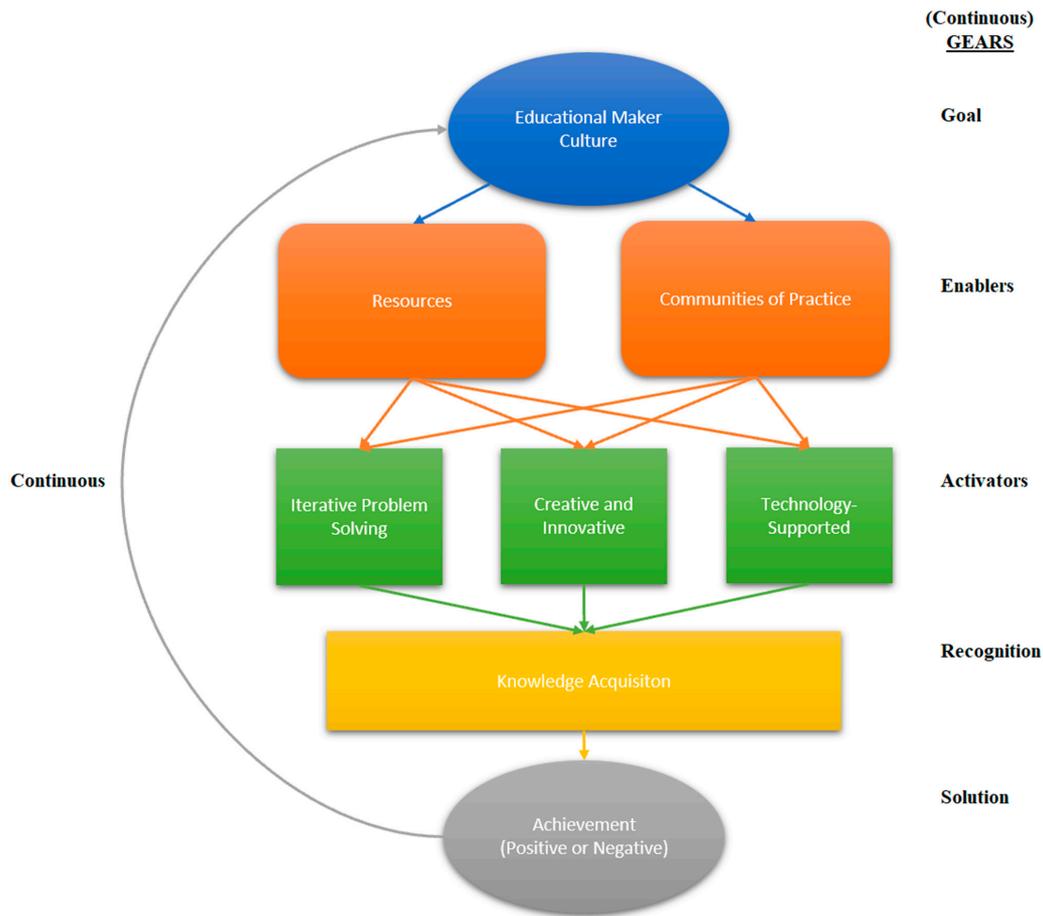


Figure 1. A summary of the key variables and concepts outlined in the GEARs framework for supporting maker culture in educational settings (created for study).

4. Research Methods

This study provides a critical analysis of the role of maker education within contemporary classroom settings by evaluating the design of innovative pedagogical solutions against student learning outcomes and opportunities. An appropriate research methodology must, therefore, be crafted with an eye towards the integration of maker education techniques into classroom settings and their impact on students’ learning experiences. It is essential that the chosen methodological approach is adept at capturing these dimensions, yielding meaningful evidence, and articulating recommendations to refine the deployment of maker education strategies in line with the study’s primary aims.

Chou [13] pioneered experimental tests for in-class applications to gauge student content knowledge and problem-solving capabilities, which aligns with a quantitative, positivist approach. This philosophy, as Bryman [33] denotes, favors the adoption of stringent methods to enhance the reproducibility and reliability of results when quantitative comparisons are feasible. Initially, this study contemplated a quantitative survey targeting students and teachers to elucidate the experiential divergences and the influence of maker pedagogies on student learning. However, as Jonker and Pennink [34] and Saunders et al. [35] caution, the precision and structural rigidity inherent to positivist research can inadvertently narrow the breadth of discernible insights, bound by the constraints of the research tools and participant range. Furthermore, the extensive time and resources required for such quantitative methods would necessitate a protracted timeline and substantial investment, exceeding the practical scope of this study’s operational framework.

Beyond the realm of statistical methodologies, alternative research philosophies such as constructivism offer a different lens through which to examine social phenomena [36,37]. Constructivism acknowledges the socially constructed nature of experiences and realities,

prioritizing narrative insights and phenomenological accounts to elucidate the intricate relationships between individuals and their environments [38,39]. For instance, Lock et al. [15] harnessed a case-based analytical approach within the constructivist paradigm to assess the impact of various maker education kits and teaching resources on the learning process and pedagogical practices. An inherent strength of constructivism in social research lies in its capacity to shape interpretations through inductive reasoning and the comparative examination of diverse experiential accounts [40,41].

While constructivism might grapple with the challenges of subjectivity and its potential to affect the dependability of findings, its focus on depth and the provision of insider perspectives were deemed particularly beneficial for this investigation [42]. To encapsulate the complexities and prospects of maker education, this study aimed for a socially constructed viewpoint, assessing a variety of classroom experiences and expectations against a series of carefully crafted open-ended prompts [36]. The research was orchestrated in several phases: developing the research instruments, selecting a representative sample of participants, and overseeing the administration and compilation of results. Through this approach, the study sought to capture a multifaceted understanding of maker education, integrating the authentic voices and lived experiences of those immersed in its practice.

4.1. Instrument Design

For the qualitative component of this study, a succinct interview instrument was developed, consisting of five open-ended prompts tailored to elicit rich, thematic data within a condensed timeframe of 10–15 min. This strategic focus aligns with Petersen's [40] advocacy for a concentrated approach in small-scale research, enabling a deep dive into specific thematic areas or theoretical constructs to enhance the pertinence and impact of research outcomes. To optimize the effectiveness of these time-efficient interviews while maintaining a panoramic perspective of the subject matter, the questions were crafted to converge on pivotal themes. These prompts were designed to explore the following:

1. Advantages of Maker Projects: To understand the perceived benefits and positive outcomes associated with engaging in maker activities.
2. Disadvantages of Maker Projects: To identify the potential drawbacks, challenges, or limitations encountered within maker education practices.
3. Maker Experience: To gain insights into the participants' personal encounters and the overall impact of maker projects on their learning journey.
4. Classroom Best Practices: To solicit recommendations and insights into effective strategies and approaches that enhance maker-based learning environments.
5. Future Intentions: To gather participants' perspectives on the potential evolution of maker education and their aspirations or plans for future maker activities.

4.2. Sampling Approach

This study honed its lens on the educators and classrooms within the Hong Kong higher education sector. A purposive sampling strategy was engaged to guarantee that the participant feedback was both representative of and relevant to the research question, as well as to maintain comparability among responses [36]. The inclusion criteria were defined to ensure a focused participant pool.

1. Current Educators: Only instructors affiliated with higher education institutions in Hong Kong were considered.
2. Maker Education Experience: Participants were required to have direct, hands-on experience with integrating maker education into their teaching.
3. Availability: Candidates needed to express a willingness to partake in the interview process within a designated 2-week period.

The initial participant target ranged between 15 and 20 educators. However, logistical considerations following consultations with administrators from various higher education institutions necessitated a tailored approach to participant engagement. Outreach efforts

were channeled through emails dispatched to nine institutions, detailing the research aims and soliciting voluntary participation. Further dialogues with departmental faculty, especially within mathematics and science disciplines, uncovered the potential benefits of a peer-referral snowball sampling technique. This method was envisaged as a way to expand the participant base [43,44]. The outcome was a select yet diverse group of individuals representing the broader Hong Kong higher education landscape.

The final assembly of participants comprised eight educators, all versed in the facets of maker education and student mentorship. To accommodate their schedules and preferences, the interviews were conducted remotely using telephone or video conferencing tools such as Zoom or Microsoft Teams. Confidentiality was a cornerstone of the research methodology, with all responses anonymized and personal identifiers removed from the transcripts to uphold ethical standards and ensure the integrity of the research [45,46].

4.3. Analysis of Findings

The examination of the collected data began with the transcription of the interview recordings, rendering the spoken words into a textual format amenable to analysis. Thematic analysis was the chosen method for dissecting the transcriptions, a technique that aligns with Merriam's and Tisdell's [44] qualitative research methodology. This process commenced with line-by-line coding of the data to discern patterns, commonalities, and divergences within the participant responses. During the coding process, recurring motifs were flagged. These frequent themes, which emerged with considerable regularity across the data set, were deemed to encapsulate the collective sentiment or shared experiences of the participant group. Hence, these dominant themes came to symbolize a consensual viewpoint within the cohort [44]. Concurrently, attention was given to outlier sentiments and anomalies in the data. These variations offered a window into the singular experiences of individual educators, providing depth and a broader spectrum of understanding of the implementation and impact of maker education in diverse pedagogical scenarios. The findings from this thematic inquiry are presented in a sequential format. This structure enables a clear delineation of the responses according to the specific interview prompts and allows for a logical unfolding of the emergent themes. By arranging the results in this manner, readers can discern the direct correlation between the questions posed and the ensuing data, thereby facilitating a coherent interpretation of the underlying narratives and insights.

5. Findings and Discussion

5.1. Interview Findings

The crux of this research is anchored in the primary data gathered through interviews with a seasoned cohort of educators adept in the application of maker education within classroom environments. The distilled essence of these interviews is captured in Figure 2, which delineates the core themes that emerged in response to the structured inquiries, and further delineates the subthemes associated with each by the participants. Specifically, the educators' responses to Question 1 (Q1) underscored the salient advantages of maker education, notably the enhancement of student engagement, the amplification of student motivation, and the promotion of creativity. In addressing Question 4 (Q4), the educators articulated the need for increased support, enriched resources, and extended autonomy in their pedagogical roles to ameliorate the educational outcomes through maker education.

The following sections will dissect the educators' perspectives, offering a comprehensive discussion of the implications of their feedback for each posed question, while directly referencing the educators' narratives. This examination will elucidate the ways in which maker education not only elevates student engagement but also catalyzes authentic motivation and creative expression. Furthermore, the educators' advocacy for stronger support structures, a richer repository of resources, and greater pedagogical autonomy will be deliberated upon. The ensuing discussion will critically engage with the congruence of

these findings to the extant body of literature, their broader implications for educational policy-making and practice, and the potential trajectories for future scholarly inquiry.

Advantages	Disadvantages	Experience	Best Practices	Intentions
Engagement	Resources	Complexity	Investment	Change
Motivation	Accessibility	Technology	Support	Commitment
Participation	Knowledge	Investment	Training	Investment
Creativity	Experience	Student Centered	Technology	Students
Problem-Solving	Resistance	Dynamic	Resources	Opportunities
Growth	Systems	Resources	Autonomy	Training
Learning	Priorities	Innovation	Learning	Resources
	Tradition			Support

Figure 2. Core themes and thematic insights.

(Q1) What do you feel are the greatest advantages of maker projects and educational strategies in the classroom?

Major Themes: Engagement, Motivation, Participation, Creativity, Problem-Solving, Growth, Learning

The educator feedback to this question indicated a variety of advantages linked to student learning outcomes and active engagement with the educational process. P8, for example, reflected that *‘the idea of making something, even if only short-term, inspires students, it sparks creative juices that might otherwise be squashed by tradition and procedure’*. Similarly, P2 suggested that *‘it is really about keeping students interested in the content; could they learn about circuit design from a book or online lessons? Of course, but when they touch those connectors and solder those prongs, there is something tangible that emerges’*. This observation of the productive value of active involvement in the acquisition of knowledge is an important insight that links the practical or tacit aspects to the internal and referential aspects. Highlighting maker strategies from a broader institutional perspective, P4 observed that

I think it shifts our priorities away from the narrow bands of curriculum that shackle our wrists and engages students in a new way of thinking, a worldly perspective, a social agenda that links personal success to the creation of something valuable. It is empowering.

This insight suggests that curriculum dependency restricts the accessibility and implementation of maker-based opportunities, potentially undermining the creativity and empowerment of a system that could otherwise reward innovation and diversify problem-solving.

(Q2) What do you feel are the greatest disadvantages or weaknesses of maker projects in the classroom?

Major Themes: Resources, Accessibility, Knowledge, Experience, Resistance, Systems, Priorities, Tradition

Through feedback from these educators, there was one clear inhibitor affecting the realization of a functional maker culture: tradition. P3, for example, indicated that *‘our dependency upon curriculum and traditions that define knowledge outcomes rather than creating functional, productive learners. What are we really teaching kids except to memorise facts and procedures?’* This same limiting effect was extended to an institutional domain when P7 argued, *‘if you don’t have leadership support, then how can you achieve progress; we are restricted in our maker attempts by the rigid structure and goals of our school. The administration must be on board’*. This proposition of support and participation is important, as it makes acquiring what P5 suggested were *‘costly resources and technologies’* a more feasible objective. Further, P2 reflected that without the support of school administrators and institutional managers, *‘there is no way to seamlessly integrate maker culture into the normal science or computer curriculum without displacing some other step or expectation’*. This lack of cohesion between maker culture

and school traditions highlights the systemic gap that P8 cautioned could be viewed as follows:

A complete and utter mess. A lack of cohesion. A breakdown of policies and school systems. There are no standard grading rubrics, there is no expectation or guideline. It is about as close to anarchy as we have gotten, and even then, there would be some kind of target or goal.

Echoing concerns regarding the openness of the school structure and support systems to student maker culture, the feedback suggested that cultural gaps limited the consistent execution of a more dynamic and integrative maker solution.

(Q3) How would you design your ideal maker experience given unlimited resources and time?

Major Themes: Complexity, Technology, Investment, Student Centered, Dynamic, Resources, Innovation

Although there were a variety of responses, the core themes identified within the participant feedback emphasized resources, technology, and innovativeness. For example, P1 indicated that *'I envision a black box classroom with a big problem and almost no assistance to start with; it's a brainstorming tsunami and everyone is drilling down until we have a path, and then we are given all the resources we need to make it happen'*. This idealized version of an adaptive classroom environment was supported by other educators including P3 who envisioned a *'fully stocked maker lab with 3D printers, AI computing, and cloud-based devices to scale our projects to any conceivable level without interruption'*. Further, P5 recommended that *'schools develop some form of empowerment programme that lets students identify a problem or innovation they want to pursue, and then uses robust resources to make it a success'*. Such visions were based on two central needs: resources to achieve the goal and the elimination of barriers (e.g., time, space, and mentors) to achieve this goal. P2 reflected that *'we should be working with cutting-edge corporations and outside mentors to help these students envision a new future; they should see their results in commercial form'*. Ultimately, this form of integrative solution could facilitate a more tangible link between curricular advantages and long-term career-level impacts on student development.

(Q4) What do you feel are the most important objectives or outcomes of a maker-based educational experience?

Major Themes: Investment, Support, Training, Technology, Resources, Learning, Autonomy

The feedback from the participants was subdivided into student and program outcomes, with educational opportunities serving as the primary mechanism of alignment. From a student perspective, P7 reflected that *'I have witnessed significant growth in self-confidence and motivation; kids are just geared towards the maker culture now; it is so different than their traditional classes'*. Similarly, P2 indicated that *'we have students awarded scholarships in technology, rewarded with grants, offered full time careers; it is a maker revolution and a lot of our student body wants to be a part of it'*. From a program perspective, P5 recognized that *'I am witnessing administrative changes and rule-bending that offers new opportunities for education, new collaborations, and really a whole new school culture because of maker opportunities'*. Extending this discussion to reflect on the tangible effects of maker-based education on various opportunities, P1 reported the following observations:

We were siloed, and subdivided into quads, into teacher/student enclaves. Now we are a collective, a community of practice that thinks critically together. We are making waves in the curricular water, and it's bringing us all on board this new raft of creativity and innovation. We are not teaching from a book. We are teaching from experiences.

Such feedback highlights concerns about the lack of coordination in framing maker culture within Hong Kong's educational settings, raising questions about opportunities for reframing creativity as a foundation of the educational system rather than as an afterthought.

(Q5) Do you plan on employing maker learning approaches in your future educational practices? Why or why not?

Major Themes: Commitment, Change, Investment, Support, Students, Opportunities, Resources. Training

The participants' feedback unanimously supported the future of maker culture in educational practices. However, there were variations in the objectives that represented various hurdles within these courses and institutions. P6, for example, reported that *'I would love to continue in a maker context full time; but we have a resource issue and we have a staff issue, how do we keep people like me in place when we lack the funding to support such full time programmes? It's frustrating'*. P8 indicated that *'I think that if the administration was open to it, we could cycle entire classes through Maker courses every semester. We could have different problems or challenges and compare the results across classes. But the structure would have to change. There has to be more opportunities'*. Owing to funding and teacher access hurdles, the goal of full-time maker education is reportedly restricted by various structural limitations. P4 argued that *'not all of our students want to participate in such programmes, but for those who do, there needs to be a creative outlet'*. To realize this objective, however, P3 recognizes that *'I myself and going to need more training; I will need ongoing education in advanced technologies. I have to be able to support my students'*. Similarly, P7 indicated that *'we need to see more advanced training and support. We need high tech resources and need to invest in tools to make functional projects'*. Without such solutions, the burden of innovation becomes a *'remarkable ideal and hope, but a programme that must be driven by investment and engagement at all levels'* (P5). Such insights suggest that all teachers would prefer to engage in maker culture in future educational settings, but are confronted with the realities of resource barriers and systemic hurdles that must be overcome to make such creative solutions a reality in the future.

5.2. Discussion

The trajectory of maker education in academic settings is intimately entwined with the evolution of technology and the provision of resources that revitalize educational frameworks, curricula, and the mechanisms of student learning. Insights gleaned from the interviewed educators identify a confluence of pivotal strengths that bridge maker pedagogy with impactful, student-oriented learning outcomes. Initially, a motivational thrust was discernible; educators reported a notable surge in student creativity, sustained involvement in classroom endeavors, collaborative processes, and teamwork. This motivational aspect is a critical driver in the active engagement and participation that maker education fosters. Furthermore, the informant teachers discerned a developmental axis, wherein maker culture and curricular integration foster a vibrant and constructive personal and academic identity, undergirded by the mastery of pertinent skills and knowledge. The assimilation of tacit knowledge via experiential learning is posited to contribute to enhanced communal engagement, invigorate motivation for continuous learning, and bolster long-term professional growth, as outlined in the literature [19]. When contextualized within specific domains or educational goals, such as mechanical engineering and systems design, the research of Chou [13] corroborates that maker-oriented pedagogical approaches exert a more profound influence on student learning trajectories in contrast to conventional educational methodologies and non-maker counterparts. The affirming testimonies of educators within this study echo these findings, substantiating the promise of heightened engagement and fostering a culture of innovation and creativity within the academic institutions of Hong Kong.

While the integration of maker culture within educational settings presents numerous benefits, educators frequently encounter challenges when attempting to navigate and transform traditional policy- and procedure-centric systems. These systems are often entrenched in established practices that can impede the adoption of innovative pedagogical approaches. Lundberg and Rasmussen [4] contend that educators in technologically advanced learning environments must embrace a departure from didactic teaching models, which merely

inform students about the world, towards methodologies that actively engage students in creative and practical problem solving. This paradigm shift aligns with the contemporary ideal of fostering creative and adaptive problem-solving skills, a skill set poorly served by the inflexibility and narrow focus of many existing curricular frameworks. In support of this shift, Santo et al. [8] emphasize, as do the educators participating in this study, that institutional support is a critical precursor to the successful implementation of maker education. The provision of dedicated resources, including specially designed makerspaces, mobile maker carts, and a variety of materials, is essential and should be made readily available to educators at no extra cost to encourage their adoption and integration into teaching practices. Such support is integral not only for the facilitation of maker activities but also for empowering teachers to personalize and enhance the educational experience, thereby maximizing the potential for student engagement and learning.

Despite the recognized advantages of maker education, disparities in resource allocation present significant impediments. Hsu et al. [5] highlight that the uneven distribution of resources across educational institutions leads to a lack of necessary makerspaces, which are critical for facilitating immersive and experiential learning opportunities. The educators consulted in this study echo these concerns, noting resistance from school administrators towards adopting new and emergent technologies. The apprehensions surrounding the costs and perceived disruptive nature of such technologies are often seen as potential threats to the stability and long-term objectives of educational systems. As educational models progressively shift towards hybrid formats, the virtualization of resources and the incorporation of digital and VR technologies are poised to play a transformative role in shaping student learning outcomes and experiences. The integration of VR into education has the potential to foster a highly interactive and student-centered approach to problem solving [32]. This is further supported by the assertion that goal setting and reflective learning strategies within VR environments can significantly influence learners' behavior and motivation [47,48]. LBM allows students to become actively engaged in the creation and resolution of problems, fostering collaborative discourse and a deeper investment in complex learning processes [26]. The impact of such active participation extends beyond the immediate learning task, contributing to an enriched knowledge base and a more profound understanding of the subject matter. The future of maker education, therefore, hinges not only on the availability of physical spaces and tools but also on the strategic implementation of virtual resources and technologies that support a dynamic and adaptive learning ecosystem.

The integration of maker culture into pedagogy presents an experiential challenge—a skills gap that educators find difficult to bridge without adequate support. This gap is particularly evident in the competencies required to effectively orchestrate group-learning experiences and to inspire students to craft impactful solutions through collaborative efforts. The skills necessary to facilitate these experiences include guiding information exchange and fostering productive dialogue among teams. The research conducted by Lock et al. [15] and Shin et al. [18] underscores the importance of brainstorming and group-based experimentation within maker initiatives, highlighting the delicate balance between individual skills and the collective strengths of teamwork. These studies suggest that when teams are underpinned by a shared metacognitive belief in their capacity to succeed, the intentional and constructive sharing of knowledge within maker-based projects can lead to significant improvements in student performance and knowledge acquisition [23,25]. To harness the full potential of maker education, it is essential that educators are equipped not only with resources but also with strategies to develop key competencies among their students. These competencies include the following:

1. **Metacognition:** The ability to reflect on one's own thinking processes and learning strategies.
2. **Technological Literacy:** Proficiency in using and understanding the technology integral to maker activities.

3. Collaborative Negotiation: Skills in managing group dynamics and encouraging equitable participation.
4. Iterative Design: The capacity to prototype, test, and refine projects in a cyclical learning process.

Supporting educators in these areas will empower them to guide student learning and maximize the educational benefits of maker courses more effectively. Professional development opportunities, resources for classroom implementation, and systemic encouragement for innovative teaching methods are all necessary to bridge the skills gap and promote a thriving maker culture within educational settings. While education is crucial for enhancing digital capabilities, it is not the sole avenue, as preventative actions and judicious policy decisions also play equally important roles in driving progress in digital skills development [47]. Developing digital literacy extends beyond conventional educational frameworks; it requires a comprehensive ecosystem that supports learning. By integrating preventative measures alongside policies that promote access to technology and encourage innovation, maker education can be a powerful conduit for comprehensive digital skill acquisition.

The creation of new educational materials tailored for Internet use and their integration into current curricular offerings is a pivotal step towards enhancing information and strategic skills across disciplines. When such development is woven into the fabric of existing subjects—language, history, biology, geography, and others—it not only fosters improvement in these areas but also potentially increases teacher engagement [48]. The rationale is that by embedding digital literacy within the context of familiar subjects, educators may find it more relevant and less burdensome to incorporate into their teaching routines. This relevance is likely to motivate teachers to dedicate the necessary time and effort to effectively implement these resources, thereby enriching the learning experience with skills pertinent to the digital age. This strategy aligns well with maker education, as it supports the incorporation of digital tools and thinking into a variety of learning contexts, encouraging both educators and students to engage with technology creatively and critically.

The technological advancements that form the bedrock of the information society elevate the importance of strategic skills [49]. As technology evolves, it necessitates not just the ability to operate tools and access information but also the capacity for strategic thinking, which includes planning, problem solving, and decision-making in digital contexts. These skills enable individuals to anticipate future trends, adapt to new technological shifts, and harness information in ways that lead to informed and effective action. In essence, strategic skills are becoming essential for navigating the complexity and dynamism inherent in the information society. Furthermore, universities and teachers are encouraged to engage directly with students, moving beyond merely supplying online educational resources. There is a pressing need for methodologies that emphasize the creative and collaborative use of Information and Communication Technologies (ICTs) to augment traditional teaching methods [50]. In harmony with this, recent research highlights a student-driven demand for greater autonomy in the learning process, gravitating towards educational approaches that prioritize student-led activities along with increased interaction and participation [51]. This shift is further reinforced by an advocacy for 'digital learning options' [51], integral to modernizing curricula and fostering an ICT-enriched environment that resonates with the digitally native student population.

6. Concluding Remarks and Recommendations

As educational methodologies progressively shift towards more immersive paradigms, the developmental benefits of maker education are increasingly celebrated for their potential to foster engagement and learning through hands-on practice. The central objective of this study was to perform a critical analysis of maker education's role in contemporary classrooms, examining the architecture and efficacy of novel pedagogical approaches in relation to student learning outcomes and broader educational opportunities. This in-

vestigation commenced with a detailed scrutiny of the existing literature, leading to the establishment of a comprehensive conceptual framework that elucidates the motivations and challenges intrinsic to the maker education movement. Following this theoretical foundation, the study proceeded with an empirical assessment of educators' experiences, aiming to distill potential best practices and strategies poised to enhance learning outcomes within future maker-based educational settings.

The primary aim of this study was to evaluate the extant literature concerning the integration of maker culture in educational milieus. Central to the discourse in these works is the valorization of creativity and innovation as a means to revolutionize pedagogy, thus empowering educators and learners to embrace novel learning modalities. In stark contrast, conventional educational frameworks are predominantly guided by standards and curricular mandates, which constrict pedagogical fluidity to the confines of quantifiable performance metrics. Maker culture, with its ethos of celebrating both high achievement and the instructive value of failure, presents a paradigm where learning is synonymous with the iterative process of creation and skill refinement. The inherent dissonance lies in the reliance on an education system that predicates student assessment on static and stringent performance criteria. Such a binary pass–fail schema is antithetical to the essence of creative and innovative endeavors. The educator testimonies within this study have underscored this tension as a contentious vestige of traditional educational doctrine.

The second aim was to construct a conceptual framework encapsulating the core objectives and aspirations of maker education initiatives. The synthesis of the literature in this domain yielded the GEARS acronym, delineating the Goals, Enablers, Activators, Recognition, and Solutions within the context of maker education. This conceptual model is versatile, relevant across diverse educational frameworks and classroom scenarios, leveraging insights from both students and educators to foster creative and innovative learning experiences.

The third aim was to undertake an empirical investigation into teachers' experiences with the integration of maker culture in educational settings. The data gathered from participants underscored the significance of foundational elements such as communities of practice, mentorship, and the provision of sufficient resources. These components emerged as pivotal precursors for the successful infusion of maker culture into educational infrastructures. In light of these insights, the trajectory of educational practices can be depicted as a positive, iterative progression within the discipline, with a concerted emphasis on devising practical responses to a ubiquitous challenge—the enhancement of meaningful learning experiences. Despite the clarity of these accounts, advocating for students' fervor and proactive involvement in areas such as robotics and sustainable energy innovation is not without its difficulties. Nonetheless, it is imperative that educational systems evolve to acknowledge and bolster the accomplishments inherent in such vibrant makerspaces.

This research confronts the intricate issue of discerning the prospects and constraints of maker education within the higher education landscape of Hong Kong, examining the strategies educators employ to overcome obstacles in the implementation of these methods for inventive classroom practices. The study's scope and its conclusions may be circumscribed by the limited number of teaching professionals involved and the extent of the questionnaire deployed to collect their insights. Furthermore, this inquiry is contextualized within the unique educational ecosystem of Hong Kong's higher education sector, an amalgam of institutions, each with distinct expectations and standards regarding the adoption of maker culture and its educational integration. To augment the robustness of future research, a balanced analysis of both educator and student viewpoints is essential to acquire a holistic picture of how maker culture is experienced and managed in interactive educational contexts. Moreover, comparative assessments of educational programs are suggested to unearth the specific knowledge and technological hurdles that influence teacher development and instructional methodologies in their quest to embrace and enhance the standard of maker education.

Education should pivot towards empowering students to be architects of their ideas utilizing technology. This approach fosters a deeper understanding and mastery over digital tools, transforming students from passive consumers into active creators and innovators in the technological landscape [52]. In observing the evolving landscape of higher education, it becomes evident that universities are undergoing a transformative shift to better equip students with essential e-skills, mirroring the collaborative and flexible practices of the modern workplace [53]. The integration of information technology within the university structure is not just beneficial but imperative for the cultivation of these skills from the onset of a student's academic journey. The barriers to technology access are steadily being dismantled by targeted public policies and the natural progression of market and technological advancements, clearing the path for a more inclusive digital learning environment. This evolution necessitates a pedagogical pivot towards learner-centered education, a move that must be carefully implemented and critically assessed within the academic sphere. As students increasingly take the reins of their education through autonomous exploration of digital resources, the role of educators is simultaneously shifting. This new dynamic calls for a reimagining of teacher training programs to embrace and enhance the informal learning processes that students are naturally gravitating towards. By adapting teacher curricula to include the facilitation of informal e-learning, we can harness the full potential of students' independent endeavors and shape a more resilient, skill-equipped generation of learners.

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