Circular Synergy City: Designing an Online Board Game to Foster Collaboration in the Circular Economy

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ABSTRACT

Makerspaces have emerged as potential facilitators of the transition from the linear economic model to a circular economy (CE). This transition necessitates collaboration among diverse stakeholders to create sustainable, yet resilient systems. However, fostering effective collaboration faces numerous barriers, including misaligned interests, competition dynamics, limited knowledge experience, power asymmetry, and lack of trust. Our paper addresses these challenges and proposes an alternative tool for fostering collaboration: an online board game called Circular Synergy City. Unlike existing games, Circular Synergy City focuses on collaboration, allowing players to interact, negotiate, and plan with each other to explore potential synergies. We tested this game with 160 players in two play sessions. Based on the feedback gathered during these sessions, we present recommendations for developing collaboration-focused content, and board games.

CCS CONCEPTS

• **Applied computing** → *Collaborative learning*; • **Human-centered computing** → *HCI design and evaluation methods.*

KEYWORDS

Game-based learning, Board game, Collaboration

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1 INTRODUCTION

The circular economy (CE) requires transitioning from the linear economic model of raw material extraction, production, use, and disposal to closed-loop systems prioritizing resource recovery, reuse, and regeneration [26]. At its core, this transition thrives on collaboration among various stakeholders [32]—ranging from designers and engineers to policymakers and consumers—who must join forces to create sustainable, resilient systems that minimize environmental impact and maximize resource value.

Fostering collaboration among these diverse stakeholders in CE is challenging. Barriers against fruitful collaboration include the difficulty finding the right collaborator [40], misaligned interests among stakeholders [8, 37, 42], the emphasis of competition over collaboration [1, 27, 29], limited knowledge/experience [37], lack of power asymmetry [1, 30], lack of trust [6, 38], and so on. In addressing these multifaceted barriers, it becomes evident that fostering effective collaboration in the context of CE necessitates concerted efforts to overcome challenges related to aligning interests, highlighting the value of collaboration to competition dynamics, knowledge-sharing, power dynamics, and trust-building among stakeholders.

Recently, makerspaces have been promoted as initiatives that could facilitate the transition to CE [17, 22, 45], by performing circular activities such as reusing, repairing, refurbishing, and recycling, and by engaging citizens in CE through these activities. Although makerspaces are established based on cultivating collaboration [39], fostering and maintaining a collaborative environment is still challenging [21]. Even though makers constitute a community with shared values, there are barriers to effective collaboration. For instance, Bakırlıoğlu et al. [2], found that makers are usually not aware of each other's activities as they tend to focus more on their individual projects and that although collaborative projects emerge within the maker movement, they originate from chance encounters rather than from structured endeavors that facilitate the recognition of gaps and opportunities in local circular loops.

Collaboration among circular makers and relevant stakeholders can be nurtured via diverse channels. Creative collaboration platforms like the European Circular Economy Stakeholder Platform facilitate the sharing of ideas and resources and enable collaboration on mutually beneficial projects [44]. Open source design repositories such as Thingiverse [52] allow the sharing of circular economy

designs, blueprints, and prototypes, helping makers to build upon each other's work. Hackathons and maker challenges like Circular Economy Hackathon [28] bring together makers to tackle specific CE challenges or develop innovative solutions, creating a sense of community, sparking creativity, and leading to new collaborations. Circular economy festivals and conferences like Circular Republic Festival connect makers with industry professionals, investors, and policymakers, facilitate knowledge exchange, showcase successful projects, and build partnerships.

These channels are all valuable for fostering a collaborative environment. However, they do not allow makers to initiate collaboration among various stakeholders at the city scale and create resilient local circular economies. This remains a challenge due to, among other reasons, a lack of ability to find and connect with appropriate collaborators with complementary knowledge, skills, and resources [4], as well as a lack of recognition of the possible lasting forms of collaboration and co-production [2].

In this paper, we contribute to these channels by offering an alternative tool for fostering collaboration among *local* maker ecosystems, i.e., an online board game called Circular Synergy City. Although there have been previous efforts to use games to foster collaboration or to encourage a circular economy mindset (e.g., RickRace, EcoCEO, In the Loop), our game differs from these through its focus on collaboration over competition. Circular Synergy City encourages interacting, negotiating, and planning with other players to explore potential synergies rather than defeating them. The game dynamics of Circular Synergy City are designed to support this aim: the more players collaborate with each other, the more points they get. Furthermore, unlike games providing mostly static and generic content, players can adapt the game board to their local city. Our second contribution to the literature is the suggestions for developing collaboration-focused content and board games for CE based on insights gathered through two separate play sessions with 160 players.

2 RELATED WORK

In this section, we will reflect on the existing circular economy literature focusing on collaborative and distributed production, existing board games for collaboration, and circular economies in the literature highlighting the gap.

2.1 Paths to Circular Economy

Circular Economy is considered a prerequisite among many other interconnected approaches [3]. The literature emphasizes the importance of localized production and value recapture (e.g., repair, reuse, refurbishment, remanufacturing, recycling) in transitioning towards a sustainable society [20]. When coupled with global knowledge exchange, localized practices can produce global designs tailored to meet local and individual needs, preferences, and desires [46]. As supply chains narrow and slow, local secondary resources are consumed closer to the production side, reducing the effect of global supply chains in terms of transport and extending the lifespan of products [25]. Digital desktop fabrication technologies and the emergence of a maker community across the Globe demonstrate how technology accessibility, high-fidelity fabrication possibilities, and international knowledge exchange can contribute to local, on-demand fabrication of tailored designs that meet local requirements [34]. Hence, the maker movement and the design, production, and post-use practices they espoused present great potential for CE [20]. This potential can materialize through collaborative, diffuse production, which poses several barriers to its implementation. Here in this section, we will discuss why collaborative and distributed production is important and need special attention in novel ways for fostering collaboration.

Collaborative production is a form of innovation that involves bringing together diverse individuals and groups to share their knowledge, resources, and skills to create novel solutions. It can occur in different spaces, online, offline, or hybrid, such as at fab labs, online communities, or open design platforms. These spaces enable access, socialization, and learning for participants, as well as foster distributed fabrication and alternative business models. Utilizing convergence and generativity to combine disciplinary knowledge, socialization and collaborative learning to develop new practices, Caccamo [12] conceptualizes the potential impact of innovation spaces on collaborative innovation. Additionally, fab labs are perceived as a means for democratizing innovation because they are easily accessible (i.e. open access). In addition to fostering collaboration, these facilities provide the necessary infrastructure for enabling individuals to pursue projects based on their needs and preferences [7, 41]. Due to the proximity of its users, such spaces can facilitate knowledge exchange and collaboration among their users [50]. The creation of such spaces also democratizes innovation processes for disadvantaged do-it-yourselves and entrepreneurs, as they promote interaction among all of the participants and provide resources they need to pursue their goals [47]. In such places, alternative forms of collaboration can emerge consistent with the implications of the democratization of innovation [10].

However, collaborative production also faces several barriers and challenges[43], such as the lack of support for entrepreneurship, local development, and diversity in some spaces, the exploitation of the participants' efforts by corporate or external actors, and the physical-digital divide that hinders the quality, replicability, and scalability of the outcomes. In such places, Vinodrai et al. [53] emphasize the lack of training and infrastructure that could support entrepreneurship. Particularly in the Global North, these spaces are becoming more prevalent. While such spaces can espouse innovative forms of collaboration, they may be disjointed from local economic development programs supporting local entrepreneurs. Diverse groups of people may not be engaged in such spaces because they do not necessarily develop and implement strategies or programs. Community members can come from various backgrounds, including different disciplines, and create interdisciplinary collaboration processes. According to Bonvoisin et al., [9], social interaction analysis of open-source innovation communities suggests that such communities are not attracting the right number of people to successfully proceed with design and product development of shared ideas. As illustrated by Coelho et al. [16], there is a large number of ideas shared in online design communities that are not further developed by the community and remain undeveloped.

Moreover, collaborative production requires effective documentation, standardization, and governance of the design knowledge and data, as well as the communities and processes involved. These

factors affect the collaboration potential and the innovation impact of collaborative production. Open-source design and hardware projects suffer from a physical-digital divide mainly because there is little documentation, or rather because the participants of OSH projects aren't motivated to document their processes and outcomes in a way that allows for replication or further iteration [18]. It becomes increasingly difficult to manage or govern communities horizontally when they advocate open-ended processes rather than project- or product-oriented processes [5]. In contrast to the potential for and barriers against alternative forms of collaboration enabled by shared spaces (online and offline) and democratizing innovations, this definition adopts a straightforward stance based on a project-oriented approach. It describes a process that ends with certain outcomes.

Kumar et al. [35] introduce various strategies for mass producers in distributed manufacturing settings such as small-scale distributed, in-house decoupled, and outsourced decoupled manufacturing. These strategies depict highly specialized production nodes and external collaborators while focal firms retain value-added processes and sales channels. These strategies are similar to decentralized production and do not reveal much about active users or prosumers/makers/DIY-ers that create value for themselves. Nonetheless, such distributed processes present various opportunities, especially when local actors are engaged in them. Distributed production especially with active, local production networks can respond to global trends or barriers more easily thanks to shorter and more responsive supply chains [23]. Such scenarios require very small, local production units collaborating in shorter supply chains and undertaking peer production.

As we argue in this paper, collaborative production should involve diffuse collaborations, which would facilitate widespread distributed production/fabrication and present alternative business models to overcome the barriers stemming from the physicality of outcomes to initiate and sustain local circular economies. In this case, another barrier to collaborative and distributed production is the difficulty of finding and connecting with suitable collaborators who have complementary knowledge, skills, and resources. This can limit the diversity and quality of the inputs and outputs of the collaborative process. Moreover, some forms of collaboration may not be recognized or valued by the existing institutions, markets, or norms, which can discourage the participants from engaging in long-term or sustainable co-production.

2.2 Board games for collaboration and circular economies

While such conceptualizations of distributed production and local circular economies are widely discussed in the literature, the challenges of finding and connecting with appropriate collaborators with complementing knowledge, skills, and resources [4] and the lack of recognition in the possible, lasting forms of collaboration and co-production [2] remain major barriers to their implementation in real life. Innovating circular business models operating at the local scale and as part of distributed networks is a complex and dynamic process that requires various competencies and skills, but even more importantly, a recognition of the potential of collaborative production at the local scale in initiating and sustaining these business models.

Games can help alleviate these challenges by enabling local designers, makers, and SMEs to co-design circular value propositions that benefit from the skills and capabilities of collaborating stakeholders [51]. Previously, scholars and practitioners have developed various games that aim to trigger the creativity of university students, practitioners, and entrepreneurs in developing alternative circular business models and products. At the product design level, these involve games like Eco Designer [19] that focus on conceptualizing the product with the lowest environmental impact. At the business model level, there are games on developing circular business models, such as Circula [15], reducing or minimizing the environmental impact of companies, such as EcoCEO [54] and the Blue Connection [31], or understanding the financial implications of adopting circular business models, such as Risk and Race [48]. There are also games about understanding the global material flows and their impact on the environment, such as In the Loop. Nonetheless, there is only a small number of games that consider sustainability at the city scale, such as Life on Wings [49], which looks at urbanization and its impact on habitat loss. The rest of the games tend to focus on either technical aspects (e.g., the environmental impact of a product or a company) or business model development but disregard the role of collaboration in creating circular offerings [51], let alone local and regional collaborative production, local circular economies, variations among different localities, varying roles of collaborating stakeholders or alternative forms of collaboration.

In this paper, we contribute to this line of work by a new online board game, Circular Synergy City. The design rationale for this board game is rooted in the findings and observations presented in the literature, particularly the work of Selvefors et al. [51]. In contrast to the competitive focus in relevant board games found in the literature, our game emphasizes collaboration. This approach reflects how makerspaces benefit from working together on circular activities and projects. By doing so, our game fosters a sense of community and shared goals, encouraging players to work together rather than against each other. Previous games have explored the possibilities that games hold for CE and collaborative production. However, the predominant focus has been on raising awareness around the concept of sustainability. Acknowledging that people may have a basic understanding of circular goals and practices, our game goes a step further. It aims to expand players' imagination regarding the range of possible circular activities and projects. This approach directly responds to the literature's emphasis on awareness-raising, extending it to help players envision practical applications of CE principles. This aligns with the literature's call for games that go beyond mere knowledge dissemination to facilitate a more hands-on understanding of circular economies [51].

3 THE GAME: CIRCULAR SYNERGY CITY

In this section, we first share the iterative game design process1, influenced by ongoing feedback from playtest sessions, incorporating insights from players. This process illustrates how it gradually

evolved through its various iterations and then describes its fundamental game mechanics to lay the groundwork for understanding our design objectives and methodology.

Circular Synergy City is a turn-based strategy game designed to immerse players in circular economy and collaboration. Players build and manage circular makerspaces within a simulated city environment. They increase their resources and get points when collaborating with other makerspaces by executing circular projects. Each circular project requires skills, supplies, equipment, and assets, necessitating strategic partnerships among different makerspaces. The game board represents a city divided into various regions. Each region houses spots for makerspaces, markets for buying supplies and equipment, and other specialized zones. The board's layout plays a role in the strategy, as players must navigate different areas to gather resources, collaborate, and execute projects.

3.1 Motivation and Design Process

This board game was designed within the scope of the Pop-Machina Horizon 2020 project to respond to a challenge identified during its early stages. The project seeks to highlight and reinforce the links between the maker movement and circular economy to promote environmental sustainability and generate socio-economic benefits in European cities. Within the scope of this project, seven circular makerspaces, as distributed fabrication areas where makers engage in circular-making activities to contribute to cities' circular economy transition, were established in seven European cities. During the project, a common challenge identified was the difficulty in finding collaborators and creating collaborations between makers in the local context, which mostly stemmed from a lack of awareness of other makers' and makerspaces capabilities and/or how different capabilities of different makers can contribute to different projects or activities on circular economy. Establishing makerspaces within the project cities was a crucial step; however, these spaces faced challenges in conducting circular activities and participant engagement. Despite numerous potential collaborators, realizing effective synergies and partnerships proved challenging.

These obstacles within Pop-Machina significantly influenced the conception of our game. The game is informed by both the literature on circular economies, as summarized in the background section, and the practical experiences derived during the project. It incorporates activities that mirror those of real-world makerspaces, thereby grounding the gameplay in the realities of the maker movement and circular economic practices.

3.2 Game Features

The game's structure and content draw from the project's framework. The skills in the game involve various themes central to circular economies, such as resource management, sharing, redesigning, reusing, reducing, refurbishing, and recycling. Furthermore, we involved core CE values like urban development, production, sustainability, and social cohesion alongside essential maker skills, including learning, innovating, sharing, making, and connecting. The selection of activities for the game cards was inspired by the actual plans co-developed with stakeholders (researchers, decision-makers, makers) and makers in each participating city. These activities were part of the pilot initiatives conducted by the makerspaces. Additionally, the depiction of equipment and supplies within the game mirrors the real procurements made for the makerspaces, providing players with a tangible connection to the practical aspects of maker activities and circular economy strategies. With this approach, we aimed to ensure that the game not only serves as an engaging educational tool but also reflects collaborative and sustainable practices within the maker community and beyond. Next, we explain the reasoning behind game features and changes made during the three versions (Fig 1).

3.3 Game Elements and Assets

The game features the following elements and assets: City Map, Makerspace Boards, Circular Points, Skill Points, Pops (Game Money), Project Cards, Skill Cards, Asset Cards, and Life Dice. These assets and how they work are explained in Fig 1. In its initial conception (Version 0), the city map was designed to represent the game city with landmarks that help gamers to locate themselves and game places about the actual city's geographical locations and distances(Fig 2). Creating such a city map as the 'board' was critical to recognising and communicating the situated challenges embedded in the local contexts. Representing geographical features and urban design elements, as well as the challenges stemming from these, was crucial to espouse a situated understanding of barriers in establishing and sustaining distributed networks of local circular economies. Accordingly, for Version 1, travel zones were added to the map to reflect a realistic sense of distance and required resources. We believe such representative maps for different cities should be created for different cities, reflecting their unique challenges and opportunities. Another change made was the addition of circular points to calculate the points awarded upon completing each successful circular project. These points were added to ensure that the actual rationale of the game, i.e. local circular economies, is properly communicated to players. These points are critical for finishing the game. For Version 2, a final edit for the game elements has included life dice, which represent the chance factor in the game, adding beneficial gains or challenges while working on a project. The life dice is a crucial addition as it represents the challenges that can be faced by makers and makerspaces that are largely operating on limited resources as well as the opportunities that emerge out of their control, but they can take advantage of due to their flexible structure.

Collaboration is the central theme of the game, considering that it emerged as one of the main challenges in establishing and sustaining distributed networks of local circular economies in the Pop-Machina project. Players must work together, combining their skills, knowledge, and foci, categorized as Circular Economy Strategies, Values, and Maker Skills (Fig 3-a), as well as resources to complete projects. These collaborations are not only necessary for progressing in the game but also for earning Circular Points, the most valuable points in the game. These points are awarded upon completing circular projects and are critical for winning the game. Each player or team manages a makerspace, which serves as their base of operations. The makerspace is equipped with a limited number of equipment (Fig 3-b) and infrastructure (Fig 3-c) cards, vital for undertaking projects. The decision to limit their numbers aimed to reflect the material realities of makerspaces in

Circular Synergy City Features	Version 0	Version 1	Version 2
Elements/Assets			
City Map	Representational city maps with **various landmarks**, so that gamers can identify the key geographical areas.	Representational city maps with **various landmarks, with travel zones** identified to reflect the commute/travel resources required.	Representational city maps with **various landmarks, travel zones**, and **resources/skill acquisition destinations** clearly identified.
Makerspace Boards	Boards for each team representing key aspects of makerspaces, such as **points (Circular and Skill Points and Pops), acquired skills, available resources and equipment, and projects archive.**		
Circular Points		Points awarded upon the completion of **circular projects** and are critical for winning the game.	
Skill Points	Points required to **acquire various skills**. Awarded upon project completion.		
Pops (Game Money)	Points representing **monetary resources**. Required to acquire various assets. Awarded upon project completion.		
Project Cards	**Collaborative project depictions** identifying the required skills, assets, and awards to carry out the project. There are four categories of projects: Makerspace, High-Tech, Organic, Low-Tech.		Added final cards to each category with **more awards** and added the Textile Category.
Skill Cards	Represent the **skills required to carry out projects**. There are three categories: Maker Skills, Circular Economy Strategies, and Values.		
Asset Cards	Represent the **assets required to carry out projects**. There are four categories: Equipment, Infrastructure, Wares, and Supplies. Each asset type has different limitations.		
Life Dice			Represents the **chance factors**, with beneficial gains or challenges towards doing projects.
Mechanics			
Turn-based game	Each team can initiate a collaboration in each turn.		
Passing Turns	Teams can pass turns if they cannot initiate a project.		
Travel zone fees		Teams collaborating across different travel zones need to pay a travel zone fee for project completion.	Teams can acquire skills and assets in defined locations on the city map and need to pay a travel zone fee for acquisition.
Random Events			Teams will be presented with random opportunities or challenges in project completion.
Gameplay			
Limited skills and assets per team at the start	Reflects the capacities of makerspaces. Primes teams to collaborate with other teams to carry out projects. Represent the skills required to carry out projects. There are three categories: Maker Skills, Circular Economy Strategies, and Values.		
Collaboration with more than one other team.	Two teams may not have enough skills or assets to undertake more complex projects, so teams can collaborate to satisfy the criteria. Reflects the potential of diffuse collaborations in urban environments.		
Negotiation on how to split project outcomes		The project awards are split between collaborating teams for each project.	

Figure 1: Comparative overview of features in Circular Synergy City Game Versions 0, 1, and 2. This table delineates the progressive introduction and enhancement of elements, assets, and gameplay mechanics across three versions of the game, illustrating the evolution of game complexity and player engagement strategies.

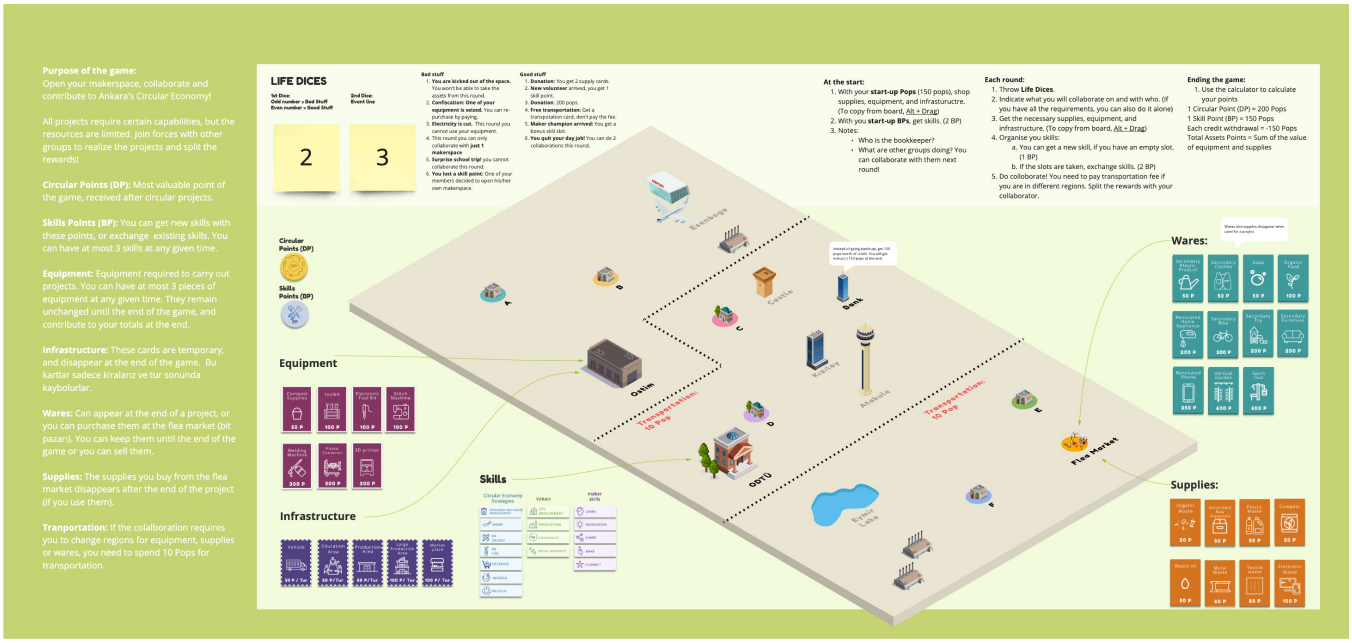


Figure 2: City Map: Representational city maps with various landmarks, travel zones and resources/skill acquisition destinations clearly identified.

general, which tend to operate as small fabrication units run by a limited number of people, with limited funds, and in limited spaces. The equipment, which is capped at three pieces per player, plays a crucial role in determining the success of these projects. Infrastructure cards, on the other hand, offer temporary benefits and disappear at the end of the round, thus requiring strategic planning for optimal use. These cards represent additional specialist services or spaces that are present in the urban structure and can be leased by the makerspaces when necessary. Wares (Fig 3-d) and Supplies (Fig 3-e) are additional resources in the game. They can be acquired either through the successful completion of projects or purchased outright. However, these resources are consumed once used in a project, adding an element of resource management to the gameplay. Transportation is another key aspect, especially for collaborations across different city regions. Players need to spend Pop for transportation when engaging in inter-regional collaborations, which adds a layer of strategic financial planning.

3.4 Game Mechanics

Circular Synergy City is a *turn-based* game. Players or teams initiate collaboration when it's their turn. Teams can choose to *pass turns* if they cannot initiate a project. In Version 2, we added *a travel zone fee* for collaborating teams that are located in different zones of the city to meet a real-life challenge. This was added to reflect the additional costs of collaborating across distances in urban environments. Another type of travel zone fee has been introduced: travel zone fees for assets/skills acquisition. Teams can acquire skills and assets in defined locations on the city map, but they need to pay a travel zone fee for this acquisition task. Another game mechanic is the *random events* that take place at each turn after the *life-dice* throw. These random events involved opportunities or challenges and were added to reflect real-life events affecting collaboration and project completion.

3.4.1 Start of the Game. Players start the game with a set amount of in-game currency, known as Pop, and two skill points. These skill points are crucial as they allow players to acquire skills necessary for completing various circular economy projects.

3.4.2 Turns. To introduce unpredictability and excitement, the game features a life-dice mechanic. At the beginning of each turn, players roll the dice to determine random events ranging from beneficial gains like extra resources or skill points to challenges that may hinder their progress, such as confiscation of equipment or limitations on collaboration.

Each makerspace selects a project (e.g. "Electronic Waste Collection) to undertake and identifies one or more other makerspaces (i.e. another team) to collaborate with. The complexity and difficulty of these projects escalate progressively within each category. This increasing difficulty necessitates acquiring additional resources and skills and choosing suitable partners. Upon successfully completing a project, the involved makerspaces place the project card in their designated "Collaborations" area. This not only signifies the completion of the project but also triggers the distribution of rewards. These rewards include 'pops', circular points, skill points, and supplies. An integral part of the game dynamics is the negotiation and bargaining process among collaborators. This process determines the distribution of these rewards, reflecting each participant's contribution to the collective effort.

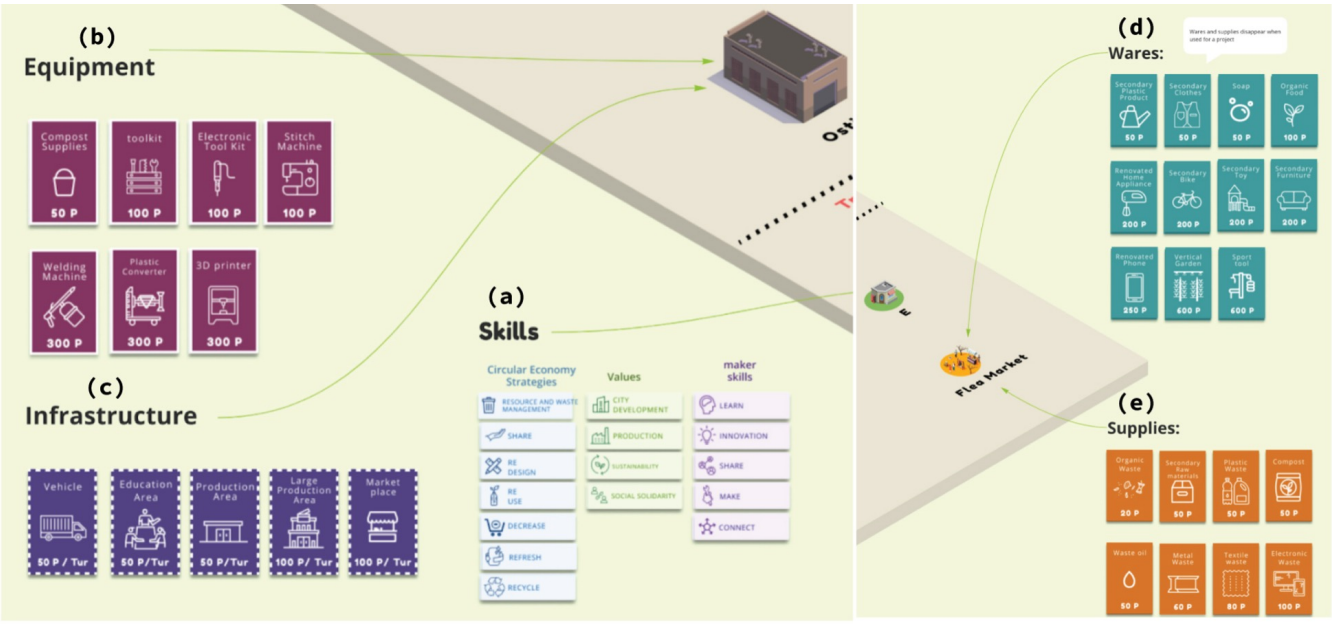


Figure 3: Game elements: (a) Skills: Circular Economy Strategies, Values, and Maker Skills; (b) Equipment and (c) infrastructure needed to run projects; (d) Wares and (e) Supplies which can be acquired through successful project completion or purchased with Pops.

The project cards (Fig 4) are categorized into five distinct areas, each representing different aspects of a circular economy and requiring unique strategies and collaborations. The design of these activities draws inspiration from the pilot activity plans of established makerspaces as part of the Pop-Machina Project.

- **Makerspace:** Transportation of Materials, Makerspace Maintenance, Circular Project Presentations, Maker Skills Training, and Utilizing Unused Spaces.
- **High Tech:** Electronic Waste Collection, Phone Refurbishment, Home Appliance Repair Party, Dismantling Electronic Waste, Building a Vertical Garden System, and Creating Energy-Producing Exercise Equipment from Waste.
- **Organic:** Organic Waste Collection, Bokashi Composting, Organic Food Production, Organic Food Production in Vertical Gardens, Soap Production from Waste Oil, Food Market, and Neighborhood Pantry.
- **Low Tech:** Secondary Raw Material Collection, Furniture from Waste Materials, Furniture Restoration, Products from Waste Plastic, Playground from Waste Materials, Plastic Sheets from Waste, Bicycles from Metal Waste, and Custom Bicycles for Special Needs.
- **Textile:** Minimalism Training, Textile Waste Collection and Cleaning, New Clothes from Textile Waste, Fashion Design Workshop, Swap Market, and Second-Hand Market.

3.4.3 Ending the Game. The game concludes when a player successfully accumulates six circular points (equals 2-3 rounds), marking the achievement of the primary victory condition. Alternatively, players can choose the length of their gameplay, with each set of 2-3 rounds approximately equating to 1 hour of playtime. The final score of each player or team is calculated by adding up their accumulated Pops, the value of their remaining assets, and their earned points. Specifically, one Circular Point (DP) is equivalent to 200 Pops, whereas one Skill Point (BP) corresponds to 150 Pops (Fig 5). Additionally, each instance of credit withdrawal from the bank incurs a deduction of 150 Pops. The player or team with the highest score is declared the winner. After the game, players are encouraged to discuss strategies and insights gained about local collaboration and circular economy, fostering a deeper understanding of the game's underlying principles.

3.5 Playtesting

Following an initial playtest conducted with five design researchers to assess the game's playability, we sought to expand our testing to a broader audience. Consequently, the game was incorporated into a final-year industrial design course on design management, as part of the 'Collaboration and New Roles of Designers' week, where it was presented to 160 industrial design students in 2021 and 2022. Across both years, a total of 160 students participated, 80 played with Version 1, and another 80 with Version 2. In this setting, the course leader was a facilitator, introducing the students to the game's mechanics and objectives. The students then formed groups, each consisting of 3-5 individuals responsible for managing a single makerspace. Each game board accommodated approximately 4 or 5 of these groups, allowing for a comprehensive evaluation of the game's dynamics in a larger, collaborative educational context. After incorporating feedback to enhance the game, we organized a subsequent play session the following year, maintaining the same course structure and setup.



Figure 4: Project Cards showcasing various circular economy themes within the Circular Synergy City game. Each card represents a unique challenge and opportunity for collaboration, inspired by real-world activities from the Pop-Machina Project's makerspaces. Categories include Makerspace, High Tech, Organic, Low Tech, and Textile, each requiring distinct strategies and fostering diverse collaborations to promote sustainability and innovation.

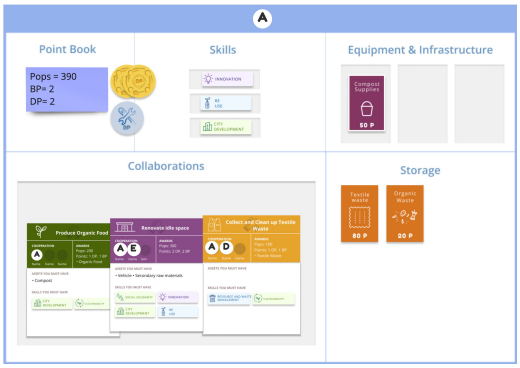


Figure 5: A sample set of game elements for one player group

To evaluate player engagement and experience in the context of a board game that integrates circular economy concepts, we created a questionnaire inspired by the Core Elements of the Gaming Experience Questionnaire (CEGEQ) developed by Calvillo-Gámez et al. [13]. We aligned the CEGEQ questionnaire more closely with the specificities of a board game, as opposed to its original design for video games. We omitted items that were less relevant to the board game format (e.g., The sound effects of the game were appropriate) and incorporated additional items related to circular economy and collaboration, elements central to our board game's design and objectives (e.g., The game increased my awareness about the circular economy.). In the questionnaire, we employed a 7-point Likert scale for each question, ranging from "strongly disagree" to "strongly agree". In addition to the Likert questions, we included open-ended questions at the end of the survey to gather qualitative feedback, providing players with an opportunity to share more detailed and nuanced perspectives on their experience with the game.

Each game session was overseen by two facilitators (i.e. two of the authors), whose role was integral to both the gameplay and our research methodology. The facilitators were responsible not only for guiding the gameplay but also for observing player interactions and behaviors. Their observations were instrumental in refining subsequent iterations of the game and in enriching our understanding of the results. The facilitators' insights offered valuable context to the quantitative data collected through the questionnaire, allowing for a more comprehensive evaluation of the game's impact on players. Lastly, after both play sessions, we conducted a general reflection session to discuss highlights and challenges.

4 RESULTS

Here, we summarize the findings related to players' experiences, their satisfaction with Circular Synergy City, and their overall reactions to this game. A total of 73 students filled out the feedback form for Version 1, while 17 filled out the form for Version 2. In assessing user engagement with different aspects of two game versions, we conducted Mann-Whitney U tests on all items to identify any significant variations since the student numbers who filled out the form for Version 1 and Version 2 are different. This analysis revealed significant differences in five items, which we discussed

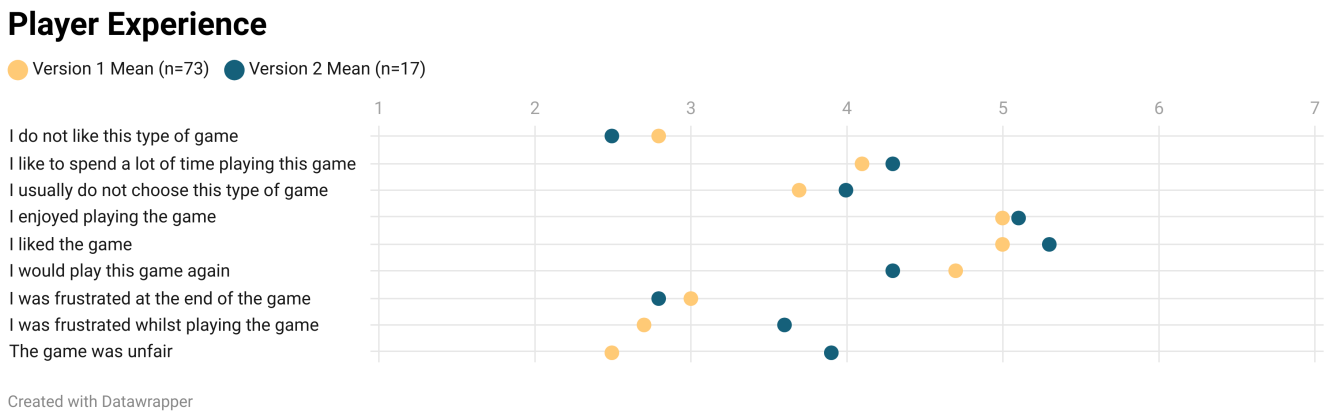


Figure 6: Post-game questionnaire scale ratings for questions related to player experience.

below. We also report findings that were not statistically significant, as these results support interpreting our qualitative data.

4.1 Player Experience

This subsection focuses on player experiences with two game versions, focusing on their enjoyment, frustration, engagement, and perceptions of fairness and complexity. For Version 1, facilitator observations indicated that the game had a more educational tone, with a noticeable deficit in entertainment value. To address this, we introduced the 'life dice mechanic'—a series of random events—in the second iteration of the game. Based on our observations as facilitators, this modification enhanced player engagement and deepened immersion in the gameplay. Looking at the t-test results, it seems that the difference between version 1 and version 2 in terms of player engagement was significant (z=-2.602, p=.009). Consequently, feedback transitioned from basic mechanical issues, common in the first version, to more nuanced aspects of the game's design, signaling an enriched gaming experience.

Players generally enjoyed the game, with average enjoyment scores being 5 (out of 7) for Version 1 and slightly higher at 5.1 (out of 7) for Version 2 (Fig 6). For instance, a participant described the game as "very fun and thoughtful," particularly appreciating its strategic aspects. The game managed to keep participants engaged, as implied by the extensive qualitative feedback provided. For instance, one participant expressed a desire to contribute to the game's development in the future, highlighting their positive experience and wish to play more without encountering technical issues. Another praised the game's realism, noting that "The best aspect of the game was that it was based on real tasks and real materials and workflows. For this reason, realistic game setup makes it more informative and useful".

End-game frustration was on the lower end for both versions. While the average in-game frustration was relatively low at 2.7 (SD: 1.4) for Version 1, this significantly increased to 3.6 (SD: 1.6) for Version 2 (z=-1.970, p = .049). The rise in frustration can be attributed to the game becoming more complex, making it difficult for players to keep track of all elements, such as various types of cards and game mechanics. One participant noted, for instance: "I think the game is a little complicated. At first, there was no problem with understanding and playing a little after playing a little, but I think it was difficult to follow. It was too dynamic to follow. I think it was challenging to be aware of every function and not to forget one of them."

Another significant finding about the player experience was the noticeable increase in players' perceptions of unfairness between the two versions (Version 1, M: 2.5; Version 2, M:3.9), mainly due to certain "overpowered" cards that made the game outcomes predictable after the initial rounds (z=-2.880, p = .004). One player pointed out the disproportionate impact of early strategic or lucky choices on the game's outcome, citing an imbalance in the value returned by different cards. Another participant highlighted the issue with some cards being significantly more beneficial than others, rendering the less advantageous cards as "dead cards" that groups were reluctant to use due to their perceived lack of value.

4.2 Game Design, Mechanics, and Platform

Here we provide an overview of the game's visual design, mechanics, and the online platform used for gameplay. Feedback on the game's visual presentation was generally positive, reflecting overall satisfaction with its aesthetic design (Fig 7). Following the feedback we received for Version 1, in Version 2, we enhanced the game map to be more integral to the gameplay by incorporating landmarks and associating specific game items with locations, such as skills with universities and secondary materials with flea markets or industrial zones. These changes improved the clarity of the map's role in understanding the city, as reflected in the increased average score from 3.81 to 4.47.

However, there was a slight decline in the ease of understanding the activity cards, with average scores dropping from 5.1 in Version 1 to 4.7 in Version 2. This aligns with players' feedback on the overwhelming variety and number of activity cards, making it challenging to manage all game elements effectively. A participant remarked, "The rules of the game were understood, but it was impossible to control everything on the board."

The use of Miro as the game platform received increasingly negative feedback, with satisfaction scores falling from 3.4 to 2.8. Players

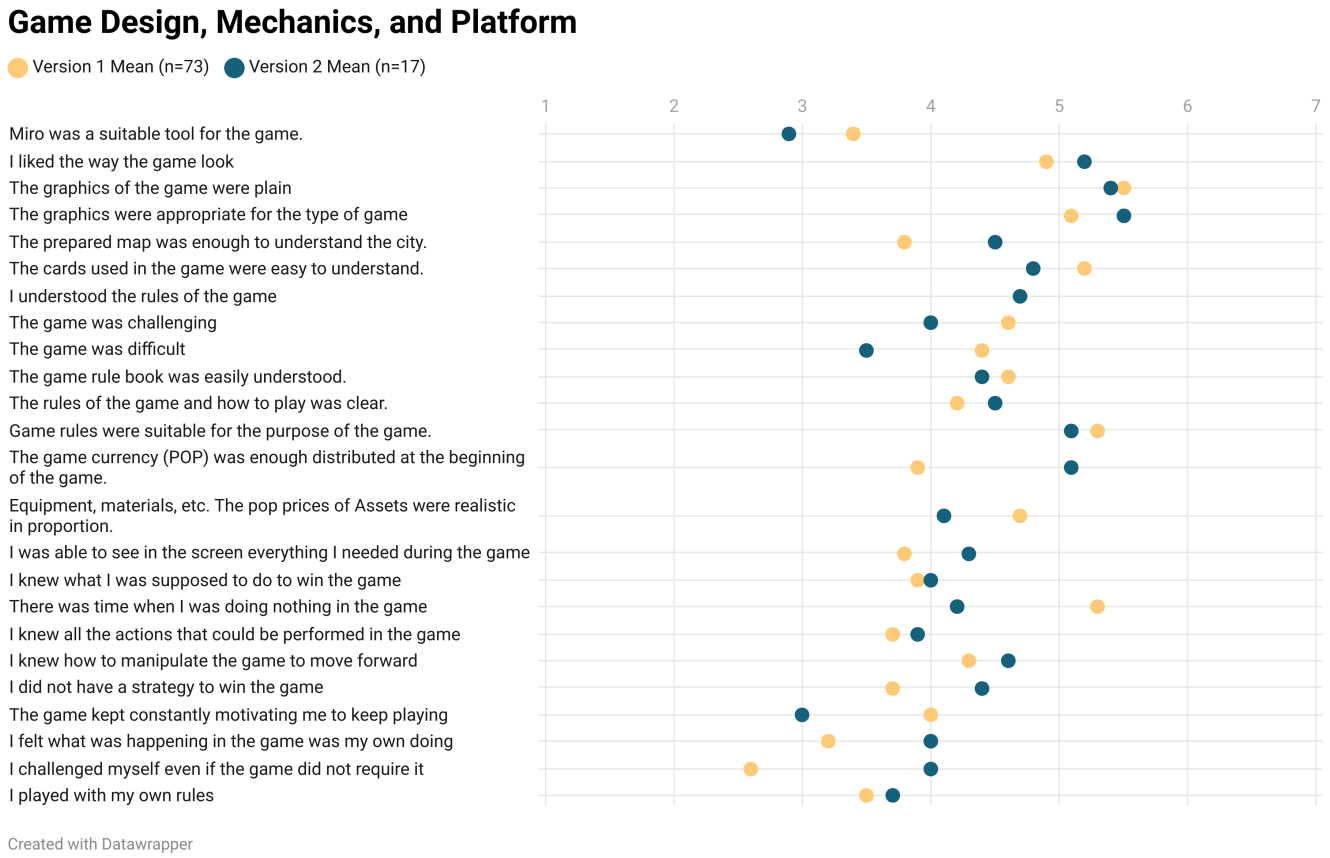


Figure 7: Post-game questionnaire scale ratings for questions related to game design, mechanics and platform

found it unsuitable for the game's complex interactions, suggesting that a digital format or a dedicated platform could enhance playability. For instance, one participant remarked, "I don't think the game is suitable for 'Board Game' format, and I think it will become more easily understandable and playable in a digital format". Another participant suggested that "Although Miro is the most usable tool among the current platforms, a separate platform and software can be developed in which teams can be created between themselves." Despite this, some participants expressed a preference for a fully physical game setup, with one noting, "I would prefer the game to be played with physical cards."

Regarding game mechanics, players consistently recognized their alignment with the game's objectives, maintaining high approval ratings (Version 1: 5.3, Version 2: 5.0). Initial feedback towards Version 1 highlighted the need for improved resource distribution and clearer objectives to facilitate collaboration. "To facilitate working together at the beginning of the game, reorganizing the resource distribution is necessary," one feedback suggested. Following adjustments, there was a slight decrease in periods of inactivity, with scores dropping from 5.2 to 4.1, indicating more continuous engagement. Additionally, the perceived adequacy of game currency improved significantly, from an average score of 3.9 to 5.1 (z=-2.402, p = .016), suggesting that the modifications successfully addressed the concerns raised.

4.3 Circular Economy and Collaborative Dynamics

Here we focus on how participants engaged with CE principles and collaborative dynamics within the context of the game designed to simulate these concepts. In the first version, participants' scores on questions about the circular economy exceeded the average(Fig 8). This suggests that the game played a role in enhancing participants' grasp of CE principles within their local environment. However, there was a general decline in these scores in the second Version. For example, for the question "The game increased my awareness about circular economy.", mean scores dropped from 4,9 to 4,1. Though the scores indicated an overall agreement with this item, from the qualitative feedback, we can attribute this decline to the game's increased complexity. Players reported being so engrossed in navigating the game's dynamics that they overlooked aspects of the circular economy. One participant described the game as puzzle-like, making it challenging to connect the gameplay with circular economy concepts. Another noted the requirement of strategic thinking, focusing more on gameplay tactics than on the underlying principles of the CE.

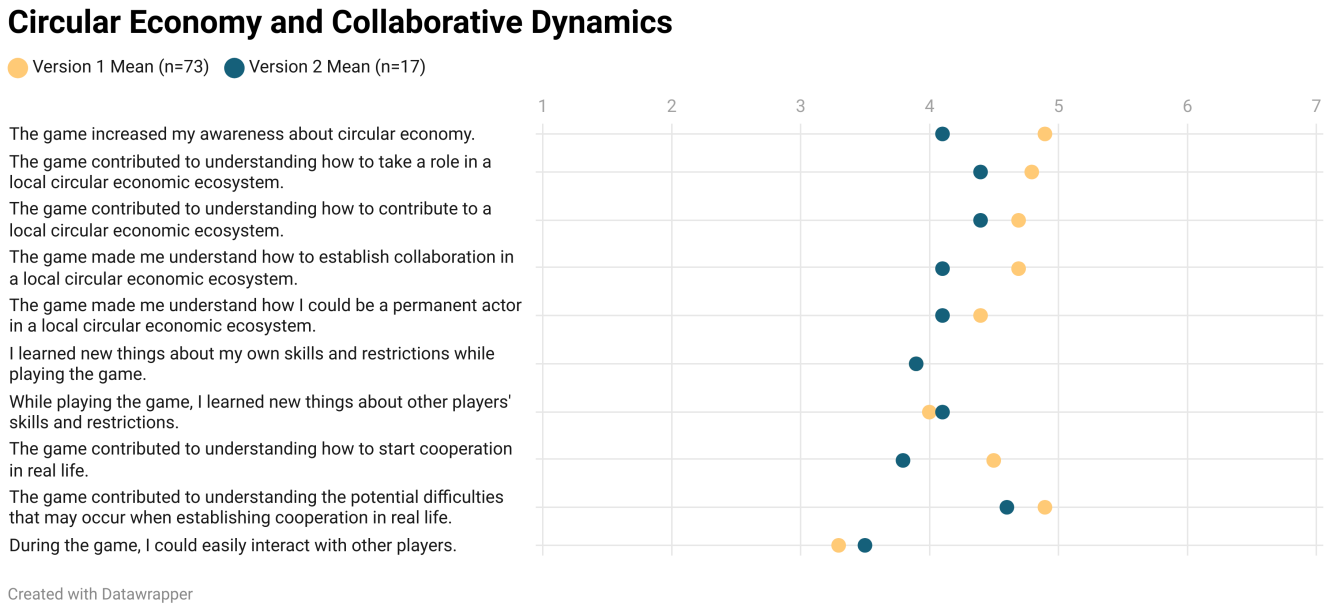


Figure 8: Post-game questionnaire scale ratings for questions related to circular economy and collaboration

Our evaluation also offered insights into collaboration. Participants indicated that the game somewhat contributed to understanding potential difficulties in collaborating in real life. (Version 1 M=4.9, Version 2 M=4.6). Despite the game's emphasis on collaboration, players often opted for self-sufficiency, even when the game mechanics required teamwork. Suggestions from participants included imposing stricter limitations on solo play to encourage more collaborative efforts. One participant noted: "Although the game aims to unite with other teams, everyone is trying to raise their own resources and earnings to the maximum, which prevents working together. In order to prevent this, perhaps working together on some cards can be compulsory or the use of Skill can be limited to 2 per Team, so that it is compulsory to work together on cards requiring 3 or 4 skills."

5 DISCUSSION

In this paper, we present the player experiences of two versions of the Circular Synergy City game and their feedback, providing valuable insights into the game's impact, design, and role in simulating circular economy principles and collaborative dynamics.

5.1 Design Insights for Collaborative Educational Boardgames

5.1.1 Balancing Engagement and Learning. Players' overall enjoyment suggests that the game succeeded in creating an engaging and strategic gameplay environment. The appreciation for the game's realism underscores the potential for educational games to enhance learning through practical simulations. However, the increased frustration levels, alongside comments on the game's complexity, signal a critical challenge in balancing educational content with playability. Previously, Lomas et al.[36], found that difficulty and game complexity decrease player motivation in educational games, and suggested that the games should be "not too hard, not too boring". The players' feedback points towards a need to streamline game mechanics to prevent cognitive overload, thereby ensuring that players remain focused on the core objectives without being overwhelmed by the game's intricacies. Simplifying game functions, as suggested by participants, could be a strategic move to enhance player engagement and satisfaction.

Feedback for Version 1 indicated that while the game's educational intent was clear, it perhaps leaned too heavily on its didactic elements at the expense of engagement and unpredictability, which are key components of a compelling game experience. In response to this feedback, in the next version, we wanted to balance educational content and gameplay enjoyment. We implemented 'life dice events,' injecting a layer of randomness and unpredictability into the game to enrich the gameplay experience. This addition was successful for the overall gaming experience, making it more dynamic and engaging for players while still maintaining the educational underpinnings of the game [33]. Yet, despite the increased engagement and positive play experience, the participants found this version more complex. These results indicate a trade-off between learning-focused gameplay and enjoyment-focused gameplay in educational games. Thus, game designers should determine game elements according to the main goal of an educational game, as in the case of designing games to teach circular economy, whether to foster engagement and collaboration or to instruct.

5.1.2 Fostering Circular Collaboration through Gameplay. The alignment of game mechanics with the objectives, particularly in promoting the circular economy and collaboration, received positive participant acknowledgment. In both versions, the majority

of the participants indicated that the game increased their awareness of circular economy principles. Looking closely at the results, there was a slight difference between the two versions' influence on this awareness, favouring Version 1. Since we did not measure the participants' previous knowledge of circular economy before the study, it might be hard to come up with a valid explanation for this observation. For example, the participants who played Version 2 might simply have more knowledge than participants who played Version 1. Another explanation could be as the game's complexity increased in Version 2, the focus on educational content may have diminished. This finding is crucial for the future development of educational games, where the core educational themes must remain at the forefront of gameplay, regardless of the game's complexity.

Feedback on collaborative dynamics within the game reflects a real-world challenge of balancing self-sufficiency with teamwork. The tendency for players to prefer individual strategies over collaboration, even when the game design encourages teamwork, mirrors common obstacles in real-life collaborative projects. Buchinger and Housel [11] suggest that collaboration among teams and team members could be increased by allocating different and complementary roles to players, supporting intra-player interaction, synchronous gameplay, creating game resources with diverse characteristics (finite, infinite, consumable, noon-consumable, introducing scores and so on). In our game design, we complied with these suggestions. However, one notable observation from the game was the emergence of synergic partnerships, where two or more makerspaces with complementary assets collaborated effectively by pooling their strengths. However, as the game progressed, the accumulation of assets occasionally hindered collaboration, as players found less incentive to work together due to their self-sufficiency, as was reported in previous work [11]. By implementing game mechanics that limit asset accumulation and necessitate greater collaboration, we could enhance the focus on teamwork and underscore the importance of collective achievements over personal gains.

5.2 Iterative Boardgame Design with Online Whiteboards

5.2.1 The Crucial Role of Game Mechanics Adjustment in Board Game Development. The development of our collaborative board game underwent an iterative process shaped by player feedback and observations. In Version 0, a pilot test involving five players highlighted the need for more balanced and realistic equipment, wares, and infrastructure costs. With Version 1, the game was tested with a larger group of 80 students in 2021. During this phase, participants expressed that the game felt too educational and pointed out a need for greater unpredictability and engagement. To address this, we introduced 'life dice events,' adding a layer of randomness that enhanced the gaming experience. Additionally, we refined the game instructions for clarity. Another observation was that the map, a prominent game feature, felt disconnected from gameplay. In response, we linked the map more closely with the game's resources, such as equipment, infrastructure, wares, supplies, and skills, by associating them with specific buildings on the map. This change not only made the map more relevant but also deepened the strategic aspect of the game. Version 2 was tested with 80 students, which revealed an issue where players identified and exploited the most profitable production lines, creating an imbalance. To rectify this, we revised the points system to close these loopholes, ensuring a more balanced and equitable gameplay experience.

These iterative revisions, informed by hands-on experiences and constructive player feedback, were instrumental in refining the game's mechanics and educational content. By addressing issues related to game balance, engagement, and strategic depth, we were able to evolve the board game into a more engaging, equitable, and educationally valuable experience. This process underscores the importance of iterative design and player feedback in developing educational board games, ensuring they convey the intended educational content while providing an enjoyable and balanced gaming experience.

5.2.2 Online Whiteboards as Game Design and Prototyping Tools. Online whiteboards have been utilized to facilitate remote collaboration and learning activities [14, 24]. Our research extends these previous studies and proposes that online whiteboards can also be effective prototyping tools for collaborative educational board games. Throughout our iterative development process, Miro proved to be incredibly useful. It eliminated the need to produce a physical or a digital version of the game, thus saving effort and cost. This allowed us to concentrate on enhancing game mechanics and increasing player engagement. Therefore, we believe digital whiteboards like Miro and FigJam can be useful tools for prototyping board games, helping test and improve gameplay, and increasing overall engagement.

In considering the optimal platform for an educational board game with complex dynamics, the varied feedback on Miro underscores the importance of selecting a medium that aligns with these dynamics. While digital formats can enhance interaction and handle complex game elements efficiently, there's also a noted preference for physical gameplay. Our analysis suggests that while Miro serves adequately for games with straightforward mechanics and proves useful for testing board game dynamics, it faces limitations in supporting more intricate elements. For an educational game with complex dynamics, a fully digitalized format or a dedicated physical game might be better suited to effectively accommodate the depth and breadth of the game.

Overall, designers of educational games for the circular economy should take into account two important questions. The first is to decide about the format: Physical and Online. Physical game sessions facilitate face-to-face interaction but are inherently limited by geographical constraints and logistical complexities associated with organizing a play session. Conversely, online sessions offer broader accessibility by eliminating travel barriers for participants. Furthermore, online environments enable the convenient recording and manipulation of player actions, which might pose challenges in physical settings. The second is deciding on the platform: dedicated vs. all-purpose. Open-source digital whiteboard platforms like Miro present advantages in terms of free access and user-friendliness, particularly valuable when developing game components for geographically specific games like the "circular synergy game" that necessitates the creation of city maps. However, its core functionality as a "digital whiteboard" inherently restricts its interactivity and overall feature set. On the other hand, a dedicated platform could offer greater customization and interactivity but necessitates

a significant investment of time and resources. Alternatively, there might be solutions that combine the strengths of both types of platforms, such as https://boardgame.io/.

5.3 Limitations and Future Work

Our game has some limitations that need to be addressed in future work. First, we observed that the game mechanics may sometimes discourage collaboration, as players become more self-sufficient with their assets and have less incentive to work with others. This may undermine the goal of fostering collaborative, diffuse production and create a competitive rather cooperative atmosphere among players. Second, we found that the game's complexity may hinder its educational effectiveness, as players may lose sight of the circular economy concepts and principles when they are overwhelmed by the game elements and rules. This may reduce the game's potential to raise awareness and understanding of the circular economy among players. Third, we received mixed feedback on the game platform and design, as some players preferred a digital format while others favoured a physical one. This suggests that the choice of medium may significantly impact the gameplay experience and learning outcomes and that different platforms may have different advantages and disadvantages for our game.

There are several directions for future work to improve and extend our game. First, we plan to develop a physical board game version and a full digital board game version to compare the gameplay experience and the learning outcomes across different platforms. We expect that a physical board game may enhance the social and tactile aspects of the game, while a digital board game may offer more convenience and automation. Second, we aim to iterate our game design to different cities and localities, reflecting the circular economy's diversity and specificity and collaborative production in different contexts. We hope this will increase the relevance and applicability of the game for different audiences and scenarios. Third, while Circular Synergy City focused on the local context and the potential for collaborative production, this might overshadow the importance of sharing and learning from best practices and innovations worldwide. Hence, we intend to explore ways of reflecting the global knowledge exchange for the local collaborative production process in iterating the game design and/or gameplay. We believe this will foster a more holistic and systemic view of the circular economy and collaboration among players.

Overall, our objective was to design a realistic and enjoyable game. While we succeeded in creating a game that was engaging and grounded in reality, its complexity escalated to a point where the emphasis on the circular economy began to diminish. Moreover, the chosen game platform struggled to support this complexity. Balancing realism, fun, and educational content is critical, yet fostering collaboration proved particularly challenging, requiring numerous constraints to encourage meaningful cooperative play.

6 CONCLUSION

In this paper, we presented Circular Synergy City, a board game that aims to foster collaborative, diffuse production in the context of the circular economy. We argued that such a mode of production could enable localized practices to produce global designs that meet diverse needs and preferences while reducing the environmental impact of global supply chains. We described the game design and mechanics and reported the results of two playtests with design students. We found that the game was well-received by the players, who appreciated its strategic and immersive aspects, as well as its alignment with the circular economy and collaboration objectives. Players' overall enjoyment suggests that the game succeeded in creating an engaging and strategic gameplay environment. The appreciation for the game's realism underscores the potential for educational games to enhance learning through practical simulations. We also found that injecting a layer of randomness and unpredictability into the game enriches the gameplay experience, providing higher player engagement. One notable observation from the game was the emergence of synergic partnerships, where two or more makerspaces with complementary assets collaborated effectively by pooling their strengths. This reflects the core idea of collaborative, diffuse production and demonstrates the game's ability to foster such collaborations among players.

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