Building in Circles.

Developing the intervention 'CREISE' for Facilitating Communication on the Role of Chemistry in the Circular Economy at the Deutsches Museum.

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This thesis has been an intense and lengthy project, spanning almost a year and a half. CREISE felt like a multi-dimensional puzzle; I had a vision of how it could look, but I had no idea of the depth and scale of what I was building or how to bring its diverse pieces together. Many people played a big role in contributing to this large, beautiful puzzle by shaping pieces, assembling them, and, most importantly, giving me the support to keep going and believing in the results during challenging times. For that, I would like to acknowledge all these valuable allies: family, friends, people from the Deutsches Museum, and the Technical University of Munich. Although I do not have the space to name each of you, I hope you recognise yourselves in these words of sincere gratitude.

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Table of Contents

List of Tables

List of Figures

0. Introduction

It seems to me that we have built many understandings of our world in circles, or at least in a cyclic way. Today, heavy rainfall is pouring in Munich. Water falls from the sky and collects on the earth's surface. In the upcoming days –fortunately, over the weekend– with the forecast of sunshine and high temperatures, some of this water will evaporate. Eventually, it will condense into clouds and precipitate once more, probably in a different location. This cycle, observable on a macroscopic scale, becomes increasingly complex when examined at smaller levels. It involves myriad species using water for various biological functions, only to release it back through transpiration or some kind of excretion. Among these species, it also involves humans, with their diverse human activities, only to release water back, often in controversial ways. But in the end, it is somehow a cycle; a large chemical cycle and similar cyclic processes are found everywhere in our close daily environment. Some are the familiar natural chemical cycles found in textbooks, and some others elude our understanding, but knowing the exact processes or not, everything is connected. At a chemical level, there are no boundaries. Atoms tirelessly rearrange under specific environmental conditions, generating new molecules with new functions that are subjected to new rearrangements.

This is perhaps just the *geek* perspective of a chemist, but it is a beautiful one. It is a perspective that places everything in the world on an equal footing, breaking down hierarchies and transcending borders. However, it is a perspective that calls for a big responsibility, responsibilities that are invisible to the naked eye but that need to be addressed for holistic sustainability. Today, despite the rain, I find myself strolling along the riverbank *en route* to the Deutsches Museum. With each step, I notice how my shoes imprint the clay-like ground beneath me. I ponder whether this imprint is merely physical or if it bears a chemical trace as well. Ever since encountering this notion, it has lingered in my thoughts, surfacing whenever I glance down to ensure I don't stumble. What chemical footprint do my shoes leave on the earth's surface? Is there a toxic residue that my shoes deposit on the ground? My shoes' soles, once adorned with a wave-like pattern, now appear smooth and worn from countless journeys. Crafted from a type of plastic, their gradual erosion means that particles of plastic are dispersed with each step I take. Thanks to the insights of Michael Braungart and William McDonough, I now embark on hikes with a heightened awareness of the impact my footwear may leave behind. This is the big responsibility that seeing things from a chemical angle implies, not only the many ones outlined in the sustainable discourses that flood our media but also those that may not yet be known. This is the mindset central to Braungart and McDonough's (2009) bestselling book, *Cradle to Cradle*.

In a world grappling with climate and ecological crises, as well as socio-environmental injustices, this perspective reveals the interconnectedness of all things and has the potential to

promote sound practices globally. Not surprisingly, this philosophy experienced a significant awakening in the first quarter of the 21st century, emerging as a framework for sustainable development[1] and revitalising an older philosophy, better known as the Circular Economy (CE) (Stahel, 2020). The concept of the CE was initially introduced by Stahel and Reday-Mulvey in 1976 as the Circular Industrial Economy (CIE). They conceptualised a loop economy to describe industrial strategies aimed at waste prevention, regional job creation, resource efficiency, and the dematerialisation of the industrial economy (Stahel & Reday-Mulvey, 1981). In essence, this approach allows industries to profit without externalising the costs and risks associated with waste. The concept of the circular economy has evolved significantly since its inception, experiencing a resurgence in recent years. Perhaps the most renowned definition comes from the Ellen MacArthur Foundation, which describes it as “an industrial economy that is restorative or regenerative by intention and design."[2]

The circular economy seems to be the new paradigm of sustainable development that promises what looks impossible: economic growth without destroying the planet. However, scepticism surrounds this new sustainability framework. Major critiques stem from the Ellen MacArthur Foundation's famous butterfly diagram, which categorises materials into biological and technical, delineating two distinct systems wherein all human activities must align. This structuring of the circular economy perpetuates a techno-optimistic and normative perspective, suggesting a feasible separation between *technical* and *biological* realms (Isenhour et al., 2022). Because – as I suggested before – if chemistry brings everything to the same level, where everything is connected, and there are no borders, how can we know the borders between the *technica*l and the *biological* realms? Furthermore, other critiques of the concept emphasise its limited social dimension, primarily addressing job creation and overlooking a more holistic and socially just sustainable approach (Geissdoerfer et al., 2017). Such criticisms underscore the importance of continued research and critical analysis of circular economic practices for achieving genuine sustainability.

Despite its imperfections, in the European context, it is important to talk about the circular economy. The concept has deep roots in Europe and forms a significant part of the sustainable paradigm in many European countries, notably Great Britain, Italy, Germany, Sweden, Denmark, and the Netherlands (Anaruma et al., 2022). As an example of this commitment, the European Commission adopted a new Circular Economy Action Plan (CEAP) in March 2020, positioning it

[1] The most widely accepted definition of sustainability is encapsulated in the notion of "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1985). The concept of development can entail multiple interpretations contingent upon values, interests, and disciplinary conventions (Geissdoerfer et al., 2017). However, all conceptions of sustainable development evoke a sense of desirability and goodness, fostering reflection on shared responsibilities and alternative pathways for progress (Ibid.; Stirling, 2009).

[2] From Ellen MacArthur Foundation’s Website

as a cornerstone of Europe's agenda for sustainable growth[3]. Thus, if the circular economy is already an important part of the political discourse on science and technology, rather than questioning whether this paradigm is the optimal path to achieve holistic sustainability, it is crucial to integrate the critiques and consider how we can imbue this existing paradigm with greater social justice or how we can create systems that do not maintain artificial boundaries, imposing toxicity to some societies while benefiting others. This entails bringing the concept to public discourse and fostering conversations about sustainable development and the circular economy.

In this master's thesis, I embark on a journey to bring the chemical perspectives on the concept of sustainable development and the circular economy to the Chemistry Exhibition of the Deutsches Museum. The aim is to explore how dialogical and participatory formats of science communication can be *successfully*[4] implemented in museum settings. In recent years, scholars in science communication have advocated for more dialogical and participatory approaches to communication, emphasising the need for practical interventions. Lewenstein (2011) underscores this necessity in his Commentary on *Taking Our Own Medicine: On an Experiment in Science Communication* (Horst, 2011), highlighting that practical engagement initiatives validate concepts from science studies concerning the multi-dimensional and directional nature of science communication. Such interventions are crucial for understanding public participation in science, as they contribute to the development of theoretical frameworks in science communication and public engagement. Therefore, interventions in science communication are essential for critically reflecting on how these practices unfold and help establish frameworks for better understanding public engagement, the publics themselves and the dynamic *event*[5] of communication.

The particular case study of this master's thesis is innovative in two more ways: because of the site of the intervention and because of the format of the intervention. CREISE is innovative due to its location, the Chemistry Exhibition of the Deutsches Museum. Museums have traditionally played a significant role in science communication and boast a unique and rich tradition of communication, with their own line of studies focusing primarily on the public. An intervention in such a space provides an opportunity to reflect on the museum's public and reassess their categorisation. Furthermore, this work is innovative due to its gamified format. Games are increasingly used to engage audiences with environmental issues and have proven to be valuable tools due to the multiple ways in which they foster engagement. However, games,

[3] Circular Economy Action Plan

[4] Success in this context hinges on the project's seamless integration and execution within the museum premises.

[5] In this thesis, I sometimes refer to the occurrence of science communication as an event. This concept is derived from Horst and Michael (2011) re-evaluation of contemporary science communication practices and formats that extend beyond traditional diffusion and deliberation models. Understanding science communication as an event acknowledges its multidimensionality and directionality, as well as the shaping of the entities that participate in it (for further details, see Chapter 2). When I refer to the "event of (science) communication," I am embracing this understanding of science communication.

particularly those in museums, are predominantly used for educational purposes, with their use as communication devices less explored. Thus, this work straddles three areas of study: science communication studies, museum studies, and games for sustainability studies. While the main focus is on science communication and, particularly, the creation and implementation of the intervention, the interdisciplinary nature of the work spans other academic disciplines, adding value to the research and unlocking promising future research avenues.

This thesis is structured into five chapters. The first chapter provides a concise historical and theoretical overview of the development of science communication studies and practices. The establishment of (social) scientific disciplines and shifts in the media landscape have significantly influenced analysis and approaches within this field. By examining the three modes of communication and aligning with the scholarly emphasis on utilising conceptual frameworks, this chapter sets the foundation for identifying and exploring specific areas and thriving practices in science communication, such as media platforms and science museums. Despite their distinctiveness, these domains are intricately interconnected, with changes in media dynamics profoundly influencing the entire science communication ecosystem, impacting museums and science centres. Consequently, this chapter concludes by delving into the evolving roles of museums and their diverse audiences, a critical consideration for the subsequent discussions within this thesis.

Chapter Two reviews the scholarly literature pertaining to games and sustainability, investigating the nexus between games and sustainability education & communication. It furnishes an overview of state of the art on (serious) games designed for sustainability purposes. This section culminates with an examination of the case study at hand, specifically focusing on the implementation of gamification in museum contexts. Subsequently, I conduct a comprehensive review of the literature pertaining to the current landscape of interventions of this nature within museum environments.

In Chapter Three, dedicated to materials & methods, I present the research design, which employs an ethnographic approach, detailing the methods of data collection and analysis, as well as the associated ethical implications. As is customary in ethnographic research, I begin with an extensive description of the intervention site. This is followed by an overview of the diverse data & materials collected and the methods of analysis. I end this section by discussing the ethical considerations inherent to the research and the reflective approach adopted for this ethnographic study.

In Chapter Four, I present findings from three different perspectives considered in the ideation, design and implementation of the game. Firstly, the focus is on content, offering insights into the messages crafted for the communication, followed by a reflective analysis of participant

engagement with these messages. Secondly, my attention shifts to the formats employed, reflecting on the diverse approaches used to present content in a way that fosters engagement and stimulates discussions within the game. Lastly, I delve into game mechanics, a unique aspect of the gamified format that can also serve communication purposes. The game mechanics facilitate and enhance engagement with its messages in two ways: by providing roles to participants with familiar scenarios for reflection and by fostering competition through a point system.

The concluding chapter, Chapter Five, discusses the results within the theoretical backdrop of Science, Technology and Society (STS) in science communication. Due to the distinctive nature of this study, I introduce a novel framework for science communication well-suited for the specific process of the development of an implementation within the particular museum space: science communication as symbiosis. Furthermore, I theorise on the broader applicability of this framework beyond the scope of the present case study and elaborate on future research directions arising from the inherent limitations of this thesis.

1. Historical & Theoretical Background

A Brief History of Science Communication.

Public communication of science has a rich tradition spanning several centuries. Whether through books elucidating scientific concepts – ranging from straightforward explanations to more literary explorations– or via exhibitions, universal fairs, conventions, and news dissemination, it has taken myriad forms throughout human history. Like any enduring practice, science communication has undergone significant evolution since its early manifestations in the 18th century. Bucchi (2008) identifies two primary *interrelated*[6] processes that have driven this evolution: (1) the institutionalisation of research as a profession with elevated social status and increasing specialisation, and (2) the widespread proliferation of mass media. In this first section dedicated to the historical and theoretical background of science communication, I delve into science communication's changing nature using Bucchi's (2008) division, shedding light on the historical trajectory and paradigm shifts that changed discourses, theories and practices in this field.

On one side, I explore the institutionalisation of research within the context of science communication. This aspect is pivotal as it lays the groundwork for the emergence of the "science of science communication" itself. The institutionalisation and specialisation of research not only elevated the status of science communication but also provided fertile ground for the development of its systematic studies. Thus, understanding the different ideological underpinnings that shaped the evolution of this academic discipline is crucial for comprehending contemporary practices and creating a meaningful contribution to the field. On the other side, I explore the impact of the proliferation of mass media on science communication. The rise of the Internet and the rapid propagation of various forms of social media have fundamentally transformed the landscape of science communication, presenting both challenges and opportunities.

Examining how mass media has influenced the communication of scientific information and interacted with evolving paradigms in science communication will provide insights into the value of innovative practices necessary to navigate this dynamic environment, particularly in the case of science communication within museum spaces. The emergence of a new paradigm in science communication within the media has also impacted other sectors, notably museums, endowing them with novel roles. This aspect is particularly intriguing within the context of this study, warranting an in-depth investigation into the roles of museums and their publics.

[6] Bucchi does not explicitly employ the term "interrelated"; however, I believe it is necessary to incorporate this word. Both factors have significantly influenced each other's development. The expansion and proliferation of mass media have been propelled by scientific innovations that are deeply entrenched in the institutionalisation of research and its specialisation.

By analysing the two driving forces of change within the realm of science communication – institutionalisation and mass media– and reflecting on the evolving roles of museums within this paradigm, this chapter aims to furnish a comprehensive understanding of the historical evolution and contemporary challenges. This understanding establishes a theoretical context within which this study can be situated and demonstrates its potential contribution to the field.

1.1. Modelling vs Framing Science Communication.

Exploring the Evolution of Models and Frameworks in Science Communication.

Formal theoretical and empirical exploration of the field of Science Communication began in the latter half of the 20th century. Driven perhaps by the institutionalisation of other (social) scientific disciplines, academic studies in science communication established itself as an "emerging discipline" (Trench & Bucchi, 2010).This field encompasses studies that involve philosophical and social analysis, as well as research methods focusing on audiences, institutions, and media formats related to the exercise of science communication (Bucchi & Trench, 2021). The consolidation of science communication as an independent academic discipline is evident through significant milestones, including the establishment of influential journals like Science Communication (1974) and Public Understanding of Science (1992), alongside many others addressing similar themes. These platforms serve as critical arenas for discussing current trends and advancements in both research and practice within the field. Moreover, the establishment of departments dedicated to science communication in numerous universities and national and international organisations worldwide further solidifies its status as a distinct practice.

Early reflections on public science communication –better known as public understanding of science (PUS)[7]– often centred on the complex interplay between experts, the public, and the media. Less attention was initially given to the scientific content and the communication process itself, a focus that emerged more prominently in recent years (Bucchi, 2008). During this period, the prevailing paradigm of communication centred on the simple transmission of knowledge from one group to another (Ibid.). This paradigm heavily influenced initial conceptualisations and terminologies that shaped the field of Public Understanding of Science. Therefore, traditional studies in PUS typically adhere to a diffusionist model that assumes that there is some *knowledge gap* between the public and experts –a deficit in scientific information that makes the public

[7] In 1983, the British Royal Society Council published a report describing ways to enhance public understanding of science, facilitating the public to grasp the scope and limitations of scientific findings and methods and thereby contribute to a "better, or even a different," world. Here, "public" means the predominately non-scientific public, "understanding" includes not just knowledge of facts but also comprehension of the nature of scientific activity and inquiry and "science" is broadly defined to include technology, engineering, mathematics and medicine ('Public Understanding of Science: The Royal Society Reports.', 1986).

sceptical towards science and technology (Millar & Wynne, 1988). Consequently, this needs to be solved through one-way, top-down dissemination of information from experts to the public.

However, contemporary science communication trends –often called critical or ethnographic PUS (Horst & Michael, 2011)–, have strongly criticised this traditional *deficit model*. This critique denounces the pedagogical and paternalistic nature of the approach, which tends to portray the public as ignorant and hostile towards science. Instead, critical PUS advocates for recognising the expertise and knowledge production of the public itself in science communication practices. Seminal works like *Misunderstanding Science* by Irwin and Wynne (1996) underscore the various ways in which the public can be regarded as experts, drawing upon personal and experiential local knowledge, particularly in areas such as health[8] and the environment[9]. In many of these situations, the public is not ignorant, nor does it need to be educated; rather, the public has lived, felt, and educated themselves through experiences. The public wishes to make themselves heard with their own unique voices[10].

In recent decades, Science Communication literature has seen a significant shift away from the traditional diffusionist approach towards exploring alternative models that prioritise the inclusivity of lay expertise. Analysing these aforementioned instances, where the public challenges scientific knowledge, critical PUS has underscored the necessity of public deliberation and two-way communication. It emphasises not only the transmission of knowledge from experts to the public but also the importance of the public's contributions to scientific discourse. Despite the advancements brought about by the integration of deliberation and dialogue into this newer model, which has afforded space for public voices and fostered a more democratic approach to science and science communication, communication is still predominantly perceived as a unidirectional flow of knowledge or values from experts to the public (Horst & Michael, 2011).

Subsequent studies within the field have identified a third model of communication, often referred to as the *participatory model* or the *model of emergence* (Bucchi, 2008; Bucchi & Trench, 2021; Horst & Michael, 2011; Michael, 2002). This model enables the consideration of any instance in science communication, seeing communication as a constitutive force in shaping entities such as science, the public, and society (Horst & Michael, 2011). Within this model, science communication is conceptualised as more than a flow; it is framed as an event, recognising the reciprocal influence in the coming together of experts and the public, as well as the subsequent impacts on science and *society at large* (Ibid.).

[8] See, for example, studies on AIDS activism (Epstein, 1995) and genetics (TallBear, 2013)
[9] See, for example, studies in nuclear power (Kim et al., 2020) and, more recently, AI (Aquino et al., 2023).
[10] Inspired by an earlier university work: Passola, E. (2022). *MEDIA REFLECTION ESSAY: Finding a suitable science communication model for Picturing the Invisible*

The overall paradigm shift from diffusion to dialogue and participation has catalysed a broader terminological transformation from *public understanding* to *public engagement with science* (Stilgoe et al., 2014). Engagement entails active involvement –being involved– with an entity in an effort to comprehend it[11]. Therefore, public engagement with science implies the public's active participation in scientific processes or activities aimed at enhancing their understanding of science. In this context, the public is recognised as a legitimate actor in the creation of scientific knowledge, transcending its traditional role as a passive recipient. Instead, the public now possesses the agency to redefine scientific messages and influence the trajectory of scientific inquiry. However, this transition has not been without controversy, as scepticism and criticism persist regarding whether this shift truly represents substantive progress or merely a superficial change in terminology intended to conceal underlying deficiencies (Irwin, 2014).

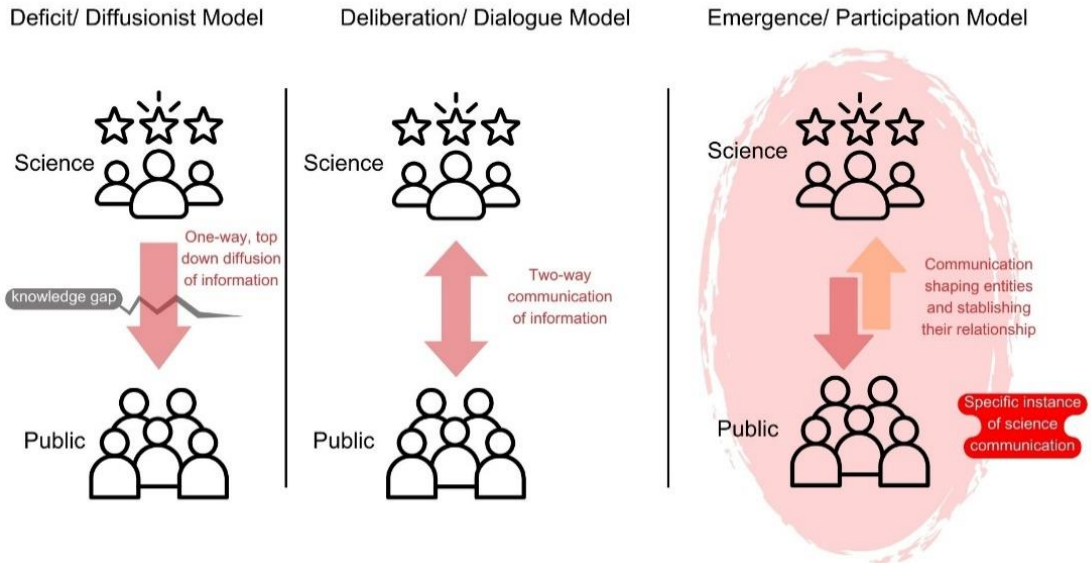

Figure 1 - Models of Science Communication

Like many scholars, I believe that discussions around the merits of each model are redundant. Instead, it is crucial to advance theoretical frameworks and observe how these ideas manifest and materialise in practices and interventions. Despite the increasing advocacy for dialogical and participatory approaches, diffusionist methodologies endure and can prove valuable in particular contexts. Considering the diverse array of science communication practices and the interdisciplinary nature of the field, a spectrum of communication models is indispensable for understanding the unique dynamics of communication in each case and reflecting on sound practice. In some instances, specific messages need to be conveyed, warranting a more diffusionist approach to communication. However, this does not entail disregarding public voices

[11] Engagement – Oxford Learner's Dictionary

or dismissing them as ignorant. As illustrated by Horst and Michael (2011) in their work on the exhibition *Landscape of Expectations*,

> "[they] had a message which they wanted the installation to convey to its visitors, and they had to work hard to make this message intelligible"; therefore, "it turned out to be necessary to think in terms of the model of diffusion."

Simultaneously, in the exhibition *Landscape of Expectations,* the authors aimed to foster dialogue with visitors and were guided by the model of deliberation. Yet, upon reflection on the learning outcomes of the installation, they found the model of emergence—or participation—to be particularly valuable.

Bucchi and Trench's (2021) framework clearly demonstrates how dissemination, dialogue, and participation can coexist within science communication formats. Many science communication formats blend various elements to convey messages while also encouraging public participation and influencing scientific discourse.

Base Model	Dissemination	Dialogue	Participation
Sci-Comm Applications	Deficit Defense Promotion Populaerisation Outreach	Engagement Consultation Interactivity Deliberation	Chat Play Co-creation Film&Fiction Art-Science
Aspects of Science	Findings: finished knowledge	Issues. applications and implications of knowledge	processes: interpreting and (re-)constructing knowledge
Public Uses	information, awareness, learning	questioning, opinion, discussion	sharing, creating, enjoyment, criotique
Social Perspectives	Science Literacy: Scientism, Technocracy	Science in Society: Mode-2, Post-Normal, Post- Academic	Society in Science: Civic Science, Citizen Science

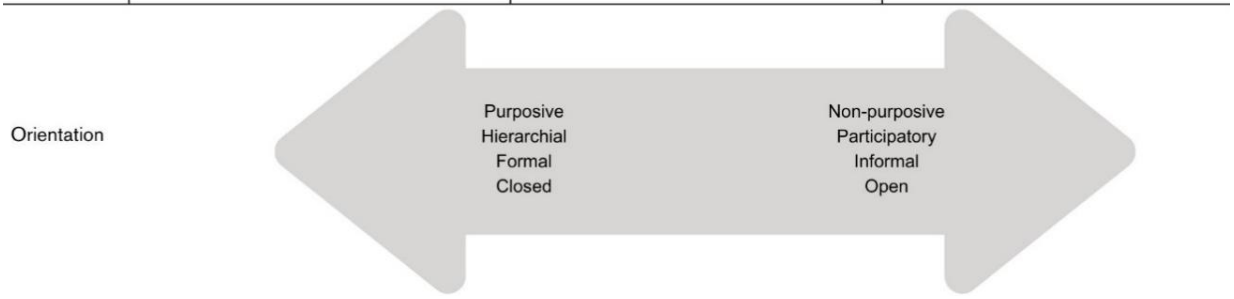

Figure 2 - Framework of the social conversations around science (Bucchi & Trench, 2021)

The progression beyond the mere debate on models has prompted an exploration of diverse conceptualisations of the nature of science communication. Scholars have depicted it as an *event* (Horst & Michael, 2011), an *ecosystem* and a *culture* (Davies et al., 2019; Davies & Horst, 2016), a *social conversation* (Bucchi & Trench, 2021), and a *boundary space* (Horst, 2022). While each conceptual framework offers valuable insights, none comprehensively encapsulates the entirety of science communication; rather, they illuminate specific case studies and practices within the

field. These frameworks emphasise certain communication dynamics while potentially overlooking others that may not be as pertinent in a given context.

Hence, instead of initiating a debate on which framework accurately captures the essence of science communication in its entirety, it is vital to reflect on the specific communication scenario and select the framework that best elucidates its aspects —or even develop a new one. A more inclusive and insightful analysis of this phenomenon can be achieved by transcending discussions solely focused on identifying the best models and frameworks and acknowledging the diverse ways in which science communication manifests in society.

1.2. New Sites for Public Engagement.

Science Communication for Sustainability and the Post-Normal Science Paradigm.

Moving from specific models to comprehensive frameworks for conceptualising science communication provides valuable insights into the essential questions and aspects that require exploration and analysis in a specific communication context. Introduced by Davies & Horst (2016) in *Science Communication as a Culture*, the framework of science communication as an *ecosystem* highlights the diverse and multifaceted nature of science communication endeavours. This perspective allows for the identification of distinct niches within the ecosystem, representing various communication practices that “sustain themselves and others in a complex web of interdependence and autonomy” (Ibid.).

One notable niche identifiable through the ecosystem framework of science communication is the media, which has traditionally been dominated by scientific journalists. However, the rapid digitisation, the rise of the Internet, and the emergence of social media platforms have precipitated profound transformations. Such changes have fundamentally altered the dynamics of communication, both in the personal and professional realms (Weingart & Guenther, 2016). The proliferation of scientific content across various unconventional media platforms has undermined the traditional role of science journalists as *gatekeepers* of science communication, prompting a re-evaluation of notions of truth and challenging established confidence in scientific knowledge (Ibid.).

The contemporary landscape of science communication is increasingly complex due to the polarisation of the political discourse as well. This is particularly evident in societal movements and crises such as climate change protests and the COVID-19 pandemic. Thus, scholars have embarked on a revaluation of science communication within this rapidly evolving ecosystem, often termed the *new ecology of communication*, drawing from Weingart and Guenther's (2016) terminology. Furthermore, a new concept has been introduced in response to these shifts and in

an attempt to make sense of and navigate this changing environment: *post-normal science* (Brüggemann et al., 2020; Funtowicz & Ravetz, 1993). This fresh understanding of science serves as a complementary tool to decode science in situations characterised by high levels of uncertainty and complexity, which are increasingly pertinent in our society, necessitating significant and challenging decision-making processes –i.e. post-normal situations (Funtowicz & Ravetz, 1993). Equally, science communication in the aforementioned contexts can be reconceptualised as *post-normal science communication*, referring to science communication happening in post-normal situations (Brüggemann et al., 2020).

Communicating the role of chemistry and new sustainable practices within the context of the circular economy involves engaging in post-normal science communication. Post-normal science is characterised by "scientific roles, norms, and practices that emerge from post-normal situations and deviate from established scientific norms" (Brüggemann et al., 2020). The intersection of sustainable chemistry and the circular economy with post-normal science arises in the face of challenges such as climate change and environmental & social justice. These issues stem from post-normal situations characterised by significant uncertainties and values with high stakes, necessitating urgent decision-making. In such contexts, public engagement in research processes becomes crucial: discussing uncertainties and the limitations of scientific certainty while considering one's own values (Ibid.).

Navigating post-normal situations in science requires meaningful (post-normal) science communication that uses diverse communication models. This is essential not only because of the need to convey pertinent messages but also because of the importance of inviting challenge and discourse from the public. Consequently, sound communication of post-normal situations in science calls for both innovative communication formats that actively engage the public and open places where science and the public come and engage together.

Returning to the ecosystem framework for science communication, this perspective aids in illuminating the diverse communication activities shared by specific organisations or actors, which possess distinctiveness from other practices while maintaining a certain degree of autonomy. Hence, another critical realm of practice identified by Davies and Horst (2016), pertinent to this study, pertains to museums and science centres. Examining the two identified niches –media and museums & science centres– through the lens of the ecosystem reveals both distinction and interconnectedness. The distinction acknowledges the unique legacy of communication and the practices of museums and science centres, setting them apart from media channels. Meanwhile, the concept of interdependence underscores the intricate influences within the ecosystem, highlighting how practices in museums are inherently entwined with other domains of science communication. Consequently, shifts within one niche can exert significant influence on others; for instance, changes in the media landscape have demonstrably impacted

practices within science museums and centres. An illustrative example of this dynamic is the observation that during times of uncertainty regarding science –specifically, during post-normal situations– many individuals turn to museums to gain a better understanding of current events (O'Hara, 2019). Visitors often perceive museums as a reliable source of information, a place where they can learn about the established facts of science. This underscores the pivotal role of museums as trusted communicators of scientific knowledge, particularly in navigating complexity and uncertainty.

In this new paradigm of communication, science communication can unfold in multiple directions, with museums notably witnessing a renewed surge of interest. Innovative communication modalities necessitate careful design to captivate the public's interest, encouraging active participation in the communication process and cultivating a supportive environment —a *brave space*— where individuals feel empowered to share their existing knowledge and values openly or subject them to critical examination. Such an approach requires the establishment of an open space for dialogue, participation, and, indeed, dissemination. Thus, it is imperative to delve deeper into the significance of museums as legitimate venues for the evolving style of communication under discussion. Moreover, museums transcend being merely a niche within the ecosystem of science communication. By employing the *cultural frame* (Davies et al., 2019; Davies & Horst, 2016), valuable insights are gained into the unique types of science communication and traditions that take place within these institutions. Museums craft scientific narratives in distinctive ways, functioning as sites of *meaning-making*. They employ strategies such as fictional narratives and storytelling to engage visitors, intentionally evoking emotions of curiosity and wonder about scientific phenomena. Moreover, the identity of a museum not only shapes but is also shaped by the curation of these experiences through meticulously crafted images and reputations. As a result, museums embody all four approaches to science communication as a culture (Davies et al., 2019) within a singular, unique space.

Therefore, in the subsequent section, I undertake a detailed exploration of the nuanced landscape of science communication within museums. Museums employ a wide array of science communication practices that are specifically tailored to the distinct characteristics of their audiences. Understanding these diverse practices is essential to position this research within the broader scholarly discourse on science communication in museum contexts. Such contextualisation requires a comprehensive examination of museums, their target audiences, and the types of communication strategies used to engage these audiences. Additionally, shedding light on these aspects will offer valuable insights into the nature of the public that this research, given its specific case study focus, is bound to engage with.

1.3. Exhibiting Science.

Museums & Science Centres and their Publics.

Museums have always been inherently intertwined with the public, given their very nature. Even before the formalisation of science communication efforts aimed at fostering dialogue and engagement between the public and science, some museums in the 19th century were already pioneers in providing hands-on approaches to scientific exploration (Cain & Rader, 2017). However, it was not until the latter half of the 20th century that museums began embracing a wider array of science communication approaches. This marked a significant shift from traditional *look-and-learn* models to a more participatory paradigm, wherein visitors actively engage —physically or socially— with exhibits to deepen their understanding and acquire knowledge (Ibid.).

This transition spurred the emergence of new institutions centred around communication rather than the mere collection of objects —the so-called *science centres*. This shift strengthens the connection between museums and the public even more, prompting scholars to reflect on the possibility of those places becoming instrumental in increasing public access to science and making public contributions to science governance (Bandelli & Konijn, 2013). Thus, museums have recently begun to embrace these new roles influenced by contemporary trends in science communication, integrating them into their missions and visions[12]. This positioning makes museums valuable venues for discussing controversial topics, as they can act as intermediaries between the public and science policy & governance.

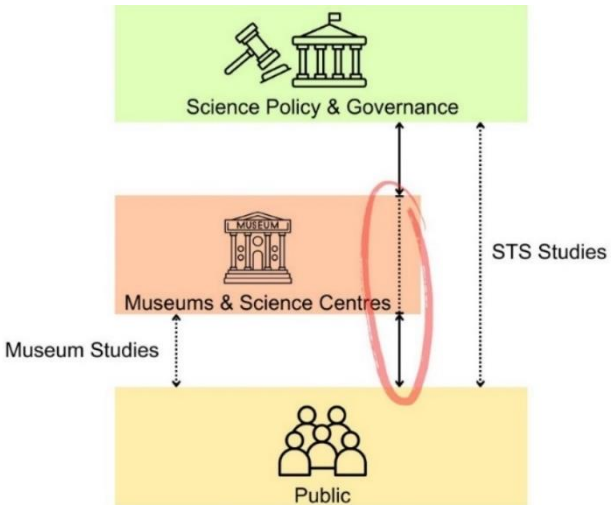

Figure 3 - Role of museums as intermediaries between the public and science policy and governance. (Bandelli & Konijn, 2013)

[12] For example, the Deutsches Museum's mission statement highlights its commitment to fostering discussion on controversial topics:
"The Deutsches Museum also addresses controversial issues and serves as a venue for the exchange of ideas, the formation of free opinions, and participation in science and technology. In doing so, it provides a framework for navigating an increasingly complex world shaped by science and technology, empowering its visitors to make informed decisions and engage in political decision-making processes." Translated from the Deutsches Museum Website: https://www.deutsches-museum.de/museum/ueber-uns/leitbild

However, amidst this ideal scenario, it is crucial to highlight a significant aspect: the diversity of the public itself –i.e. the public invited to participate in shaping science and its policy and governance. Scholars in Science and Technology Studies have extensively discussed the concept of *publics* when examining public participation and deliberation in science governance (Braun & Schultz, 2010). These studies have revealed how participation and deliberation entail the construction of various publics, exploring processes in which very much-designed types of publics are targeted and included while other types are deliberately left aside. Through case studies conducted in both the UK and Germany, Braun and Schultz (2010) delineated four distinct types of publics: the *general public*, the *pure public*, the *affected public*, and the *partisan public*. A later study conducted by Hetland (2019) in Norway is of particular interest to the context of museums. Hetland interviewed scientists employed in museums to explore how these professionals conceptualise and engage with the public in the realm of science communication. Drawing from Braun and Schultz's typology, Hetland identified four primary constructions in the museum communication landscape:

- *General public* encompasses the entirety of potential audiences, often approached through various media channels. This categorisation may sometimes be streamlined to prioritise specific demographics, such as children, families, and senior citizens.
- *Pure publics* are individuals actively participating in museum exhibitions, open days, and botanical garden events. Their engagement is driven by personal interests, with children notably included within this category.
- *Affected publics* consist of amateur naturalists and museum supporters who play a role in shaping the evolution of museums and their collections.
- *Partisan publics* comprise organisations or groups holding strong opinions on pertinent issues or possessing vested interests in museum activities.

	Practices and Settings	Scientists' Drivers	Speaking position publics	Designated Outcomes
The General Public	General dissemination activities often by mass media channels	Credibility, science identity, tenure	Anonymous individuals, initiation of feedback and dialogues	Public appreciation of science, visibility, creating attention, conveying knowledge and process
The Pure Public	Exhibitions, collections, open days, local venues	Personal rewards, broadened	Concrete individuals, naïve citizen as subject of education, children	Public engagement with science, educating citizens, transforming attention into caring
The Affected Public	Amateur naturalist, amateur organizations, collectors and observers, directly or by social media	Involving the public in doing science	Concrete individuals, the authentic expert	Critical understanding of science, building collections, educating the expert, knowledge exchange, knowledge building
The Partisan Public	Organizations influencing knowledge building and agenda setting	Funding, collaboration, partaking in knowledge and policy development	Interest groups, political organizations	Critical understanding of science, participation in shaping new knowledge and new policy

Figure 4 - Types of publics constructed through museums' science communication. (Hetland, 2019)

Hetland's study offers initial insights into the types of publics encountered in museums and their respective locations within the museum's different activities. Given that museums serve as hubs for science communication, academic education and scientific research, they need to engage with diverse audiences for different purposes and at different levels. Therefore, recognising the type of public that may be encountered due to the activity and the situation can help to find initial approaches on how to intervene in such spaces in a sound way. In the context of this specific study, which investigates how to communicate a particular concept within a designated exhibition space, the type of public seems already predetermined by the nature of the activity – science communication – and the spatial context – exhibition space.

Following Hetland's classification, this study would be addressing what Hetland terms the *pure public*. Pure publics are characterised by their lack of familiarity with the issue at hand and their openness to education (Braun & Schultz, 2010). This definition suggests that, when engaging a *pure public* in the science communication process, dissemination models of communication become nearly indispensable. In such instances, dissemination models serve as the backbone of communication (Brossard & Lewenstein, 2010; Stocklmayer, 2013).

As discussed earlier, contemporary trends in science communication emphasise the importance of dialogic and participatory approaches. Consequently, it may seem contradictory to design an intervention in a space that inherently targets such an audience. However, it is important to note that emphasising dialogical and participatory trends does not imply exclusive reliance on these models. If the goal of the intervention is to convey specific messages, a diffusion model may be appropriate. Moreover, the use of dissemination models does not preclude the use of other dialogical and participatory methods, which allow for a discussion and contestation of these messages. Thus, in this study, the dissemination model is employed, drawing from Horst and Michael (2011) approach, which focuses on the willingness of the intervention's creators to convey specific messages rather than assuming ignorance on the public's part.

On a related note, Braun and Schultz (2010) also observe that pure publics are often targeted with the intention of transforming, shaping, and refining their understanding. However, this study does not aim to alter the perceptions of the targeted *pure public* but to create and facilitate discussions through a designed intervention aimed at fostering dialogue on sustainability approaches and chemistry's role. Therefore, it is important to consider how this particular audience reacts to the intervention and reflect on whether the targeted public exhibits the expected characteristics of a *pure public* or if they emerge as something more. Such a reflection can bring new valuable insights into the categorisation of the public in museum spaces.

2. Literature Review

Games for Sustainable Development Communication and Games in Museums.

Navigating communication within post-normal science situations—those characterised by high complexity, uncertainty, and contention—demands the adoption of novel communication formats. Given that sustainable development frameworks like the circular economy manifest within such contexts, it becomes almost imperative to explore non-traditional formats of communication to make a meaningful contribution to the evolving landscape of science communication and public engagement. One promising avenue for exploration is games.

The use of games and simulations for environmental and sustainability purposes traces its origins back to the 1980s (Robinson & Ausubel, 1983). However, in recent years, there has been a notable surge in interest in this field, driven by several factors. Firstly, there is an increased societal awareness of environmental challenges and an urgent need for creative solutions to engage communities in sustainable practices[13]. Secondly, the gaming industry and games engineering education have experienced significant growth and consolidation[14], fostering an environment conducive to the development of interactive tools for sustainability communication. Lastly, there has been a marked improvement in the accessibility of technological resources facilitating amateur game creation, spanning both physical and digital realms[15]. This trend is further evidenced by the growing body of literature dedicated to the subject and the widespread integration of games into various sectors of society.

Prior to 2014, the volume of published papers addressing the use of games for environmental and sustainability purposes remained relatively consistent, with an average of approximately two publications per year (Galeote et al., 2021; Tan & Nurul-Asna, 2023). However, a notable shift occurred in 2015, characterised by a substantial increase in publications within this domain (Ibid.). This surge can be attributed to the perceived synergy between gaming experiences and desired learning outcomes, aligning with environmental and sustainable goals. In the preceding section, the communication of sustainability was discussed as embodying a post-normal science communication practice, necessitating novel formats of communication to create spaces for dissemination, dialogue, and participation to foster public engagement. Building upon

[13] See, for example, Calculli et al. (2021) for a discussion on the rise in public awareness of climate change and environmental issues. Additionally, Mitchell and Walinga (2017) explore how theories of creativity can be leveraged to promote more sustainable practices.

[14] See, for example, Palma-Ruiz et al. (2022) for an overview of the recent global evolution of the gaming market.

[15] Platforms like Unity exemplify this trend, as they have revolutionised the gaming industry by providing accessible tools for game development. Furthermore, Actionbound, which was used to create CREISE—the gamified intervention for the Chemistry Exhibition at the Deutsches Museum—and is widely employed in the museum's visitor programs, demonstrates the increasing utilisation of digital tools.

this foundation, this section will argue for the exploration of games as a format conducive to communicating such complex topics.

The forthcoming sections delve into the potential of games as a powerful tool for communicating sustainability. Initially, I examine how games offer learning outcomes that intersect with experiential learning, a cornerstone for sound communication of sustainability issues. As engagement with sustainability-related themes transcends mere comprehension of scientific principles or the imperative of climate action[16], it manifests in multiple forms of engagement (Galeote et al., 2021). Consequently, I delve into how games have the potential to enrich all these forms, thereby fostering diverse dimensions for engagement.

This inquiry underscores the significance of games as a medium for meaningful communication within the realm of sustainability. Furthermore, these findings resonate with contemporary perspectives in science communication, which underscore the importance of dialogical and participatory approaches. Subsequently, I briefly review the state of the art of such interventions within the context of sustainability and the circular economy, aiming to pinpoint any gaps and faced challenges in the existing literature regarding the use of gaming formats. As customary, this review will conclude by shifting the focus to the specific context of museums.

2.1. Sustainable Engagement?

The Role of Games in Facilitating a 3-Dimensional Engagement with Sustainability.

Engagement with sustainability encompasses a multitude of topics and directions for engagement. In the context of this study, the aim is to foster engagement with the concept of circular chemistry and economy, in other words, to stimulate discussions on climate change and our industry from a chemical point of view. Thus, my endeavour is to embrace the principles of sustainable development, inherently entailing an exploration of the multifaceted challenges posed by climate change. Scholarly inquiry has delved into the intricacies of sustainable development and climate change engagement, discerning three key dimensions of connection: cognitive (comprehending the issue), affective (empathising with the issue), and behavioural (taking action on the issue) (Galeote et al., 2021; Geiger et al., 2017; Lorenzoni et al., 2007).

On a cognitive level, games serve as powerful tools for visually representing complex concepts. Understanding sustainable development necessitates a broader, holistic comprehension of the interconnectedness among diverse elements —a principle inherently tied to system thinking (Dieleman & Huisingh, 2006). A critical challenge in sustainable education and

[16] As mentioned earlier, engagement with sustainability requires also listening to public's values and local knowledges.

communication lies in integrating natural, social, and managerial sciences into a cohesive framework (Ibid.). Games offer a unique opportunity to immerse ourselves in and experience the behaviours of large and complex systems, enabling us to understand the effects of certain interventions within these systems. With their meticulously crafted worlds, encompassing sound elements and aesthetics such as storyline, characters, and mechanics, games have been demonstrated to serve as a powerful framework that brings together different stakeholders (Nygren et al., 2022).

On an affective level, empathising with such issues involves becoming emotionally invested. Games are particularly effective at fostering this emotional involvement due to the immersive elements such as rich narratives, compelling characters, and sometimes even atmospheric and sound design. This deep engagement with the game world allows players to develop a strong sense of connection to the issues being addressed, also fostering interest in the topic at hand. As players navigate complex ethical dilemmas and confront the consequences of their actions within the game, they can be prompted to reflect on their own values and beliefs. Consequently, games can spark new ethical perspectives and cultivate critical thinking skills (Qian & Clark, 2016), with high levels of realism serving to further enhance these outcomes. Realism in games, including the portrayal of multiple actors, environmental policies, and technological constraints, intensifies players' emotional connections and prompts deeper reflection on the implications of their decisions (Torre et al., 2021).

On a behavioural level, games serve as effective facilitators for taking action on the issues because they can create interactive spaces where reality can be experienced and transformed (Galeote et al., 2021). They provide experiential learning, wherein individuals acquire knowledge through direct experiences[17], providing a platform for testing solutions without real-world consequences (Plass et al., 2015). This enables players to experiment with various scenarios, explore different approaches, and observe the outcomes of their decisions in a safe and controlled environment (Dieleman & Huisingh, 2006). By allowing players to engage in hands-on problem-solving, games promote active learning and skill development (Qian & Clark, 2016). Moreover, the interactive nature of games can encourage iterative experimentation, empowering players to refine their strategies and adapt to changing circumstances. Ultimately, this experiential learning process not only deepens players' understanding of the issues but also can equip them with the knowledge and skills necessary to effect positive change in the real world.

Finally, and arguably most importantly, these three dimensions of engagement cannot exist independently but rather within a cultivated social context where the game unfolds. Games serve as a platform for social interaction (Ouariachi et al., 2017), enabling the exchange and co-

[17] Institute for Experiential Learning (2024)

creation of ideas through this social engagement, which is in line with social constructivist theories (Powel & Kalina, 2009). Through various dimensions of engagement, games offer the opportunity to create shared experiences, which is crucial as it lays the groundwork for shared problem definitions and consensus on potential solutions (Dieleman & Huisingh, 2006). This overarching dimension reveals the potential of the gaming format for contemporary scientific communication in line with current calls for dialogue and participation.

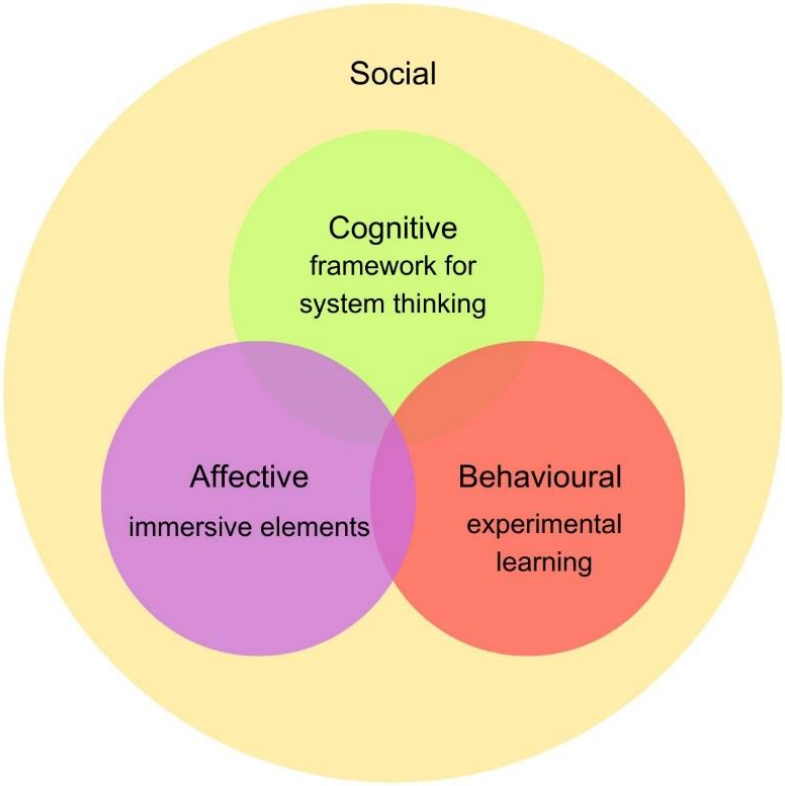

Figure 5 - Dimensions of Games for Engagement

As previously discussed, understanding science communication practices requires framing the event of communication in order to identify and analyse its relevant aspects. Given that games foster shared experiences, a critical area of inquiry that emerges from games is the examination of how they facilitate processes of meaning-making. Therefore, examining science communication within games could be approached from a cultural perspective. Furthermore, as games offer environments where problems can be approached from diverse perspectives, they have the potential to foster multidisciplinary understanding and collaboration (Dieleman & Huisingh, 2006). Analysing science communication through games can also be explored within the framework of a boundary space, which facilitates interactions between scientific and non-scientific domains (Horst, 2022), as well as between different social worlds (Nygren et al., 2022).

In conclusion, games represent an interesting avenue for science communication. Their ability to create immersive environments offers unique opportunities to explore current

frameworks of dialogue and participation. Thus, games can allow us to put into practice these more innovative and recent approaches to communication that have not yet been explored much through practical interventions. Due to their complexity, games can accommodate various communication models simultaneously. They can convey messages through compelling narratives (dissemination), evoke emotions to stimulate critical thinking (dialogue), and provide hands-on experiences (participation). Consequently, games emerge as a compelling format for sustainable and environmental communication, allowing the intricacies of post-normal situations to be represented in the depth they require. It is not surprising, therefore, that there is a burgeoning body of literature dedicated to games addressing sustainability and wicked problems in communication. Scholars have even proposed frameworks to guide the design of such games (Fabricatore et al., 2020). In the following section, some of these games will be reviewed to identify gaps in their creation and outline future necessary steps.

2.2. Review on (Serious)[18] Games for Sustainability.

As our society confronts ever more complex socio-scientific situations, meaningful conversations are essential but often challenging to foster due to the intricate nature of these issues and the diverse voices and ethical dilemmas involved. In response, new approaches in education and communication have recognised the value of interactive and engaging formats. Consequently, there has been a proliferation of gamified interventions, accompanied by a plethora of reviews documenting these trends. It is particularly noteworthy that many of these interventions leverage the concept of *serious games*.

Originally developed for non-entertainment sectors (Abt, 1987), serious games constitute a category of games designed to transcend mere entertainment. Instead, they focus on facilitating education, advertising, informing, and training players (Susi et al., 2007). Acting as platforms for knowledge acquisition and skill development, serious games immerse players in unfamiliar situations and have the potential to induce behavioural changes (Torre et al., 2021). While the term *serious game* is commonly used to describe educational games addressing environmental and sustainable issues, it is important to recognise that not all serious games focus primarily on

[18] The term “serious” is placed in parentheses to indicate my critical stance on its usage. Games labelled as serious are often used in educational and training settings. With the increasing demand for environmental education and awareness, more games are incorporating environmental themes and being classified as serious games (Tan & Nurul-Asna, 2023). However, not all games with sustainability themes qualify as serious games. For instance, *Monopoly Go Green* includes an eco-friendly element, allowing players to make properties more sustainable while still engaging in capitalist practices (Ibid.). Moreover, not all serious games address sustainability issues. The parentheses serve as a reminder of the need for a responsible and reflective approach to using the term *serious*, and the importance of such games to include thoughtful considerations on how serious elements are framed and how the public engages with such games.

education and sustainability[19]. However, upon closer scrutiny of games tackling environmental concerns, it becomes apparent that many interventions indeed fit within this classification. This is frequently attributed to the inclusion of serious elements, such as the use of real data for modelling and the dissemination of authentic information[20].

Systematic literature reviews on serious games for environmental purposes offer critical insights that help identify the most favourable characteristics for designing gamified interventions aimed at communicating sustainable development[21]. Simultaneously, they also shed light on formats and genres that have been less explored, indicating a need for further investigation to uncover potentially meaningful avenues within the specific context of this work. The initial broad classification of these games distinguishes between individual and group play. Single-player serious games are predominantly digital-based, including browser and smartphone games. This format offers the advantage of efficiently gathering substantial amounts of data, which can prove invaluable for evaluating game outcomes and for emerging methodologies like citizen science (Radchuk et al., 2017). Another classification can be established based on the genre of games, including puzzles, simulations, role-playing, adventure, and strategy. Among these, puzzles and simulations stand out as the most effective in terms of interaction and engaging game formats. Conversely, action games are less adaptable and may not facilitate adequate player engagement, often proving to be distracting (Ibid.). An important observation is that many digital games lack socialising features, and the combination of genres is, so far, unexplored (Ibid.).

In addition to digital formats, traditional board games –typically involving role-playing and strategy– offer a physical format that promotes social interaction and experiential learning. Because these features align with the aforementioned principles of sustainable development and the challenges posed by wicked problems, they are particularly well-suited for addressing complex environmental issues. These physical formats have been widely adopted in educational and communicative contexts to tackle such challenges. Numerous examples in the literature, such as those related to biodiversity offsetting (Nygren et al., 2022) and the circular economy (Manshoven & Gillabel, 2021; Whalen, 2017; Whalen et al., 2018; Whalen & Peck, 2014), demonstrate the potential of board games in engaging audiences and enhancing understanding and communication of these complex –and wicked– topics.

Notably for this work, a substantial body of literature has delved into the use of these games to facilitate circular economy education, particularly within university settings. As noted in

[19] Susi et al. (2007) review the many digital game applications related to health and healthcare, as these topics lend themselves well to representation in such formats.
[20] Susi et al. (2007) and Torre et al. (2021) review numerous instances where real-world data and information are utilised for constructing simulation models.
[21] See the works of (den Haan & van der Voort, 2018; Galeote et al., 2021; Radchuk et al., 2017; Tan & Nurul-Asna, 2023; Torre et al., 2021).

the review of Torre et al. (2021), these studies often aim to elucidate the financial dimension of circular business models (Manshoven & Gillabel, 2021) or to introduce the rationale behind the circular economy while targeting one crucial aspect of this approach, such as material criticality (Whalen et al., 2018). As a result, a significant gap in current research is the lack of engagement with broader audiences beyond university settings, coupled with the scarcity of attention given to such games for communication purposes. Furthermore, there is an underrepresentation of developing games around the concept of circular economy that tackles the socio-scientific aspects of the circular economy.

(Serious) Games represent a promising tool for science communication and public engagement; however, like any promising endeavour, they come with significant challenges. Firstly, developing the framework of a game and simplifying or exemplifying the reality it seeks to represent can be quite complex (Manshoven & Gillabel, 2021). This complexity can render games difficult to understand and, in some cases, very costly (Torre et al., 2021). Additionally, while it is believed that games can have a positive impact on the public, assessing their learning outcomes proves challenging in practice (Whalen & Kijne, 2019), leading to scepticism among some scholars regarding their effectiveness (Qian & Clark, 2016). Nevertheless, the adoption of such games is on the rise, especially in museums and institutions that have encountered similar challenges in the past. These establishments often possess the necessary infrastructure and expertise to address some of the hurdles associated with game implementation. Consequently, the final section of this literature review concentrates on exploring the role of games in museums and the current trend of integrating such games within these institutions.

2.3. The Museum Dilemma.

Places for Experimentation or Theme Parks?

Museums have become fertile ground for experimentation with innovative interactive formats of science communication. With the emergence of new trends in science communication, which seek to actively engage and involve the public in scientific discourse, alongside the ever-expanding array of technologies capable of captivating audiences and sparking fascination with science, they have undergone profound transformations over the past century (Cain & Rader, 2017). Indeed, technological advancements are increasingly finding their way into museum settings. Scholarly literature indicates that museums are actively exploring the realms of virtual, augmented, and mixed-reality experiences (Jung et al., 2016), with efforts underway to develop models to reflect on the transformative effects of these technologies (Trunfio & Campana, 2020).

The integration of new technologies into museums transcends mere changes in science communication's participation strategies. These advancements offer a plethora of additional

benefits for such institutions, ranging from surmounting physical limitations to enhancing the preservation and valorisation of cultural heritage. By embracing new digital formats, museums can provide alternative avenues for access, thereby reducing reliance on physical objects and mitigating the risks of degradation (Trunfio & Campana, 2020).

While these advancements undoubtedly offer great opportunities for museums, they also invite scepticism regarding the direction museums should take. Rader and Cain (2014) relayed the concerns of the director of Berkeley's Museum of Vertebrate Zoology, who lamented an apparent shift in the American Association of Museums towards prioritising dioramas over scientific discoveries. This sentiment was revisited by Cain and Rader (2017), who juxtaposed it with a more recent worry voiced by editors at Nature, questioning whether the pursuit of media attention risks commodifying museums into theme parks.

Science and natural history museums have grappled with the ongoing challenge of reconciling their dual objectives: attracting broader audiences while maintaining a focus on rigorous research (Cain & Rader, 2017). Yet, it is precisely this tension that imbues museums with their distinct enchantment and unique potential for science communication, warranting further investigation. It is for this reason that in the concluding section of this literature review, I delve deeper into these institutions and their innovative gamified approaches. A brief review will be conducted of the novel communication strategies adopted by museums, with a specific emphasis on the nascent role of (serious) games in enhancing scientific understanding and communication within these dynamic spaces. The objective is to illuminate the current state of experimenting with gamified formats in these specific contexts, identifying gaps that require attention in this regard.

2.4. Review on (Serious) Games in Museums.

Museums have increasingly embraced diverse technologies to engage audiences in novel and innovative ways, a trend substantiated by scholarly literature highlighting the growing significance of games (Anderson et al., 2010; Paliokas & Sylaiou, 2016; Wang & Nunes, 2019). This literature underscores how museums have adopted the concept of serious games as well, leveraging them to underscore the broader implications of their gamified interventions beyond mere entertainment. Paliokas and Sylaiou (2016) have noted a substantial rise in publications focusing on serious games for cultural heritage sites since 2009. These technologies enable museums to transform participants from passive observers into active participants (Aguirrezabal et al., 2014; Cordova-Rangel & Caro, 2021).

Museums adopt gamified experiences as a means to deliver their content in an engaging format, offering visitors enjoyable yet informative programs (Paliokas & Sylaiou, 2016). Moreover, such approaches are employed to promote new exhibitions and enhance visitor engagement as well (Cordova-Rangel & Caro, 2021). Considering museums' dual role as essential spaces for both formal and informal learning, these gamified formats often align with museum agendas by providing educational activities that complement classroom learning (Wang & Nunes, 2019). While the main objective of this work may not be explicitly focused on educational purposes, it's important to acknowledge that due to the nature of the intervention and its context, educational outcomes can naturally arise from the intervention.

In the academic literature, a plethora of examples illustrate the deployment of gamified interventions within museum contexts. While these approaches exhibit considerable diversity, it is noteworthy that they predominantly manifest as digital-based gamified interventions. One significant type is the use of prototypes and demonstrators. These are reconstructions of historical sites that visitors can explore, providing immersive experiences. Interestingly, such projects also serve archaeological exploration purposes, enabling archaeologists to test hypotheses related to the past in the present (Anderson et al., 2010). Another approach involves virtual museums, offering alternative means for presenting cultural heritage sites in the digital world (Ibid.). A third line of gamified interventions involves punctual games, which are developed as targeted interventions within museums to address specific topics or enhance the content of exhibitions (Cordova-Rangel & Caro, 2021). These games serve as focused tools to engage visitors and deepen their understanding of particular objects and content of the museum.

Gamified interventions have proven to be beneficial because they deliver an engaging format that is well aligned with the museum’s current objectives of fostering dialogical and participatory interactions with the public. Games provide interactive and captivating means for visitors to explore the museum’s contents from different perspectives and make the information more accessible and memorable (Anderson et al., 2010). As argued earlier, many museum’s agendas have evolved, opening open museum doors for a discussion of new –and sometimes controversial– research and discoveries in science and technology. Numerous museums aspire to be perceived as spaces where the values and ethical dilemmas of science and technology can be shared. Although many museum and science centre exhibitions continue to rely on established scientific and technological knowledge, I perceive the potential of alternative visitor formats, such as games, to serve as a conduit for the introduction of lesser-known facts, recent discoveries, and contentious issues associated with these subjects. This allows for the rapid expansion of exhibition content, enhancing the overall visitor experience and engagement.

On a related note, Paliokas & Sylaiou (2016) have observed that games can be crafted to suit various age groups and learning styles, thereby enhancing accessibility to a broader

audience. This observation is intriguing as it reveals the capability of games not only to captivate visitors through their inherent attractiveness and interactivity but also to customise experiences for different museum audiences. Thus, this versatility underscores the role of games as a tool for fostering engagement and enriching the museum-going experience for individuals of varying backgrounds and preferences – and even inviting marginalised publics.

As previously mentioned, studies on science communication in museums have categorised museum visitors into four distinct categories. However, I believe that these categories entail more complexity than they might initially show. The concept of "pure public" reflects a type of audience predisposed to learning, yet it surely encompasses more than mere receptivity. “Pure public” represents a spectrum of individuals with diverse cultural backgrounds, genders, and ages. This diversity makes pure publics less homogeneous, as they possess unique cultural values and interests that may vary among individuals. Therefore, games can enhance accessibility by encompassing reflections of segments excluded from the targeted "pure public" due to factors like age, gender, and culture. By considering these diverse perspectives, games have the potential to attract new audiences to museum spaces.

I believe that gamified interventions in museum spaces have the capacity to customise their content and objects to accommodate the diverse interests of their audiences while also facilitating a deeper comprehension of the complexity of these publics. This enables a revaluation of categorisations within more meaningful frameworks. Moreover, in the literature on gamified interventions in museums, there exists a gap beyond the traditional focus on education and enhancing museum content. Therefore, I find it meaningful to explore how such interventions can be used to facilitate discussions on controversial topics in science and technology that impact museum visitors. These discussions may intersect with the audience's existing values and concerns and shed some light on the creation of new publics within these spaces. Thus, such interventions represent a novel approach in this regard worth exploring.

In conclusion, games are emerging as valuable tools for museums and science centres to enhance science education and communication and promote public engagement. Consequently, they present an intriguing avenue for delving into how more dialogical and participatory approaches to science communication can be applied within museum spaces. However, they remain understudied, with existing literature predominantly focusing on their educational utility. Consequently, the potential of games as communication tools to facilitate dialogue on controversial topics in science and technology remains largely unexplored. Thus, it is crucial to investigate how such gamified interventions can be created and implemented to provide visitors with an interactive platform to explore, discuss, and engage with intricate issues that complement the exhibits' content and objects. Moreover, as highlighted by numerous scholars, there is a lack of standardisation and evaluation of gamified interventions; by establishing a long-lasting

intervention within these spaces that can be studied beyond the duration of this project, I am actively addressing the literature gaps that intersect the fields of science communication, gaming formats for environmental purposes, and museums.

3. Material & Methods

3.1 Research Design.

3.1.1 Exploring Gamified Interventions.

Dialogical and Participatory Approaches to Science Communication in Museum Contexts.

This study seeks to explore how dialogical and participatory approaches to science communication can be applied in museum spaces, particularly in the context of sustainable development. Museums, renowned for their diverse visitor programs, have recently embarked on exploring the potential of gamification as a means to enhance visitor engagement. Given the urgency of fostering discussions around sustainable development and the recognised role of museums as platforms for deliberating contentious issues in science and technology, I propose a gamified intervention aimed at facilitating communication on the topic of circular economy and the role of chemistry within this emerging sustainable paradigm.

While gamified interventions might have been studied in the realms of science communication, sustainability, and museum studies individually, scant attention has been paid to their intersection. The absence of such interventions underscores the novelty and importance of the proposed research endeavour. By developing a gamified intervention for sustainable development communication within a museum site, this study aims to shed light on its potential beyond traditional educational and experiential enhancement functions commonly associated with games in museums, as noted in the existing literature.

Through an ethnographic study, I aim to delve into the intricate nuances of the game design process, revealing how dialogical and participatory approaches to science communication can be developed and applied within museum settings. This involves providing a reflective account of the rationale behind specific design choices and the underlying messages that shape the various activities and storyline of the intervention. The primary research question guiding this study is as follows:

RQ: How can a visitor program, in the form of a game at the Chemistry Exhibition of the Deutsches Museum, cultivate public engagement on the topic of the circular economy while stimulating dialogue and discussion on the role of chemistry within this emerging sustainability paradigm?

This primary research question is approached from three different perspectives

SQ1: How can the **content** of the game be engaging and invite discussion? What strategies can I employ to construct and convey messages?

SQ2: How can the **format** of the game foster engagement and discussion? Which sub-formats should be integrated?

SQ3: How can the **mechanics** of the game facilitate better engagement? In what way are they contributing to engagement?

The methodology and data used in this study are designed and collected to explore these questions by analysing the three dimensions of the game: format, content, and mechanics.

This reflective analysis will offer valuable insights into how dialogical and participatory approaches to science communication can be applied in a museum and potentially new avenues for further research, such as how the public interprets these messages and how they construct meaning around the game's structural themes of chemistry, sustainability and circular economy. Therefore, it holds significance not only for its contribution to the field of science communication and advancement of innovative dialogue and participatory approaches but also for its potential to offer fresh insights into science communication within museum settings, prompting reflection on their audiences as well. Furthermore, the active involvement of key stakeholders, including the Educational Department, the curator, and the laboratory responsible for the Chemistry Exhibition at the Deutsches Museum, underscores the interdisciplinary nature of this study. While the primary focus lies in exploring the creation and implementation of a gamified intervention for sustainable development communication and circular economy, the engagement with museum professionals, in particularly the Educational Department, inevitably brings this work in the intersection with education and enhancement of visitor experiences in museums. While not the central focus, these aspects underscore the holistic value of the proposed intervention.

3.1.2 An Ethnographic Approach.

Ethnographic approaches have been widely employed in game design to delve into the complexities of real-world practices and discern the attitudes, practices, and environmental factors shaping the design process (Mol et al., 2017). In alignment with this tradition, the present study adopts an ethnographic framework to attain a multifaceted understanding of the iterative process involved in developing such an intervention in order to gain insights into how more participatory and dialogical approaches to science communication can be implemented in museum spaces.

This ethnographic research incorporates various methodologies to comprehensively explore the intervention's creation. Detailed field notes document a series of diverse meetings with stakeholders from the museum involved in the intervention's development. Additionally, feedback gathered from two rounds of testing with museum staff and three participating schools

enriches these field notes, providing insights into the game's limitations and the evolution of different iterations to address these issues. Moreover, recordings from discussion sessions integral to the final activity of the game, known as *The Final Puzzle*, conducted with three different schools, have been meticulously coded and integrated into the field notes to discern main trends and recurring themes of discussion around sustainability, circular economy and the role of chemistry in creating sustainable futures. This coding process is instrumental in unveiling the types of knowledge circulating among the public, thereby illuminating key narratives surrounding sustainability in public consciousness.

These methodological approaches facilitate systematic and controlled data gathering, aiming to offer insights into multiple dimensions. They not only deepen understanding of science communication and the value of participatory approaches but also shed light on how public understanding and engagement in science are shaped within a science communication event through the public's interpretations derived from the game. Furthermore, they elucidate the role of gamification in communicating complex sustainability concepts. By fostering dialogue on these topics, the study also contributes to an understanding of public discourse on sustainability-related issues, potentially prompting an investigation into the formation of diverse publics within museum spaces and contributing to a deeper understanding of visitor dynamics and interactions within museum environments.

3.2. CREISE: Eine chemische Reise durch die Kreislaufwirtschaft.

CREISE: A Chemical Journey towards the Circular Economy[22].

CREISE is a gamified intervention located in the Chemistry Exhibition of the Deutsches Museum to facilitate communication and engagement with sustainable development and the circular economy while fostering discussions on the role of chemistry within this sustainability paradigm. The development of this intervention took place during the summer and fall of 2023, with implementation and testing conducted during the winter of 2023-2024. CREISE offers a metaphorical escape-room experience wherein participants are challenged to discover sustainable principles or solutions in order to *escape* from one thematic island to the other. This differs from the traditional escape room experience since participants are tasked to find sustainable solutions rather than seeking codes to escape the different rooms. The game targets teenagers aged 14 to 18 years old who are encountering chemistry in high school for the first time. Using both the Modern Chemistry Area and the laboratory area of the Chemistry exhibition,

[22] CREISE is a wordplay combining the German words "Kreis," meaning circle, and "Reise," meaning journey. The use of "Creise" with the letter "C" suggests the chemical journey promised in the extended title of the intervention.

the game accommodates an entire school class, with a maximum of 30 participants playing at once. The game works as follows:

CREISE starts with participants assuming one of six main industry roles, each corresponding to a different thematic island within the exhibition. At the outset, participants select an industry role, and their mission is to explore ways to enhance sustainability and circularity within their respective industries. Each group engages in a unique combination of three activities consisting of two chemical experiments and one large-scale activity within the exhibition space. These activities provide participants with insights into potential strategies for making their industries more sustainable. Two of the activities pertain to industries external to the participant's own, emphasising the importance of interdisciplinary collaboration between industries and fields. The final activity corresponds to the participant's own industry, prompting a reflective examination of their specific case. Throughout the game, participants accumulate points by completing small and large activities[23]. With each completed large activity, participants earn a puzzle piece with extra points. Participants must collect a total of three puzzle pieces, one for each large activity. Once all activities are completed, the entire group reconvenes for the final activity –*The Final Puzzle*. During this activity, participants present their industries, outline associated problems, and share the sustainable solutions they have uncovered while assembling the puzzle pieces in front of their peers. Each group engages in this final activity, collectively constructing a larger puzzle. As all industries are present, participants will realise the puzzle is incomplete, prompting reflection on what is missing. This incompleteness symbolises the inherent deficiency of relying solely on chemistry to ensure a sustainable future, underscoring the need for additional forms of knowledge or support - political, financial, social, and beyond.

3.3. Site Selection.

3.3.1. The Deutsches Museum[24].

The selection of the Deutsches Museum in Munich, Germany, as the site for conducting this intervention is informed by both personal connection and the museum's suitability for such endeavours. My prior engagement with the Chemistry Exhibition during my master's degree, particularly through an internship experience where I designed a visitor program for the

[23] Being the large activities chemical experiments or activities in the exhibition area.

[24] In this section, various sources from the Deutsches Museum website have been consulted. These sources include:
Leitbild - Deutsches Museum (deutsches-museum.de)
Wer wir sind - Deutsches Museum (deutsches-museum.de)
Die Zukunftsinitiative - Deutsches Museum (deutsches-museum.de)

Exhibition's Visitor Laboratory, has provided invaluable hands-on knowledge and inspiration for expanding upon this initiative. Beyond personal motivations, the Deutsches Museum offers an ideal setting for interventions of this nature.

Regarded as a preeminent institution in the realm of scientific and technological museums on a global scale, the Deutsches Museum is committed to animating science and technology while accentuating their cultural significance through a distinctive array of artefacts. It endeavours to inspire and shape the future by transcending traditional roles of object collection and preservation, aiming to bridge research with education. The museum fosters public engagement with contentious scientific topics, facilitating free discourse and active participation in discussions concerning science and technology's societal impacts. It aims to equip visitors with critical thinking skills necessary for navigating a complex world influenced by scientific advancements, empowering them to engage meaningfully in political processes.

With a strategic vision to establish itself as a leading institution for science and technology, the museum actively cultivates dialogue on the planet's future, inviting diverse stakeholders to participate in constructive discourse. Furthermore, the museum is committed to modern scientific communication, continuously updating its exhibitions and infrastructure to incorporate cutting-edge technologies and communication methods. Noteworthy is the *Future Initiative*, launched in 2006, aimed at modernising the museum's exhibitions and infrastructure through the integration of contemporary technologies. This initiative has led to the introduction of new exhibitions reflecting current scientific understanding and engagement with science and technology. In 2015, a significant portion of the exhibitions on Museum Island in Munich were temporarily closed as part of the ongoing modernisation efforts. These exhibitions reopened in the summer of 2022, marking the first phase of the museum's extensive renovation. The reopening encompassed the complete redesign or updating of 20 permanent exhibitions, with the chemical exhibition being among them. However, it also entailed the closure of half of the museum, with its exhibitions scheduled to reopen in 2028. These efforts underscore the museum's dedication to staying current not only in terms of scientific content but also in the methods of communication used to convey it.

Within the confines of the exhibition space at the Deutsches Museum communication predominantly takes shape through exhibitions, a multifaceted format characterised by the presentation of objects and information in diverse ways. By leveraging a heterogeneous array of sub-formats within its exhibitions, the Deutsches Museum facilitates the simultaneous engagement of diverse audiences across varying levels of comprehension and interaction. However, exhibitions do not constitute the sole mode of communication within the museum's exhibition space. In tandem with exhibitions, the Deutsches Museum designs visitor programs

tailored to specific audience demographics, thereby augmenting accessibility and comprehension of exhibition content for the targeted public.

For these reasons, the Deutsches Museum is an exemplary institution to conduct this research. The innovative nature of the proposed communication approach aligns with the museum's ongoing efforts to innovate in the field of science communication.

3.3.2. The Chemistry Exhibition.

The Chemistry Exhibition at the Deutsches Museum underwent a more prolonged closure compared to the other exhibitions renovated in 2015. The preceding exhibition, dating back to 1972, was conceived as a comprehensive guide elucidating fundamental chemistry topics, including *Atom and Molecule* and *Analysis and Synthesis*. However, the exhibition primarily relied on visitor-activated chemical experiments through push-button mechanisms, lacking substantial contextualisation regarding the practical relevance of chemistry in everyday life. Its simplistic and outdated design fell short of the museum's elevated content standards, leading to the decision to close the exhibition in 2009[25].

In 2022, the revitalised Chemistry Exhibition opened with a fresh perspective, distinct from its predecessors. The new exhibition departs from expert-centric approaches and endeavours to immerse visitors in the realm of chemistry, showcasing and engaging them with the chemical phenomena in their everyday lives. Under the working title *Exciting Chemistry in Our Everyday Life*, its primary objective is to convey the message that chemistry permeates every aspect of our lives, both in historical and contemporary contexts. At its core, the exhibition wants to present Chemistry as an innovative, forward-looking science with universal relevance and responsibility[26]. To achieve this, the exhibition is organised into three main sections: Historical Chemistry, Laboratories, and Modern Chemistry.

The Historical Chemistry section features three walk-in dioramas representing different chemical laboratories: The Alchemical Laboratory, the Lavoisier Laboratory, and the Liebig Laboratory. Upon exiting these dioramas, visitors encounter a real laboratory setting. The laboratory area consists of two sections: the *Besucherlabor* (visitor's laboratory) and the *Hörsaal* (lecture hall). The latter also includes laboratory equipment for public demonstrations and science shows. In front of the laboratory area extends the area of Modern Chemistry, which shows the visitor the multiple aspects in which chemistry takes part in our modern life.

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[25] Rehn-Taube, S. (2011). Vorfreude auf die neue Chemieausstellung

[26] The curator, Susanne Rehn-Taube, presents the new chemistry exhibition in the video "Die neue Chemieaustellung" from the Deutsches Museum's YouTube Channel.
Retrieved from: https://www.youtube.com/watch?v=hhNDK3Gj4MU&ab_channel=DeutschesMuseum

3.3.2.1. How Engagement and Discussion Are Facilitated in the Chemistry Exhibition Through Familiar Contents[27].

In Modern Chemistry Area – the area where the intervention is being installed – it is remarkable how the exhibition's physical space is used to enhance the communication of its content. The content is divided into two kinds of information – basic chemistry knowledge and chemical knowledge in our everyday life – and so the space. The structural foundations of the exhibition space (walls and columns) are used to communicate the basics of chemistry. The only wall without windows or doors is dedicated entirely to the periodic system, while the columns represent the pillars of chemistry, such as chemical bonds or models. The other kind of information found is the one dedicated to chemical knowledge in our everyday lives. For that, the exhibition is divided into seven thematic islands, where seven aspects of our modern life are explained from a chemical perspective. In the next table, the seven islands are presented with their main elements:

ISLAND NAME	**MAIN ELEMENTS**
Energy and chemistry today and tomorrow	Raw materials and fuels - Oil - Alternatives: biomass Chemical Industry
Nutrition: Food is chemistry	Additives Chemistry in the food Chemical reactions in the kitchen Pesticides Fertilisers
Chemistry of today and tomorrow	Batteries and rechargeable batteries Hydrogen as fuel Liquid crystals Rare-earth elements
Chemistry in and around us	Cosmetics Chemistry in our body - Chemistry in the blood - Neurochemistry - Chemistry in the eyes Soaps Surfactants
Construction: What holds the world together	Lime Cement Concrete
High-performance thanks to chemistry	Polymers Polymers and clothes Adhesives Polyester Polymers and protection
Analytical chemistry: actual blood or just pigment?	Chemical analysis Different methods to analyse traces (solving a crime with chemistry)

Table 1- Thematic islands in the Chemistry Exhibition and their main elements of content.

[27] The subsequent sections stem from the material gathered in the Field Notes during the Summer of 2023.

The preceding table delineates the primary content elements featured across the various thematic islands. Here, it is evident how chemical knowledge is contextualised and seamlessly integrated into everyday life. Moreover, this contextualisation exemplifies the relevance and coherence of the new exhibition with contemporary dialogical and participatory paradigms of science communication. Thus, scientific information is not solely disseminated from experts to the public; rather, it emerges organically from the everyday experiences of the public themselves. By contextualising chemical knowledge, the exhibition fosters engagement with chemistry, prompting visitors to ponder, "What relevance does chemical knowledge hold in my near environment?". As a result, the new exhibition offers a space for visitors to immerse themselves in the presented scenarios, facilitating a deeper comprehension of new information as it resonates with familiar contexts. Relatable and familiar content is empirically proven to enhance memory retention, as it aligns with our experiences and interests, rendering it more relevant. Therefore, the new chemistry exhibition employs this content strategy to craft engaging messages, which are essential for sound science communication practices.

One last thing I want to highlight from the exhibition is the disposition of the content, which can be observed in the following map of the exhibition:

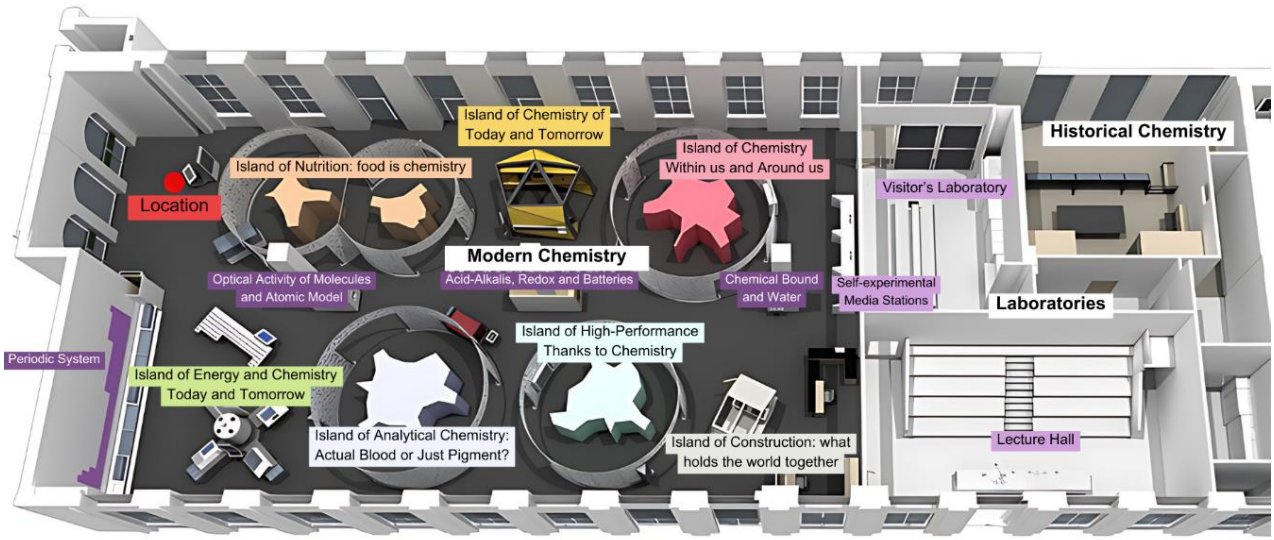

Figure 6 - Map of the Chemistry Exhibition of the Deutsches Museum – Deutsches Museum[28].

It is noteworthy how intertwined the content in the exhibition is to the same exhibition space and how the design of the exhibition at the same time tries to reinforce the different messages in the exhibition itself. The connection between the foundations of space and the

[28] This photo has been edited to show the names of the different areas inside the exhibition in English. The map shows the area of Modern Chemistry and the laboratories. The area of Historical Chemistry is partially visible, but not entirely, as it has an L shape that starts next to the Visitor`s Laboratory and extends to the right side of the map. In the Modern Chemistry area, the position of the seven islands and the fundaments of chemistry situated in the foundations of the exhibition can be identified.

fundamentals of chemistry is genius and beautiful, but this goes further. Thematic islands are an overarching physical format that is very effective in communicating a message because everything on the island connects to the main content of the island itself. Even the walls outside the island connect to the content of this one. As can be appreciated in the photo, there are white walls surrounding each island, and these walls have a pattern that resembles the content of the island. For instance, in the “Island of Chemistry Within Us and Around Us”, the walls are bubble-like since one of the main topics discussed on this island is soaps. in the “Island of Analytical Chemistry: Actual blood or just pigment?”, the walls resemble a spectrum, one of the techniques used in analytical chemistry. Moreover, every island has a different colour so that the visitor can intuitively understand what belongs together.

This very same organisation in the exhibition inspired me to create an escape room game as a visitor’s program because while observing the exhibition, I imagined every island as a small room and the visitor travelling from one island to another completing activity.

3.3.2.2. How Engagement and Discussion Are Facilitated in the Chemistry Exhibition Through Formats.

Format is how *things* are presented and in the exhibition space, *things* can be reduced to two categories: objects and information. Although this, at first glance, seems to be an easy separation, objects and information are difficult to separate because there is an entanglement between them. The physical appearance of an object informs us something about the object, but at the same time, objects are presented in a way that tries to convey specific information. The Modern Area of the Chemistry Exhibition exemplifies this complexity, employing a diverse array of formats to showcase its various objects and informational content. Through deliberate presentation strategies, the exhibition constructs a narrative to convey the exhibition’s main message that chemistry can be found in all facets of our modern lives. This strategy consists of creating the thematic island with their small sub-narratives unfolding through prominent banners bearing captivating titles. This narrative caters to the *pure public* and follows a structured format, typically featuring bold titles with wordplay, intriguing questions, or statements to capture visitors' attention. Titles are then elaborated upon in two to four paragraphs accompanied by relevant and/or interactive objects & information.

1ST STRATEGY OF ENGAGEMENT: **TITLES AND PARAGRAPHS**

Figure 7 - Photo Collection 1. **Message dissemination**: On the left, a photo from the "Island of Plastics and Polymers", on the middle from the "Island of Chemistry Around and Inside Us" and on the right from the "Island of Nutrition". All photos show a structure in the information presented – title in bold and explanation in short sentences and a maximum of four paragraphs. The objects try to make this information more understandable while appealing to different publics. As a clear example of that, in the photo of the "Island of Plastics and Polymers", the tablet on the left displays more detailed information about polymers, while the tablet in the middle with the metallic wheel is a small demonstration of how different types of polymers can have different strengths (if polymers are elastic the visitor can turn the wheel easily, while if there are not elastic, the wheel cannot be turned around). In the other photos, these differences in objects can also be found.

The presentation of objects and information that complements the main narrative can be made in more or less interactive ways[29]. This is not a binary classification but rather a continuum. For instance, objects typically displayed behind barriers, such as glass, present a less interactive format. However, objects equipped with buttons for visitors to press, despite barriers, demonstrate a higher degree of interactivity. Similarly, information can be categorised within the spectrum of interactivity. The interactivity of a piece of information is highly influenced by the interactivity of the object containing the information. However, information can also be interactive by itself, shaping the way in which the object containing the information should look like. Closed forms of information, such as factual statements on banners, are less interactive, whereas open formats, like rhetorical questions and visual aids, encourage engagement and critical thinking. Riddles, quizzes, and juxtaposition of contrasting information further enhance interactive information presentation.

[29]Interactive means reciprocally active, acting upon or influencing each other (Oxford English Dictionary)

Figure 8 - Photo Collection 2**. Interactivity in Objects:** On the left, the object is depicted in a static, non-interactive manner, while on the right, a more interactive display is presented. The interactive object on the right invites visitors to engage by touching it without any physical barrier.

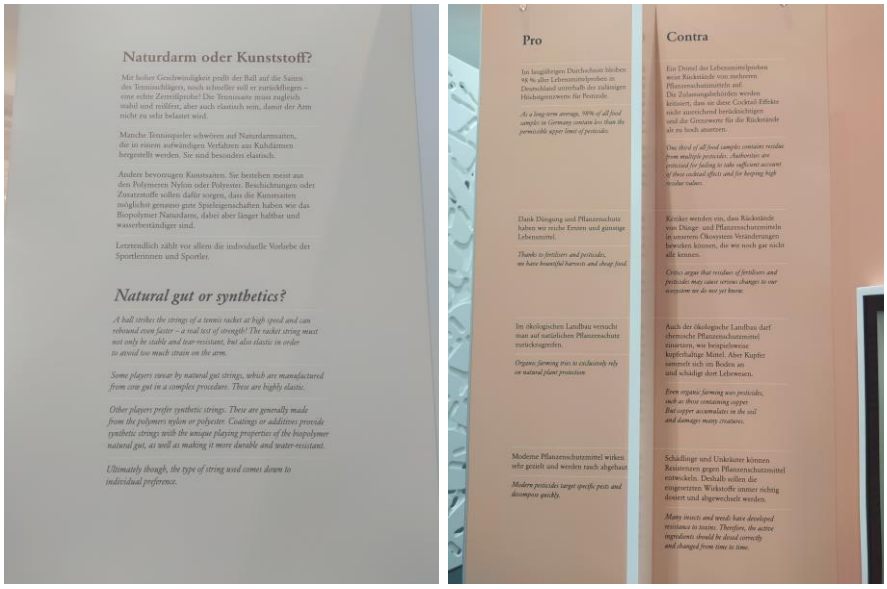

Figure 9 - Photo Collection 3. **Interactivity in Information**: On the left, the attention of the visitor is captured through a rhetorical question (Natural gut or synthetics?), and the reasons for each choice are explained, allowing the visitor to decide for themselves what they prefer. On the right, the pros and cons of using fertilisers are listed, with a dividing bar in the centre separating them and enabling the visitor to cover one side.

The degree of interactivity is crucial in engaging audiences with the subject matter. A more interactive format is a format that allows the visitor to act upon it and, therefore, promotes engagement with the message the format tries to convey. However, it is crucial to emphasise that interactivity alone does not ensure engagement, as the audience remains the central component of it. Despite being highly interactive, a format may fail to engage the audience due to various factors external to the format itself, such as content. Nevertheless, the format itself can also play a significant role, as evidenced by the following examples that illustrate how, although a main

narrative caters to a general “pure public”, different formats can allow for different kinds of engagement targeting segmented demographics.

In the Chemistry Exhibition, as well as throughout the entirety of the Deutsches Museum, the *Kinderspur* (kid’s trail) is a highly interactive format of communication that simplifies the main narrative of an exhibition to the children. Marked by a red owl, a character from the museum that guides kids during their visit, the *Kinderspur* allows children to experience the museum differently by following the owl through the exhibitions and engaging with objects and information adapted to their capacities. This approach creates a more meaningful way to engage children with messages that might otherwise be difficult for them to comprehend. Conversely, media stations installed within the exhibition provide more detailed information about the objects for visitors seeking in-depth knowledge on a topic. These examples, among others[30], indicate that by offering a variety of formats within exhibitions, diverse audiences can be engaged simultaneously on different levels. This is an interesting observation, as it highlights the ability of the Chemistry Exhibition to accommodate varied audience preferences and interests. While the overarching narrative may target a broad *pure public* demographic, the inclusion of specific formats of communication serves to resonate with distinct audience segments. Thus, these findings suggest a nuanced heterogeneity within the so-called *pure public* demographic.

3RD STRATEGY OF ENGAGEMENT: **ONE NARRATIVE, DIFFERENT FORMATS, DIFFERENT AUDIENCES**

Figure 10 - Photo Collection 4. ***Kinderspur* (Kids Trail):** The two photos on the left showcase how the exhibition caters to younger audiences. The red owl acts as a guide to interactive and age-appropriate activities, aiding children in understanding the exhibit's themes. Additionally, the images provide glimpses into the everyday lives of children (left photo, representation of different kinds of polymers with different daily objects), further enhancing their connection to the content. **Media Station:** The two photos on the right depict an exhibition's media station and part of its content, which offer visitors seeking deeper insights, access to additional facts on specific topics displayed within the exhibition.

[30] Another example are the objects and information adapted for people with reduced visually capacities.

I extensively discussed how formats foster engagement in the chemistry exhibition. However, there exists a complementary facet to consider—how can it also promote discussion? The emphasis on engagement is warranted, as meaningful discussion inherently depends on a solid engagement with the subject matter. Many of the strategies employed in the Chemistry Exhibition to foster engagement can also stimulate discussion. When information is presented openly –in a more interactive way–it tends to ignite discussion. Various strategies for sparking discussion can be observed, such as juxtaposing contrasting information –including pros and cons– on topics relevant to participants, such as the use of fertilisers, pesticides and cleaning agents, or posing rhetorical questions like whether the natural gut is superior to synthetic materials for tennis racquets[31].

TWO SIDES OF A SAME COIN**: AN STRATEGY FOR PROMOTING DISCUSSION**

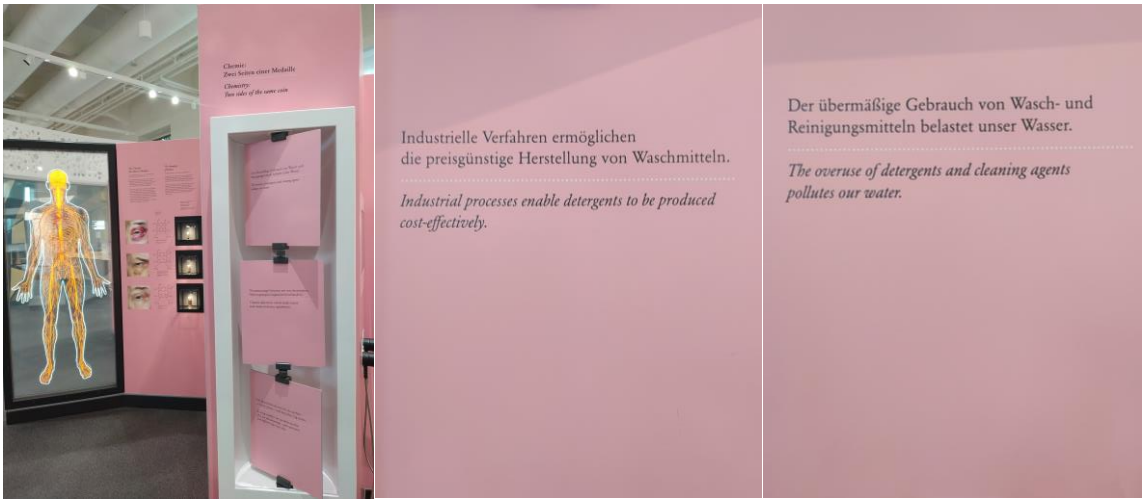

Figure 11- Photo Collection 5. **Formats to Stimulate Discussion:** In the foreground on the left, three distinct *coins* are prominently displayed. Each coin presents pros and cons regarding the use of personal hygiene products and makeup, with visitors able to flip them to view both sides. In the middle and on the right, close-up shots focus on one of these coins. The middle photo depicts how industrial processes enable cost-effective production of detergents, while the right photo highlights the issue of detergent and cleaning agent contamination in water.

[31] Fotos regarding the fertilisers and pesticides and the natural gut vs synthetic materials for racquets can be observed in photo collection X when showcasing interactive information.

3.4. Museum Stakeholders & Game Participants.

3.4.2. Museum Stakeholders.

The collaboration began with the Chemistry Exhibition at the Deutsches Museum, where I initially connected with Dr. Susanne Rehn-Taube, the curator, and Dr. Ilka Schmitt, the Visitor's Laboratory Responsible. Their consistent support and guidance were indispensable throughout the project. They provided invaluable advice and facilitated access to necessary infrastructure, granting me the autonomy to shape the intervention according to my vision. At the heart of our collaboration was a mutual objective: to develop a program that would remain integrated within the exhibition, thereby increasing its visibility to a wider audience. Recognising the substantial scale of the proposed gamified intervention, they facilitated connections with another department of the Museum renowned for its proficiency in large-scale interactive visitor programs—the Educational Department (Bildungsabteilung). This department hosts a diverse array of activities. Specifically, the division I collaborated with focused on programs tailored to families, youth, and educational institutions, encompassing holiday workshops, science shows, thematic summer schools, and more. Leveraging their proficiency in managing extensive and group-oriented visitor programs proved vital to the project's success. Contact with the educational department led to the essential collaboration with museum educator Franziska Kumm, a specialist in Actionbound interventions. Her team's expertise and assistance were invaluable in crafting a successful intervention. They actively participated in the early testing sessions of the game, providing highly appreciated feedback to ensure alignment with the museum's standards.

3.4.3. External Game Participants.

The intervention is tailored for teenagers aged 14 to 18 who are either encountering chemistry for the first time or have some prior experience with the subject in their high school curriculum. This demographic selection was a result of the collaboration with the educational department of the Deutsches Museum. Given the educational department's close ties with schools, it was deemed appropriate to focus the intervention on this specific age group. This targeted approach not only allows for the customisation of the experience to suit the needs and interests of teenagers but also ensures a homogeneous participant population. Hence, this homogeneity is advantageous for the coherent analysis of the intervention. Three tests were conducted with two different high schools in Munich—two tests involved the same school but different classes. All students were in the 11th grade, approximately 17 years old.

3.5. Data Collection Methods & Analysis.

The study of the creation and implementation of this game is approached from an ethnographic perspective, employing the following methods:

Participant Observation: Through my collaboration with the museum, I seamlessly became an integral part of its institution. This involvement required my attendance at meetings to report on the game's development, thus immersing me in the context I was studying: the implementation of more dialogical and participatory science communication practices within museum settings. Through this collaboration, I experienced the museum's social interactions and cultural practices and norms in the development of visitor programs. I gathered data from my interactions with the museum by documenting experiences. These included:

- **Team meetings with the Chemistry Department:** Team meetings with the curator, Dr. Susanne Rehn-Taube, and the person responsible for the Visitor's Laboratory, Dr. Ilka Schmitt, sometimes in the presence of other personnel from the Chemistry Exhibition.
- **Meetings with the Educational Department:** meetings with the museum educator Franziska Kumm.
- **Meeting with the Chemistry Department and the Educational Department:** Meetings with Dr. Ilka Schmitt and Franziska Kumm
- **Testing rounds of the game with the museum staff:** diverse testing rounds of the game with different personnel from the museum pertaining to the Chemistry Department and the Educational Department.

Additionally, I was invited to participate in two training sessions on the use of Actionbound in museums and two tests from other Actionbound interventions that were being developed in the museum as well. These experiences provided me with helpful insights into their methodology for program creation. All of this information is recorded in the form of field notes (although the meetings were in German, the field notes were written in English).

Artefact Examination: For a meaningful selection of the objects from the chemistry exhibition to include in the program, a careful examination of those was necessary. Artefact examination involved extended periods within the Chemistry Exhibition, meticulously observing the presented information and artefacts. The goal was to seamlessly integrate them into the game, fostering a cohesive narrative that harmonises with the exhibition, thus creating a unified and immersive experience. This approach to data collection also involved the documentation of observations in the form of field notes and photos to inform further development and refinement of the game.

Discussion Sessions: The final activity of the game –*The Final Puzzle*– serves as a dedicated forum for participants to engage in reflective dialogue regarding their experiences. The session is crafted to cultivate profound discussions surrounding the elements needed for a sustainable future, and it is structured around two questions that require participant groups to collaboratively address and present their findings to the other participants:

1. What is your industry and your associated environmental problems?
2. What can you do to make your industry more sustainable?

Through these inquiries, participants not only share insights garnered from the game but also utilise it as a catalyst for exploring sustainable development strategies and the role of chemistry in those. However, upon the puzzle's assembly, participants are confronted with a realisation that their individual solutions may fall short of achieving comprehensive sustainability: the puzzle is incomplete. This revelation prompts further discussion through the question:

3. It appears that our collective solutions are insufficient to ensure a sustainable future; what might be missing?

Participants initiate discussions on non-chemical activities that can complement chemical practices and contribute to sustainable development.

These sessions were conducted in German and recorded through filming and voice recording. The recorded interactions (in German) were transcribed (in German), and an initial round of coding was conducted directly in English to identify major discourse trends.

Actionbound App: The decision to employ the Actionbound App as a digital facilitator within the game stemmed from its capability to store and access player responses. Consequently, the collected responses from participants were utilised in the study and analysed. This analysis was conducted through observation of the response patterns and to identify areas within the game requiring modification or adaptation. Furthermore, some of the response patterns, while compared with the discussion round codes, also provided insight into the elements of the game that resulted in more engaging than others. Such observations are collected in the field notes of the school tests.

Physically collected material: Physically collected material includes two game activities that provide additional game answers not collected through Actionbound and final feedback on the game. The first activity involves participants filling out a formulary during the Material Passports activity, where they brainstormed new lives for objects salvaged from a soon-to-be-demolished building. The second activity entails the final arrangement of the puzzle created in *The Final Puzzle* activity, as classrooms may complete the puzzle differently using distinct missing pieces.

Both materials offer insights into how participants construct sustainable meanings within the game. Additionally, there is a small feedback sheet that school participants completed after testing the game, rating on a scale from 1 to 10 if…

1. I liked the game
2. I found it interesting
3. I learned something
4. I find a game an adequate format

The data collected from these three different materials were analysed through observation and documented in the field notes for each corresponding test.

A chronological overview outlining the key methodologies employed during the game's design and implementation phases is presented in the following table:

EVENT DESCRIPTION	**DATA COLLECTION METHOD**	**REMARKS**
Examination of the Chemistry Exhibition	Field Notes, Summer 2023	Examination of the content of the exhibition. Collection of material mainly through photos
1st Team Meeting with the Chemistry Department	Field Notes, 17.04.2023	Presentation of the initial game idea
2nd Team Meeting with the Chemistry Department	Field Notes, 17.07.2023	Presentation of the first draft of the game concept
1st Meeting with Educational Department	Field Notes, 17.08.2023	Presentation of the game and initial contact with the App Actionbound
Actionbound Training	Field Notes, 18.09.2023	Training session on how to use the app Actionbound
Diorama Drama Test	Field Notes, 18.10.2023	Participation in a test of an Actionbound in the museum
Espionage Test	Field Notes, 16.11.2023	Participation in a test of an Actionbound in the museum
1st Test CREISE with Museum Staff	Field Notes, 29.11.2023	The first test of the game in the museum, was conducted with museum staff as participants
2nd Meeting with Educational Department	Field Notes, 06.12.2023	Feedback session following the first test, involving discussions on significant revisions for the second version of the game, including the streamlining of activities from 6 to 3

2nd Test CREISE with museum staff	Field Notes, 15.12.2023	Recorded feedback, transcribed and coded	Transcription and coding are integrated into the field notes
1st Test CREISE with Schools	Field Notes, 15.01.2024	Recorded discussion and feedback, transcribed and coded	Transcription and coding are integrated into the field notes
3rd Meeting with Educational Department	Field Notes, 15.01.2024		Feedback session following the school test, during which the final activity was revised to integrate industry cards into the concluding puzzle
2nd Test CREISE with Schools	Field Notes, 29.01.2024	Recorded discussion and feedback, transcribed and coded	Transcription and coding are integrated into the field notes
Meeting with the Chemistry Department and the Educational Department	Field Notes, 05.02.2024		Discussion on the future of the game and next steps for the game's integration into the museum
3rd Test CREISE with schools	Field Notes, 04.03.2024	Recorded discussion and feedback, transcribed and coded	Transcription and coding are integrated into the field notes
3rd Test with Museum Staff	Field Notes, 20.03.2024	Recorded discussion and feedback, transcribed and coded	Presentation of the game to new interns of the educational department
Actionbound Training Course	Field Notes, 21- 22.03.2024		2-day training course on how to conduct Actionbound interventions in the museum
CREISE Training	Field Notes, 22.04.2024		Training on how to conduct the game in the museum, Handing over the game to the museum
Reflections on CREISE	Field Notes, Winter 2024		Compilation of field notes derived from the transcription and coding processes, capturing impressions and reflections following the implementation phase that could not be assigned to punctual events.

Table 2 - Summary of collected material and related events in the development of the game and its implementation in the Chemistry Exhibition.

3.6. Ethical Considerations.

Voluntary participation: The schools engaged in the test rounds voluntarily, driven by their own interest and motivation. No economic compensation was provided to the schools, and the test

rounds were conducted free of charge. This ensured that participation was based solely on the schools' willingness to contribute to the study's objectives without any external incentives.

Informed consent: Prior to recording any participants, an informed consent form was shared with the schools, who then distributed it to the families of underage participants. Permission from parents or legal tutors was obtained before any data collection activities commenced. Participants were fully informed about the study's purpose, duration, and the confidential handling of their data and recordings. Their agreement to participate was obtained after understanding and agreeing to these terms.

Confidentiality: The identities of all participants are kept confidential, and any personally identifiable information is anonymised. Answers and information collected during the study were aggregated and reported in a manner that prevented individual identification. This safeguarded the privacy and confidentiality of participants' data throughout the research process.

Potential for harm: Measures were implemented to minimise the potential for physical harm during the study. Clear instructions on the safe use of the chemical laboratory were provided at the beginning of each session, and all chemical experiments were meticulously designed using the safest substances and products available. This ensured that participants were not exposed to any unnecessary risks or hazards during their involvement in the study.

3.7. Reflexivity.

As the primary researcher conducting this study, it is crucial to acknowledge my position and recognise the potential biases that may have influenced both the process of data collection and subsequent analysis. With a background in chemistry and a longstanding interest in sustainable development, my prior experiences and predispositions could have shaped my interactions with participants and influenced the interpretation of their responses.

In response to these considerations, reflexivity has been integrated into the research framework to critically reflect on my experiences and the findings. Prior to commencing data collection and throughout the game design phase, a deliberate process of self-reflection was undertaken to identify and interrogate any personal biases or preconceptions that might have impacted the study's outcomes. This involved immersing myself in diverse literature and engaging with alternative perspectives on sustainability, challenging prevailing societal discourses, and actively seeking to broaden my understanding of the subject matter. The open-ended discussions within the game itself were strategically employed to facilitate a dialogue between my own

viewpoints and those of the participants, thereby facilitating a more nuanced exploration of the research topic and reducing potential biases in the data collection process.

In the documentation of field notes during the data collection phase, a concise reflexive analysis was incorporated to capture my thoughts, emotions, and reactions during interactions with participants. This method allowed for critical self-reflection on my role in shaping the research process. Furthermore, regular feedback sessions were conducted with museum personnel, who served as invaluable critical allies throughout the research endeavour. These sessions provided an opportunity to glean insights into school dynamics and recurring themes from discussions. More importantly, they were critical for deliberating on necessary adjustments to the game design and ensuring better accommodation of the target demographic and an enriching experience within the museum setting and beyond the study's immediate objectives.

By continually engaging in reflexivity and soliciting input from external sources, concerted efforts were made to reflect on the influence of personal biases and uphold the integrity and credibility of the study's findings within an academic context.

4. Results

CREISE is a game-based visitor program situated within the Chemistry Exhibition of the Deutsches Museum, designed specifically for teenagers aged 14 to 18 who are starting to discover chemistry in high school. I designed this innovative game in response to the following research inquiry: “How can a visitor program, in the form of a game at the Chemistry Exhibition of the Deutsches Museum, cultivate public engagement on the topic of the circular economy while stimulating dialogue and discussion on the role of chemistry within this emerging sustainability paradigm?”

To address this question comprehensively, I approached the problem from three distinct angles. Firstly, I explore the content of the game, reflecting on how it has been designed to foster engagement and discussion on sustainable chemistry & circular practices in our industry. Drawing inspiration from the methodology that the chemistry exhibition employs in crafting engaging content, I embarked on a similar process of curation for the game. This involved formulating a core message and subsequently deconstructing it into smaller thematic units. Hence, I developed a primary message for the game alongside an array of sub-messages corresponding to the different thematic islands within the exhibition. Furthermore, in curating the content, I adopted a selection process prioritising familiarity, relatability, and relevance as a means to enhance engagement. In this first section of the results, I expose then this curation process in detail, elucidating the methodological framework used. Subsequently, I briefly explore participant engagement with the messages from the final game discussions.

Secondly, I examine the format of the visitor program –a game– aiming to decode how it can facilitate engagement with the topic within the specific site of the intervention. Through this critical examination, I distinguish how other forms of engagement inherent to the topic and the location emerge, offering avenues to reinforce engagement with the broader themes of sustainable development and the circular economy – through engagement with chemistry and engagement with the exhibition. In the context of CREISE, the primary format is a game, but smaller formats have been employed to enhance engagement(s) in this particular setting. Such formats include chemical experiments, curated objects & information selected from the exhibition, and a digital app—Actionbound. Reflecting on participants' experiences, I assess the different formats and argue that the Actionbound app serves as a unifying medium that seamlessly integrates chemistry, the exhibition, and the circular economy into a cohesive experience.

Lastly, I delve into the distinctive perspective provided by the game format: mechanics. When employing games as a medium for science communication, considerations of format and content alone are insufficient. It is also crucial to evaluate the role of gameplay mechanics and how they

contribute to engagement and discussion. Mechanics encompass the methods by which the game facilitates participant interaction, distinguishing them from the game's format and content by defining how participants engage with both. Therefore, I conclude by examining the intricacies of game mechanics, with a particular focus on roles and point systems, reflecting on their well-thought design to foster engagement with the discussed topic.

4.1. Content.

4.1.1. Translating exhibition content into game content.

Similar to the approach employed in the Chemistry Exhibition, CREISE uses a thematic framework to curate objects, information and construct a cohesive narrative within the exhibition space. In CREISE, a comparable methodology was adopted, wherein a central working message served as the foundation. This overarching message was subsequently deconstructed into smaller thematic ones, each serving as a focal point for narrative development. Through an iterative process, content from the exhibition was strategically selected to reinforce these thematic messages and build the narratives within the game. This section delves into the formulation of the overarching message, the delineation of smaller thematic ones, and the construction of the narrative(s) of CREISE.

4.1.1.1. The main message. Imagining a sustainable future through chemistry.

The main topics of the game are sustainable development, circular economy and chemistry, and the main message I wanted to convey is that: *imagining a "sustainable future" does not mean thinking about the ways to have a "chemical-free future" but engaging in a conversation about how chemical knowledge can be used to make our industries more sustainable.*

In broader terms, the main message served as a compass for identifying suitable elements in the exhibition that could be integrated into the game in terms of content and format. Additionally, it served as a toolkit for developing new activities and experiments – new formats with new contents – and defining positive reinforcing game mechanics.

4.1.1.2. The small messages. Integrating circular chemistry principles in the game's sub-messages.

For the creation of small messages, I drew inspiration from the *Principles of Circular Chemistry*. *Circular Chemistry*, a novel concept introduced by Tom Keijer, Vincent Bakker, and J. Chris

Slootweg in a commentary published in *Nature Chemistry*[32], extends the notion of sustainable and green chemistry to encompass all chemical processes and products. Given that my objective is to develop a game that communicates the role of Chemistry in the Circular Economy, it is crucial that this role aligns with the contemporary perspective of what a "fully sustainable" chemistry should look like. My approach for the game is to reinforce the main message by enacting messages of circular chemistry on each island. The 12 principles of circular chemistry are the following:

1. Collect and use waste	Waste is a valuable resource that should be transformed into marketable products.
2. Maximise atom circulation	Circular processes should aim to maximise the utility of all atoms in existing molecules.
3. Optimize resource efficiency	Resource conservation should be targeted, promoting reuse and preserving finite feedstocks.
4. Strive for energy persistence	Energy efficiency should be maximised.
5. Enhance process efficiency	Innovations should continuously improve in- and post-process reuse and recycling, preferably on-site.
6. No out-of-plant toxicity	Chemical processes should not release any toxic compounds into the environment.
7. Target optimal design	Design should be based on the highest end-of-life options, accounting for separation, purification and degradation.
8. Assess sustainability	Environmental assessments (typified by the LCA) should become prevalent to identify inefficiencies in chemical processes.
9. Apply a ladder of circularity	The end-of-life options for a product should strive for the highest possibilities on the ladder of circularity.
10. Sell service, not a product	Producers should employ service-based business models such as chemical leasing, promoting efficiency over production rate.
11. Reject lock-in	The business and regulatory environment should be flexible to allow the implementation of innovations.
12. Unify the industry and provide a coherent policy framework	The industry and policy should be unified to create an optimal environment to enable circularity in chemical processes.

Table 3 - The twelve principles of Circular Chemistry. Keijer, Bakker, Slootweg (2019).

Guided by these foundational principles, sub-messages for the thematic islands of the Chemistry Exhibition are created in the game and clustered into different ones[33]:

[32] (Keijer et al., 2019)

[33] The assignment of the various Principles of Circular Chemistry and the subsequent creation of messages underwent an iterative process to ensure alignment with the activities on each island, as well as with the selected objects and information. The process involved the rearrangement of principles from one island to another and the reformulation of

ISLAND NAME	PRINCIPE(S) OF CIRCULAR CHEMISTRY	MESSAGE
Energy and chemistry today and tomorrow	10. Sell service, not a product 11. Reject lock-in 12. Unify the industry and provide a coherent policy framework	Chemistry alone cannot make our future more sustainable; we also need other things, such as a supportive policy and an open mindset.
Nutrition: food is chemistry	2. Maximise atom circulation. 9. Apply a ladder of circularity.	It is important to design products that can be safely returned to the soil; otherwise, we will only be extracting resources, contributing to soil depletion. Chemistry helps us design such products.
Chemistry of today and tomorrow	4. Strive for energy persistence 7. Target optimal design	Everything in the world contains energy: think outside the box to unlock sustainable ways for energy production. Chemistry helps us identify such potential energy sources.
Chemistry in and around us	8. Assess sustainability	Sustainability is assessed locally: practices that make sense in a particular environment can be ineffective and unsustainable in other places. Chemistry helps us understand such differences.
Construction: what holds the world together	1. Collect and use waste	Waste is material without identity: by giving identity to the materials, we can track them and find new ways to use them at the end of their lives. Chemistry helps us assess the properties of materials and identify new uses for them.
High performance thanks to chemistry	3. Optimize resource efficiency 5. Enhance process efficiency	Resource efficiency: Plastics are valuable materials crucial for sustainability due to their diverse properties. Understanding the necessity of different types of plastics and implementing proper usage and recycling methods is essential for maximising their benefits while minimising environmental impact. Chemistry can help with that!
Analytical chemistry: actual blood or just pigment?	6. No out-of-plant toxicity	No toxicity: No toxicity starts by not using toxic substances that can endanger the environment. If the use of these substances is necessary, then proper management is mandatory. Filters are an important element for that. Chemistry helps to assess toxicity and select greener alternatives.

Table 4 - Creation of sub-messages (namely, the main messages in each island) by combining islands with Principles of Circular Chemistry.

The message assigned to the first island, titled *Energy and Chemistry Today and Tomorrow*, may initially appear somewhat disconnected from its chemistry content. This is because the themes addressed on this island extend beyond conventional chemical knowledge.

messages and reselection of objects and information multiple times to achieve the final coherence presented in the table.

As illustrated in Table 2, topics such as raw materials and the chemical industry are explored here. However, in the game, this island is called the *Island of Industry* and serves not as a central activity hub but rather as both a starting point and a finishing line. At the outset of the game, it functions as an introduction, where the Industry Roles within the game are assigned[34]. As a concluding point, the island serves as a place for reflection on how the themes explored throughout the game can contribute to the creation of sustainable futures. During this reflective process, participants will discuss the various messages conveyed by the different islands and consider the role of chemistry in shaping the future. Moreover, they will also come to realise that sustainability cannot be solely achieved through chemistry alone, prompting a discussion about other essential elements that are missing, such as policy and an open mindset.

4.1.1.3. The selected content in the islands. Fostering engagement through carefully curated information.

In the game, each island has a unique curated story and small activities in the form of quizzes to make the main story more interactive[35]. These narrative threads and quizzes serve the dual purpose of enhancing participant engagement and providing contextualisation for the island's central activity, thereby reinforcing the thematic message intended by each island. Essentially, each island features a primary activity integral to its resolution, which serves as a vehicle for communicating the island's overarching message. This central activity manifests either as a chemical experiment – and the participants need to go to the visitor's laboratory – or as an activity constructed from additional materials that takes place on the island itself. The islands' crafted stories and content are showcased in the boxes below.

ENERGY AND CHEMISTRY TODAY AND TOMORROW (ISLAND OF INDUSTRY)
The *Island of Industry* is pivotal in the game, marking its beginning and end. Because of this role, rather than selecting existing content from the island to create the narrative of the island, new material has been developed to introduce the game in a way that feels connected to the exhibition. At the beginning of the game, the content of this island is structured as follows: 1. **Welcome and general information about the game:** Participants are introduced to the game's purpose and what they'll uncover as they play. 2. **Chemistry and its relationship with nature:** Exploring how chemistry helps us understand natural processes, emphasising the harmony and lack of waste in nature's cycles. 3. **Chemistry and its relationship with modern life, a threat to "nature"?** Chemistry has significantly contributed to modern lifestyles, wealth, and industrial development, albeit posing certain dangers to natural cycles and environments.

[34] Further elaboration on these roles will be provided in the "Mechanics" section. For now, the Industry Roles refer to the roles assigned at the beginning of the game to each group of participants. Consequently, the participants represent an industry during the game, with their objective being to find ways to make their industry more sustainable.

[35] This story and activities are programmed in the Actionbound App; therefore, when talking about content, we are implying the content presented in this App. The entire game can be found in the Annex.

ENERGY AND CHEMISTRY TODAY AND TOMORROW

4. **Problems of our current industry:** Many issues arise from the linear approach of our industrial processes, which disrupt natural cycles.
5. **Circular economy, what it is, and how it can contribute to a more sustainable future:** Explaining the concept of decoupling economic growth from finite resource use and previewing strategies to be further explored in the game.

At the game's conclusion, *Industry Island* serves as a space for reflection, discussion, and *The Final Puzzle* activity. Participants can summarise their experiences and propose solutions for enhancing industry sustainability. The puzzle activity underscores the message that sustainable futures require more than just chemistry, leaving room for participant dialogue on additional essential elements.

NOURISHMENT: FOOD IS CHEMISTRY

The island in the game is named *Nourishment Island* and focuses on promoting the importance of composting & creating products that can safely return to the soil. For that, different exhibition elements of the thematic island were selected, all of them part of the *fertilisers section* –or using the museum's original title *Fertiliser: food for our plants*. The content of this section in the museum is divided into five subsections, and two of them were selected for the game: *What do plants need to grow?* and *Nutrition to our food*. The first section explores the different elements that a plant needs to grow, and the second one explains what happens if these elements are not present in the soil.

These two elements from the exhibition are combined with external information and a main activity –a puzzle exclusively created for the game that shows the different cycles of a product– to create the whole story of the island, which unfolds as follows:

1. **Nutrients are needed in the soil:** The exhibition section *What do plants need to grow* serves as the hook of the island. It features a kid-friendly puzzle presenting essential plant molecules, allowing participants to gain insights into soil necessities by completing it as the first island activity.
2. **Composting: circular method to return nutrients to the soil:** This is connected to the main activity on this island, which is to complete step by step the exclusively created puzzle that contains different cycles for a product. The first cycle is the composting cycle, which is found in our daily lives and is a sustainable way to create the nutrients our plants need to grow.
3. **Soil depletion: a serious problem in agriculture:** The need for nutrients for a plant to grow is connected to the fact that in harvesting the plant, the nutrients inside the plant are not returned to the soil, resulting in nutrient deficiency.
4. **Agricultural waste: the nutrient paradox:** The content of the exhibition is extended by externally curated content. Participants learn about the paradox of soil depletion alongside the mismanagement of agricultural waste.
5. **Creating new uses for agricultural waste:** Participants are asked to complete the second circle of the puzzle, which reveals a circular practice: the creation of textiles from agricultural waste.
6. **Closing the circle: can we simply compost textiles?** Participants are tasked with completing the last puzzle circle, depicting the composting of the textile and its return to the soil. This prompts them to question the feasibility of the process and encourages critical thinking about product circularity and sustainability claims. Particularly, when biodegradable materials are mixed with toxic substances harmful to soil, the supposed circularity may be compromised.

CHEMISTRY OF TODAY AND TOMORROW

In the game, the island maintains the exhibition's name and focuses on sustainable energy production, highlighting various methods of harnessing energy. Content from the *hydrogen as fuel* section –originally named *Hydrogen: the lightest element* in the museum– was chosen to convey the message that sustainable energy can be produced in multiple ways. This includes a model demonstrating circular energy production through hydrogen and a video explaining it. The main activity involves a chemical experiment to create a bio-battery, showcasing hands-on sustainable energy generation.

The constructed narrative unfolds as follows:

1. **Everything in the world contains energy, and energy is the foundation of our modern life:** Participants are directly confronted with a key message: that everything in the world contains energy in different quantities. Humans have developed various methods to harness this energy throughout history. Energy is the pillar of our modern society and is expected to continue growing in importance in the future. However, the question arises: are these methods sustainable?
2. **Hydrogen fuel cell: a circular energy production method used in nature as well!** Participants are invited to explore a *sustainable* and circular method of energy production, understanding how it works and why it is considered circular. Simultaneously, they confront the reality that the yield of this method is low. Nonetheless, nature utilises a similar method to create energy, albeit coupled with numerous chemical reactions, making it profitable. Will we be able to do the same in the future?
3. **Bio-batteries: unleashing the power of the earth:** Participants are invited to visit the laboratory to discover another method of sustainable energy generation. Through hands-on practice, they explore how these batteries function and are prompted to consider potential applications.

CHEMISTRY IN AND AROUND US

In the game, the island maintains its original exhibition name and focuses on the local environment, stressing the importance of local thinking. Content selected from the soap and surfactants section –the museum's original names: *Soap: Clean Chemistry* and *Surfactants: Small Head and Long Tail*– includes objects displaying the effects of hard and soft water on clothes, along with explanatory texts on surfactant use and detergent composition and influence of water types. These elements, together with external information and a chemical experiment in the visitor's laboratory, demonstrate how water types affect soap reactions. The island's main narrative revolves around water types, highlighting the significance of local differences for environmental solutions and the importance of assessing these locally:

1. **Water is not the same everywhere:** Participants are first introduced to an example used to convey the main message that water is not the same everywhere and may have varying consequences. Different water types may imply different environmental conditions.
2. **Surfactants, soaps and water:** Participants briefly gain insights into the different elements found in detergents, the role and use of surfactants, and their consequences. Simultaneously, participants observe that different types of water react differently with soap, which they could witness firsthand through an object in the exhibition.
3. **Hygiene and health are connected to our environmental conditions:** This statement is presented to participants to help them scale up their observations to the broader environment. Due to varying environmental conditions, not all health and hygiene practices are effective or sustainable everywhere.
4. **Hard water and soft water: different waters, different chemical reactions:** At this point, participants are invited to the laboratory to observe everything from a chemical standpoint.

CONSTRUCTION: WHAT HOLDS THE WORLD TOGETHER

In the game, the name of this island is just *Island of Construction* and emphasises the importance of infrastructure for material tracking and salvage. The selected exhibition's content is a tablet that displays information on the chemistry of construction, briefly mentioning the environmental impact of the construction industry. The other element is a picture illustrating the CO2 footprint of concrete. These elements, along with externally curated information and an exclusive activity on material passports, form the island's narrative:

1. **The big ecologic footprint of concrete:** Participants learn about concrete's significant ecological footprint.
2. **More materials: more value:** Additional content enriches the exhibition, highlighting not only traditional construction materials displayed in the exhibition –lime, cement, and concrete– but also the abundance of other valuable materials used in construction. Participants are made aware of the risk of losing the value of these materials during demolition, where they are often indiscriminately mixed and crushed together.
3. **Demolition waste: is it properly handled?** Participants are informed about Germany's demolition waste volume and relatively high recyclability rates. However, despite these statistics, participants are prompted to ponder whether this implies optimal material usage.
4. **Material passports, materials with identity:** Within this context, participants should grasp the energy- and resource-intensive nature of construction. Additionally, they should recognise that recycling demolition waste may not always be the most effective solution, as it does not guarantee optimal material usage. Reusing materials directly could conserve energy and resources that would otherwise be expended in demolition and recycling processes. Material passports are essential for tracking these optimal material uses, ensuring intelligent and sustainable practices.
5. **Salvaging materials from an old house and bringing them into a new one:** The main island activity involves connecting materials from old houses to their respective passports and brainstorming new uses. This practical experience underscores the importance of sustainability in construction.

HIGH-PERFORMANCE THANKS TO CHEMISTRY

In the game, the island retains its exhibition name and emphasises the significance of discussing plastics and their recyclability. Elements from thematic sections on polymers and polyester, originally named *Molecule Chains - What Are Polymers* and *Polyester - A Multifaceted Synthetic*, are chosen to convey this message. These elements include one text explaining polymer creation, plastic waste objects, and a recycling process video. External information and a laboratory experiment illustrating plastic separation principles complement the narrative of the island, which unfolds as follows:

1. **Reducing the amount of plastic is a first step towards sustainability:** The story begins with the main component of plastic, oil, which itself significantly damages the environment. The first step to reducing the impact of plastic on the environment is to decrease the amount of plastic used in our daily lives. Participants reflect on which objects are easier to substitute with non-plastic alternatives.
2. **Reducing is not enough; we need to ensure that the plastic used stays in a closed loop to prevent its escape into the environment:** Participants here explore one of the most common methods to recycle plastic, particularly PET bottles, gaining insight into the different products that can be produced from recycling this material. Textiles are the most common product created from this method, prompting participants to check the labels of their clothes to see if they contain this material.
3. **To create high-quality recycled plastic, we need to separate different plastics very well:** At this point, participants are invited to the laboratory to discover methods for separating plastics. This consists of an experiment where different plastics are separated based on their densities. It is stressed that while this may be easy in the laboratory due to the selection of plastics with very different densities, it may be more complicated in real life.
4. **Look closely at your t-shirt: could you separate the plastic in your t-shirt like you did in the laboratory?** With this concluding question, participants are prompted to ponder the applicability of this separation method to other items containing plastics. The aim is to underscore the importance of not only separating plastics initially but also avoiding recycling practices that involve mixing them with other materials that may complicate their separation later.

ANALYTICAL CHEMISTRY: ACTUAL BLOOD OR JUST PIGMENT?

In the game, this island was simply called the *Island of Analytics* and focuses on water management for environmental protection, emphasising the need to avoid toxicity in our environments. Due to the island's original format –a criminal trail not suitable for the game's content– a small section of digital content –titled *Is Everything Alright?*– from the island's media station is selected. This section offers insights into water management, which is crucial for conveying the message about toxicity. Effective water management involves eliminating toxic substances through various cleaning methods before reintroducing them into circulation.

Additionally, externally curated content on water usage in Germany is incorporated, along with a chemical experiment on filtration. The island's narrative centres on responsible water use and management and is structured as follows:

1. **Water, our natural cycle:** The story begins with the cyclical reality of water to emphasise the concept of circularity.
2. **Water, one of the most studied substances for human consumption?** Participants engage in various activities centred around the museum's media station to become aware of the extensive research conducted on water's suitability for human consumption. Despite rigorous treatment processes, participants realise that these methods are not infallible and that traces of contamination may still be present in drinking water. While Munich boasts high water quality, the complexity of the treatment processes is thoroughly acknowledged.
3. **Is our use of water sustainable?** Participants are prompted to reflect on water consumption levels after understanding the investment required for water treatment, questioning the sustainability of current usage practices.
4. **Cleaning water: a small and simplified water treatment facility:** Participants experiment with water purification in the laboratory using physical filters. However, the limitations of this process become evident as it only addresses particle size, leaving smaller microorganisms and toxic molecules potentially present in the water.
5. **Cleaning water in real life: a very complex process:** Participants engage in a final reflection, where it is shown how the water treatment process in real life is more complex and energy intensive. Consequently, the first step towards sustainability is to avoid contaminating water.

In this section, I showcased the production process of the game content, which involved integrating materials from the exhibition along with externally curated information and activities to convey messages and construct a cohesive narrative. While the previous section outlined the messages tailored for each island, here I illustrated the curation process of the game's content based on these messages. It is worth noting that this order of events does not reflect entirely the nature of the real process. Game creation is an iterative process where elements from the islands inspire specific sustainable messages and vice versa; some messages influence the selection of elements for the islands. This process entailed numerous iterations, and despite its organised presentation here, it was inherently complex, with many elements undergoing changes throughout the various versions of the game.

Following the inaugural game round, significant observations and content changes emerged from the two subsequent feedback sessions with the museum (Field Notes, 29.12.2024; 06.12.2024). Museum's staff expressed a desire for curated information that resonated more closely with their local context, arguing that this could potentially enhance participant's engagement with the game. Specifically, there was a suggestion to spotlight Munich's renowned tap water quality within the *Island of Analytical Chemistry*, where discussions on sustainable water

management take place. Munich has a well-established narrative of boasting clean tap water that residents can readily consume, and it is a point of pride emphasised in local education (Field Notes 06.12.2023). This narrative was used to underscore the uniqueness of this situation and the importance of preserving it, thus urging greater attention to water use and management. Another example proposed by the museum to integrate familiar content into the game involved a task within the *Island of High-Performance Thanks to Chemistry*, prompting participants to evaluate the polyester content in their own t-shirts (Ibid.).

Consequently, in the upcoming iteration, I incorporated this feedback by including the t-shirt task as well as data on water consumption in Germany. Furthermore, the feedback sparked a broader initiative to integrate similar localised insights into the game. As a result, additional graphics now depict the current state of agricultural and food waste, as well as demolition waste in Germany, providing participants with tangible data to grasp the scale of these challenges. This commentary underscores the significance of creating *familiar* and *relatable* content. While the museum initially emphasised this aspect in their feedback, subsequent tests have confirmed higher levels of engagement after tailoring information to resonate with the audience's cultural and educational backgrounds (Field Notes, 15.12.2024).

In summary, the iterative curation process of the game's content has revealed an essential characteristic necessary to foster increased engagement among participants: content must align with participants' cultural and educational backgrounds, thereby requiring it to be relatable and familiar. This understanding influenced my choices regarding which exhibition content to include and guided my selection of external content to effectively convey my intended messages, both within the smaller island sections and across the entire game. Since messages are meaningless without an audience and their reception, the final sub-section of this *Content* section will be dedicated to which messages were observed to have a higher impact on our public and which ones were more difficult to convey.

4.1.2. Analysis of the public's reaction to the content of the game.

The game was tested three times with three different school classes, all of them from 11th grade, which means that the participants were aged around 17 years old. Notably, two of these classes hailed from the same school, motivated by their involvement in a sustainability project. The teachers showed significant interest in participating in the testing process, recognising the inherent alignment between the game's content and their ongoing curriculum. During the ensuing discussion rounds, the influence of parallel instruction became palpable. A couple of participants from this high school referred to things that were not explicitly presented in the game but that were easy to reflect on through the activities. This observation highlights the complexity of analysing the participants' reactions and the intricate nature of evaluating public responses to the

game. It underscores the difficulty in discerning what constitutes a new perspective fostered by the game and what stems from participants' existing education or overarching sustainability narratives. In this second subsection, I delve into the turning moment that spurred my realisation about the potential impact of school curriculum on participants' meaning-making process during the final discussion of the game. With this reflection in mind, I embarked on analysing the recurring messages highlighted in the discussions, as well as those that were less prevalent. I conclude by contemplating beyond the potential influence of school content on the discourse but also the significant role that prevailing sustainability narratives in public discourse may have played.

4.1.2.1. How the school's own sustainable narrative influenced communication in the game.

The idea that school education might have shaped participants' reactions to the game's content became evident to me during a discussion session with the third school group, specifically when we were deliberating sustainability practices related to plastics. While nearly all participants across all testing sessions acknowledged the significance of employing reusable plastics and effectively segregating and recycling non-reusable plastics, the group from the final test placed considerable emphasis on the necessity of segregating various types of plastics (Field Notes, 04.03.2024). They highlighted that without proper separation, it becomes unfeasible to produce high-quality recycled plastics from mixed plastic waste –a message communicated through the game. Nevertheless, they drew significant attention to the type of plastics that require separate treatment –PP and PET. Although this issue is briefly addressed in the game, the detail in which this last round of participants discussed the issue contrasted sharply with earlier participants who did not delve into such specifics. It leads me to suspect that this emphasis might have stemmed from the sustainable project undertaken within their class.

TRANSCRIPT EXTRACTION: **SCHOOL TESTING SESSION 3**

Participant 10: Dann haben wir noch [das Problem] gehabt [..., dass] sehr viel verschwendet wird, einfach mülltechnisch, auch Plastikmüll usw. Und dass schwer recyceln werden kann, wenn es nicht getrennt wird und dass dadurch erstens Mülltrennung selber nicht nur nach diesen Arten, also nicht nur nach Plastikmüll, Glasmüll, Papiermüll, sondern dass auch Plastikmüll im spezifischen untereinander getrennt werden sollte. Mehr in PET, PP, usw. Weil die Stoffe nicht miteinander recycelt können.

English translation: Then we also had the issue of a lot of waste being generated, especially in terms of garbage, including plastic waste, etc. And that it can be difficult to recycle if it is not separated, and that therefore, firstly, waste separation itself should not only be based on these types, so not only plastic waste, glass waste, paper waste, but also that plastic waste in particular should be separated from each other. More into PET, PP, etc. Because the materials cannot be recycled together.

TRANSCRIPT EXTRACTION: **SCHOOL TESTING SESSION 3**

Participant 14: „Also wir haben *Polymer- und Kunststoff Industrie* als Industrie. Wir haben uns mit der Trennung von Kunststoffen beschäftig. Restmüll wird halt einfach alles verbrannt. Wobei das auch ein bisschen kritisch zu beachten ist, weil halt sehr wenig eigentlich nur recycelt wird und was recycelt wird, damit halt auch der Großteil nur exportiert in irgendwelchen anderen Ländern oder landet halt in Mülldeponien. Genau das Problem ist halt, dass es verschiedene Kunststoffarten gibt, wie PET, PP und noch weitere, dass man nicht einfach zusammen mixen kann. […] Das Ding ist, man kann die halt nicht wieder aus den PP und PET nicht ein wiederverwendbarer Kunststoff herstellen. Deswegen wird halt einfach viel verbrannt und deswegen muss man gucken, dass das ganze gut getrennt wird. Eine gute Sache sind Mehrwegprodukte sage ich mal. Zum Beispiel Mehrwegpfandflaschen, die halt nicht wieder neu eingeschmolzen werden müssen, sonst wiederverwenden werden können."

English translation: So, we have the *polymer and plastics industry* as an industry. We have been dealing with the separation of plastics. Residual waste is simply burned. However, it is also critical to note that very little is actually recycled, and what is recycled is mainly exported to other countries or ends up in landfills. The main problem is that there are different types of plastics, such as PET, PP, and others, that cannot simply be mixed together. [...] The thing is, you can't produce a reusable plastic from PP and PET. That's why a lot is simply burned, and that's why we have to make sure that everything is well separated. One good thing is reusable products, I would say. For example, reusable deposit bottles that don't need to be melted down again but can be reused.

The message in the "Island of High-Performance Thanks to Chemistry" – the island dedicated to the plastic industry and sustainable plastic practices – centred on the importance of creating solid structures for the use and end-of-life options of plastics (i.e., their reuse and recyclability). This theme resonated strongly with all participants during discussions on sustainable solutions. However, after the experience with the last group of participants, I gained awareness that perhaps this might be not only because of the efforts of the game but also because of an influence of the main narratives of sustainability communicated in and outside schools. Hence, while the following section explores the primary messages underscored during the game's discussion, I am fully aware that the game does not exclusively create these.

4.1.2.2. Highly recurrent messages emphasised by participants during the game's discussions[36].

Poor waste management, ineffective reuse and recycling structures: Inadequate waste management systems, notably in reuse and recycling practices, emerged as a widespread concern among participants across various industry sectors, indicating high levels of participant engagement with such topics. Plastic waste garnered significant attention, followed by agricultural and food waste, with occasional mentions of electronic waste and single-use hygienic products. Participants who identified these later waste problems highlighted the importance of reusability,

[36] This results section amalgamates the discussion rounds held during the activity *The Final Puzzle* at the conclusion of the game. The presentation of these results originates from the initial coding process of these discussions, integrated with field notes collected during three testing sessions conducted in schools. Specifically, it incorporates observations from 15.01.2024, 29.01.2024 and 04.03.2024.

advocating for the right of repair and reuse in electronics and the necessity of deliberating single-use hygienic products and finding reusable alternatives. Regarding agricultural and food waste, many participants appreciated the insights the game brought into innovative solutions for agricultural waste management, such as extracting cellulose from agricultural waste for textile production or diverting it to compost facilities instead of allowing it to rot or be incinerated in landfills. Many participants expressed surprise at the possibility of creating materials from such waste.

Biological waste; nutrients for our soil, requiring careful consideration: The significance of composting practices for soil enrichment received considerable emphasis, with participants reflecting on the problems of soil depletion. When considering the possibility of composting materials such as t-shirts made from agricultural waste, concerns were raised about the potential introduction of toxic substances that could hinder the composting process after these products are used. This indicates a high level of engagement with the message conveyed through activities on “Nourishment Island”, as demonstrated by participants' active involvement in discussions surrounding product biodegradability.

Reduce the use of non-renewable resources, both in plastic production and energy generation: Participants voiced concerns regarding the environmental ramifications of utilising fossil fuels and other non-renewable resources, spanning both plastic production and energy generation. Strategies aimed at mitigating the environmental impact of fossil fuel usage in plastic production primarily revolved around previously outlined solutions. These strategies emphasised the imperative of reducing plastic consumption, ensuring appropriate plastic separability, and promoting the adoption of reusable alternatives. Similarly, participants also discussed the possibility of transitioning to plastics made from renewable resources, stressing the importance of avoiding hazardous substances in these processes. Notably, many participants welcomed the insights provided by the game regarding the potential hazards associated with the development of biodegradable materials. Participants, therefore, engage with the critical evaluation of the true sustainability alternatives, highlighting the complexity inherent in sustainability considerations.

In terms of energy generation, participants drew on the importance of finding clean energy sources such as hydrogen or even using energy in the soil, as was presented in one of the experiments. Many participants found this energy generation option very interesting and commented on the possibility of using it in the agricultural context.

Contamination of water and, therefore, our environment: Contamination of water and the importance of a proper water management system were commonly mentioned in discussions. Many participants echoed the challenges posed by microplastic pollution in oceans, highlighting its adverse effects on biodiversity and the potential risks associated with seafood consumption.

Additionally, participants emphasised the importance of reducing hazardous substances in various products, particularly hygiene products. Furthermore, they linked this problem to one of the solutions proposed during the game: the use of filters for water purification.

An intriguing observation here is that because the filters used in the laboratory are only physical filters – segregating particles based on size – at the end of the experiment, the water was not completely clean – since it could contain smaller microorganisms, heavy metals, and toxic molecules that were smaller than the last filter used. Several participants acknowledged this limitation and expanded on the challenges associated with separating particles like microplastics from water, underscoring the necessity of responsible water usage. A minority of participants also noted the potential for transforming certain molecules extracted from wastewater into fertilisers for later agricultural use, highlighting this as an innovative and sustainable practice.

Need for context-specific sustainable approaches: In the very same context of water, the experiment involving different types of water enabled many participants to identify connections between regional environmental characteristics and the imperative of tailoring sustainable solutions accordingly. They recognised that what may prove effective and sustainable in some regions may not necessarily apply universally, emphasising the need for context-specific approaches.

The need for more sustainable construction; many different factors to be considered: In the context of construction, participants frequently highlighted the environmental issues associated with cement production, particularly the significant CO2 emissions. Some emphasised the importance of constructing smaller, more resilient homes tailored to their surroundings and capable of withstanding future climate uncertainties. Additionally, participants stressed the importance of energy-efficient or entirely self-sufficient buildings, showcasing creativity in proposing solutions. Suggestions included integrating bio-batteries, observed in laboratory settings, with solar panels. Participants also recognised the waste management challenges within the construction industry and the extensive use of materials. They underscored the issue of wasted material value during demolition and advocated for recycling and reusing materials from buildings.

Interestingly, no one mentioned the use of material passports to streamline this process, indicating a low engagement with this sustainable solution. This leads me to reflect on the aspects I attempted to convey through the game but were overlooked during the discussions.

4.1.2.3. The “inexistent” role of material passports and the content that participants had difficulties to engage with.

Half of the participants, based on their industry roles, were assigned the task of working with material passports. This activity was introduced to highlight the potential of this strategy for tracking material life cycles. I personally find the concept of material passports to be a very interesting concept that, although it has been developed in the context of construction, could be used in many other different fields. In the game, the industries that had this activity were the *Construction and Urban planning Industry*, the *Electronics and Energy Industry*, and the *Hygiene and Health Industry*. The rationale behind assigning this activity was to encourage reflection not only within the construction industry but also within the electronics and hygiene sectors regarding the potential adoption of such a strategy for product tracking. For instance, in the electronic industry, electronic products could have some kind of passport to facilitate their reparability, while in the hygiene industry, packaging for products like soaps and cleaning agents could incorporate a passport to promote their reusability, perhaps through a deposit system. Surprisingly, none of these possibilities were mentioned, which indicates low engagement with this sustainable solution.

4.1.2.4. How main narratives of sustainability might have influenced the game.

The second part of *The Final Puzzle* activity involves discussing the missing pieces of the puzzle, which symbolise the aspects of sustainability that were not addressed by the chemical insights provided in the game – i.e. the sustainability solutions beyond chemistry’s territory. Many participants appealed to the importance of supportive politics and fundraising for research & innovation as well as interdisciplinary collaboration. Particularly noteworthy was the emphasis placed by many participants on the significance of consumption patterns. Across all conducted tests, participants suggested that responsible consumption might be a crucial missing piece of the puzzle. In the words of the participants themselves, "What is the point of being sustainable or replacing some things with more sustainable options if, at the end of the day, we are consuming so much?" (Participant 22, Field Notes, 15.01.2024). Additionally, many argued that perhaps the missing part of the puzzle is *us*, indicating that sustainable change should commence with individual action. Participants stressed the need to *act now* and not wait for future solutions. This reflection is very interesting because it shows the power of the main narratives surrounding sustainability and how these are embraced in the game to talk about sustainability. Participants, therefore, when discussing the game, used their own knowledge of sustainability, and they applied it to the activities and the final discussion. This is again an example of how difficult it is to discern the game's direct impact versus their prior knowledge.

In conclusion, in this final section dedicated to the game's content, I observed how participants used part of the content of the game to discuss sustainability solutions to the problems associated with their role industries. Therefore, I tried to analyse which content was being used more often and which one was left aside. Because this analysis is not the main purpose of the thesis, this has been done on a broad scale[37]. Still, it shows very interesting paths of future possible research, not only a more detailed analysis of the way in which the game creates its own messages but also how the participants create their messages through the game and the influence of major sustainable narratives that are being communicated outside the game. One of my main interests was to create a game that also transcended the dominant sustainability narrative centred around consumer responsibility. I acknowledge the reality that many consumers do not have a choice due to their social circumstances. Consequently, I believe it is crucial for industries to assume responsibility and drive sustainable change. Although the majority of the game content focuses on this perspective, it is interesting to note that many participants reverted to the narrative that change should begin with individual actions during the end-of-game discussions. This underscores the potency of this particular narrative within the German sustainability context.

4.2. Format(s).

This second subsection of the results section examines the format(s) of CREISE, illustrating its function in fostering engagement and discussion on Sustainable Development (SD) and Circular Economy (CE) and chemistry's role. By drawing inspiration from the engagement and discussion strategies employed in the exhibition, this analysis reflects on their implementation within the game, assessing their impact on participant engagement.

4.2.1. How engagement is fostered in the game.

The overarching strategy in the game for promoting engagement with SD & CE revolves around cultivating this engagement through tangible forms that are unique to the site. While focusing solely on "engagement with SD & CE" may lack specificity and lead to a myriad of possibilities, directing attention to the empirical site study –the Chemistry Exhibition at the Deutsches Museum– offers more concrete avenues for engagement inherent to the location. Exploring "engagement with the exhibition" and "engagement with chemistry" provides structural

[37] In the sense that the coding process did not achieve saturation of data due to the limited scope of the research. Only the three sessions with the schools were transcribed, and a first round of coding was conducted to observe the major trends in the discussions.

frameworks for developing a suitable and captivating format. These two forms of engagement establish a solid foundation from which to craft an engaging format.

4.2.1.1. Engagement with the exhibition. Selecting interactive objects:

In the game, engagement with SD & CE was partially fostered through engagement with the exhibition itself. This involved carefully selecting objects and information relevant to sustainable development and the circular economy. After several rounds of testing with museum staff and critically examining how different chosen elements influenced their engagement, a strategy emerged for selecting objects and information that facilitate engagement with exhibition content, game activities, and messages: more interactive elements tended to be the most engaging. Consequently, part of my game design strategy primarily focused on curating interactive objects and information related to sustainability and the circular economy within the exhibition.

This reasoning stems from reflections following the initial testing phase with museum staff and the improvements made to the game afterwards. In the first iteration of the game, a media station featuring written information and photographs of various types of batteries was selected to convey the message that there are multiple materials in the world that can be used to create energy – and some are more sustainable than others. However, feedback from museum staff revealed that this choice actually hindered overall engagement with the activity. Some participants felt overwhelmed by the text-heavy format of the media station and ended up guessing rather than actively engaging with its content to find the correct answer to the question posed as part of one of the island's small activities (Field Notes, 29.11.2023).

INTERACTION VS ENGAGEMENT: **THE FAILURE IN OBJECT SELECTION**

Figure 12 - Photo Collection 6. **The Unengaging Media Station:** The initial version of the game featured a media station displaying the information depicted in this collection of photos. This station provided written details about various types of batteries. Although the object allowed for interaction, the passive presentation of information resulted in limited engagement from participants with the activity.

Based on the feedback received from the initial test, the second version of the game replaced the digital media station with a more interactive set of elements (Field Notes, 06.12.2023). One of the newly selected objects was a model demonstrating a circular method of energy generation through water electrolysis paired with a hydrogen fuel cell to produce both energy and water. The object was presented in a glass box and could be activated by a button. Additionally, an adjacent video explaining the model's functionality was integrated into the activity. This new collection of objects and information featured a more interactive format than the text-based media station. They also proved, during the second test of the game with museum staff, to better facilitate participant engagement with the small designed activity on the island and its overall message (Field Notes, 15.12.2023). Furthermore, these additions reinforced the concept of circularity by illustrating a circular chemical reaction used for energy generation.

INTERACTION VS ENGAGEMENT: **A MORE ENGAGING COMBINATION OF OBJECTS:**

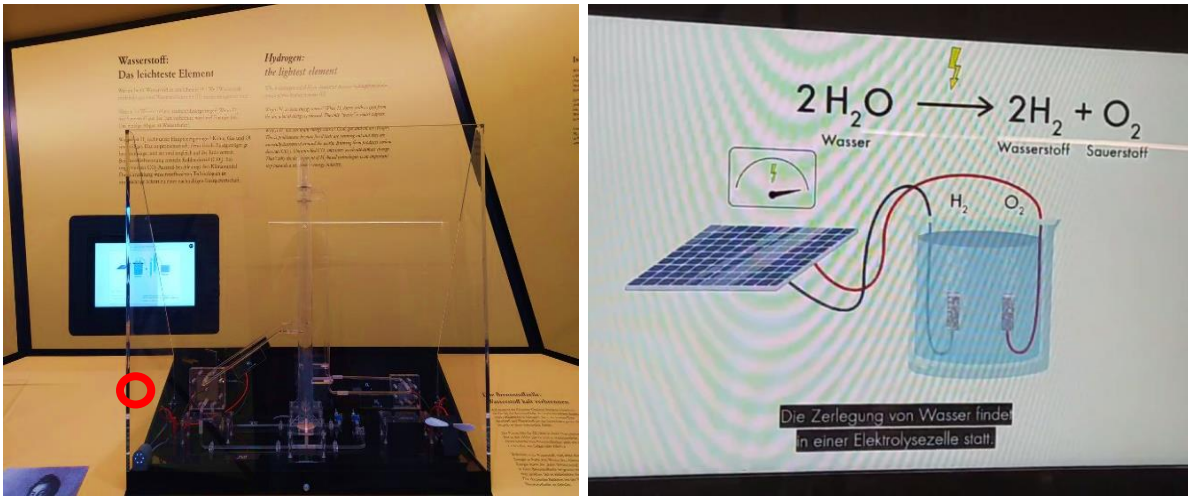

Figure 13 - Photo Collection 7. **The Engaging Reaction Model:** In the second iteration of the game, we opted for the depicted model accompanied by a video. The model features an interactive button (circled in red) enabling visitor interaction while the video is displayed on a tablet. In this instance, both formats—objects and information—were interactive, resulting in significantly heightened engagement levels with the activity.

The inherent interactivity of an object can indeed contribute to fostering engagement within a visitor program; however, it is not the sole determinant of an engaging format. Merely selecting highly interactive primary formats from the exhibition does not guarantee an engaging visitor program since there are many different factors that play an important role as well. Nonetheless, a degree of interactivity is essential, as evidenced by experiences in game design. While non-interactive elements can be included in the program, an overabundance of such elements is likely to diminish interactivity and subsequently undermine participants' engagement

with the topic. Therefore, striking a balance between interactive and non-interactive elements is crucial in crafting an engaging visitor program.

4.2.1.2. Engagement with Chemistry. Chemical Experiments as highly engageable formats:

A complementary strategy employed in the game's design to promote engagement with sustainability and the circular economy is through fostering engagement with chemistry. This involved creating chemical experiments that communicate principles of sustainable development and circular economy. Chemical experiments are worth exploring because they have the potential to facilitate high levels of engagement with chemistry by offering tangible means of illustrating complex chemical principles and knowledge. Additionally, this engagement can be further enhanced by providing participants with a fully immersive experience, including the laboratory environment, safety gear, and the use of laboratory instruments and chemicals – even though, in the context of this game, these chemicals were limited to water, earth, salt, and plastic trash. By integrating chemical experiments as a complementary format in the program that simultaneously addresses certain principles of circular economy, I aimed to promote engagement with both SD & CE and chemistry. Empirical evidence gathered during the program's tests supports this assertion. In feedback sessions, participants expressed how these experiments helped them visualise and comprehend messages regarding the circular economy and sustainability.

TRANSCRIPT EXCERPT: **SCHOOL TESTING SESSION 1**

Participant 13: „Uns als Gruppen wir haben die Aktivitäten schon sinnvoll gefunden, weil man quasi wirklich Gute Informationsquellen hatte, die sehr anschaulich waren und man gut damit befasst hat, dass wenn man im Labor gegangen ist und die Sache, die man gerade gelesen hat, sich nochmal verdeutlich hat durch Versuche.“

English translation: We as a group found the activities meaningful because we essentially had very good sources of information that were very illustrative, and we dealt well with the fact that when we went into the laboratory, the thing we had just read about was clarified again through experiments.

For instance, one participant highlighted how a chemical experiment related to the separation of plastics enabled them to grasp the intricacies and costs associated with plastic separation. The experiment involved the separation of four different types of plastics based on their densities. Initially, all four plastics were placed in a beaker of water, where only one floated while the rest sank to the bottom. The participant used tweezers to retrieve the floating plastic. To separate the remaining plastics, the participant added salt to increase the water's density until it exceeded the density of one of the plastics, causing it to float. The participant then retrieved the floating plastic with tweezers again. This process was repeated until all plastics were separated. The experiment was designed to facilitate easy separation based on substantially different densities. Therefore, a significant amount of salt was required to distinguish between the last two

plastics. Unfortunately, one participant, in a rush, added too much salt, causing both plastics to float simultaneously and resulting in failed separation. This incident prompted the participant's reflection on the arduous nature of separating only four distinct plastics in the laboratory, highlighting the considerable time investment required and how impatience could ultimately undermine the experiment's success. Through this reflection, the participant further connected their experience with real-life plastic separation and gained awareness of how cost and resource-intensive this process is.

TRANSCRIPT EXCERPT: **SCHOOL TESTING SESSION 1**

Participant 9: „[ich habe gelernt, dass die] Trennungsprozess an sich so aufwendig ist und ich mir vorstellen kann, dass in großes Ziel ist, dann schon ein großer Aufwand. […] Wir haben mindestens das Problem gehabt, dass bei der letzten Stufe zu viel Salz gegeben haben und beide Kunststoffe gleichzeitig schwamm und wussten wir nicht welcher Stoffe jetzt schwerer oder leichter wäre. Das habe ich neu gelernt, das fand ich cool."

English translation: [I learned that the] separation process itself is so elaborate, and I can imagine that, on a big scale, it requires a lot of effort. [...] We have at least had the problem that in the last stage, too much salt was added, and both plastics floated at the same time, and we didn't know which substance would be heavier or lighter. I learned that anew, and I found that cool.

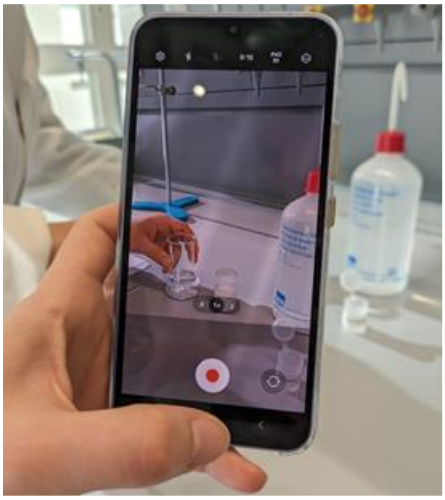

Figure 14 - Photograph depicting the plastic separation experiment.

4.2.1.3. Building engagement with the circular economy: A format to unify them all.

Museum visitor programs employ diverse formats to synthesise a wide array of objects and information within the museum, crafting bespoke experiences for audiences. These formats encompass a spectrum of activities, ranging from interactive science demonstrations and experiments to gamified experiences such as scavenger hunts and research sheets. Upon identifying the two complementary forms of engagement necessary to facilitate engagement in SD & CE within the specific context of CREISE — i.e. engagement with chemistry and the exhibition through the inclusion of chemical experiments and interactive elements— the subsequent endeavour is to forge a coherent format that sustains these engagements. This

format should allow for the application of a narrative structure observed in the chemistry exhibition, characterised by clear titles and brief paragraphs.

In devising such a program, the selected unifying format must nurture this interlacing of engagements, permitting complexity and depth. A game format was chosen for this purpose, drawing inspiration from escape room games. Crafting an escape room-type experience facilitates the integration of diverse smaller formats while allowing flexibility for varied types of engagement. Furthermore, the game format introduces a novel dimension to the program, one distinct from other formats such as science shows and experiments: mechanics. Mechanics play a pivotal role in justifying the suitability of games as meaningful formats for public engagement. They engender engagement by evoking emotions, such as satisfaction upon triumph or frustration and disappointment upon setback. Additionally, mechanics such as point systems can perpetuate these emotional responses, ensuring sustained engagement throughout the experience.

Once the decision was made to adopt the guise of an escape room game featuring chemical experiments that integrate elements from the exhibition, the subsequent step involved determining the optimal approach for building this game within the Chemistry Exhibition. Consequently, a comparative analysis was undertaken to evaluate the feasibility of developing the game in a purely physical format, possibly using a narrative booklet, versus digitally implementing it through an application like Actionbound[38].

BOOKLET		**ACTIONBOUND**	
PROS	CONS	PROS	CONS
Accessibility: Consolidates all game information into a single, easily accessible resource. Doesn't require access to smartphones or internet connection, making it inclusive for all visitors regardless of their technological capabilities. **Flexibility:** Any kind of small paper activities can be included.	**Limited interactivity:** Compared to digital platforms, booklets may offer less dynamic or interactive gameplay experiences (for example, the visitors will need to count themselves their points) **Update limitations:** Any updates or revisions to game content would require reprinting and redistributing new booklets.	**Interactivity:** Offers dynamic and interactive gameplay experiences through multimedia integration and various quiz formats. It also has a point system. **Real-time data collection:** Allows for immediate data capture and analysis, facilitating real-time feedback and adaptive gameplay.	**Technological barriers:** Requires smartphones and internet connectivity, potentially excluding visitors without access to such devices or networks. Different devices and operating systems may experience compatibility issues or require specific versions of the app, leading to user frustration or limited accessibility.

[38] A comparison involving additional formats was conducted. There was also consideration given to conducting the game without the use of booklets, opting instead for printed posters in the exhibition where participants could retrieve and record their answers. However, this option was quickly dismissed due to its inherent complexity. Another alternative discussed was utilising the media stations (tablets) positioned at various points within the exhibition. Nevertheless, this option was promptly discarded upon recognising that these tablets only supported textual content, providing no means for participants to input their answers or save the results.

Tangibility: Provides a physical memento of the game experience, which can enhance memorability and engagement.	**Space constraints:** Limited space may restrict the amount of content or activities that can be included in the booklet. **Cost:** Printing booklets is more expensive and environmentally damaging than using the app	**Updating ease:** Any updates or revisions to the game content can be easily done.	Requires a license to create the game, which could limit accessibility if the license expires. **Dependence on the already proposed activities:** The app has its own mini-activities; this is a small number, and any game developed in the app will need to be a combination of those

Table 5 - Comparison between two possible game formats. Booklet vs Actionbound.

The Actionbound app was chosen over the traditional booklet format due to its advantages, including interactivity and real-time data collection. The iterative nature of game creation necessitates the ability to gather data in real time and observe participant reactions, both of which are vital components of the process. Additionally, the ease of updating changes in the game's content in the app further enhances its appeal. While Actionbound has drawbacks, such as potential technological issues and a limited variety of activities, these can be addressed. The museum can provide tablets for gameplay in case visitors encounter device-related issues. Furthermore, the museum's partnership with Actionbound ensures continued support and updates. The limitation of activity variety can be mitigated by incorporating a diverse range of chemical experiments and carefully selecting exhibition objects and information to curate engaging activities. Furthermore, the inclusion of new supplementary materials specifically designed for the game alongside the use of Actionbound – such as the created physical cards and puzzles can enhance the available activities in Actionbound, making them uniquely engaging.

4.2.2. How discussion is sparked in the game.

In the game, I drew inspiration from some of the exhibition's methodologies to catalyse discussions, but I also introduced a novel strategy: *The Final Puzzle*, which is a discussion tool to facilitate dialogue and the exchange of experiences at the end of the game.

To explain how particular formats spark discussion in the game, it is crucial to note that the game's design facilitates discussion on two levels. Firstly, as the escape room game is inherently a group activity, discussion is prompted within each group through diverse activities and chemical experiments. Once all groups have completed the initial phase of the game, it transitions into a second part, *The Final Puzzle*, where participants must collaborate to solve a puzzle to find the key to a sustainable and circular future; here, discussion is encouraged among the different groups.

4.2.2.1. Discussion within the groups.

Promoting discussion through good old-fashioned questions: Questions serve as a traditional yet effective method for initiating discussion. In CREISE's primary narrative conveyed through the Actionbound app, rhetorical techniques are employed to engage participants actively. A notable example of this strategy is evident in the game's introduction, where participants are directly prompted: "If chemistry helps us to understand the secrets of nature, could we design our industry in such a way that it acts in harmony with nature?" Moreover, within CREISE's storyline, the Actionbound app facilitates the formulation of direct inquiries through polls, allowing for the collection of responses for subsequent game evaluation. In one instance, a semi-polemical question was posed: "Would you wear a t-shirt made from food waste?" Participants were given three response options: "yes," "no," and "maybe". This inquiry was associated with an activity in which participants explored the feasibility of producing textiles from food waste, such as orange or banana peels, by extracting cellulose and fashioning it into fibres.

SPARKING DISCUSSION THROUGH QUESTIONS

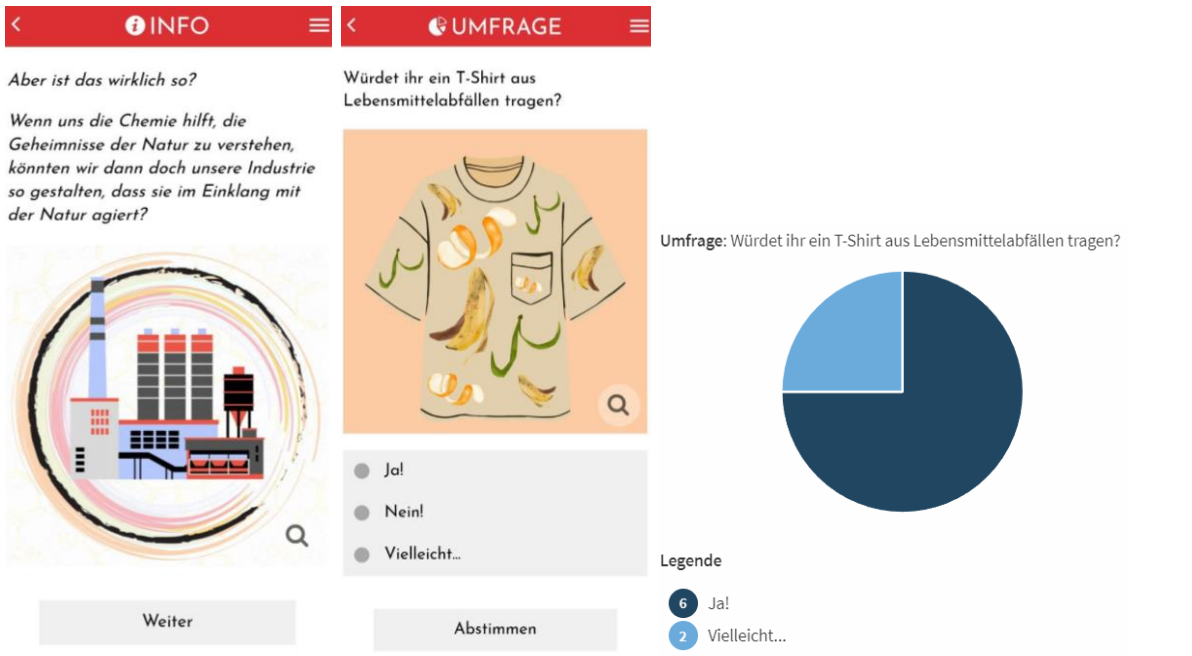

Figure 15 - Photo Collection 8. **Sparking Discussion Through Questions:** Screenshots of the digital game in the Actionbound app illustrate the use of a rhetorical question (left) and a direct question (middle) as mechanisms to spark discussion inside the group. On the right, the results of the direct question are visible. For the full game translation and additional activity details, refer to the Annex.

The graphical representation of responses to the posed question may not precisely reflect the ongoing discussions within the group during gameplay. However, the substantial reference to the t-shirt example during the final discussion round of *The Final Puzzle* activity highlights the active engagement of participants in the activity (Field Notes, 15.01.2024; 29.01.2024). An

illustrative instance of this occurred when a participant linked another game topic—plastic recycling practices—with the creation of compostable t-shirts to elaborate on the possible missing piece of a sustainable future: the existence of numerous unknown problems and the potential consequences of various industrial products (Field Notes, 15.01.2024). This line of reasoning reflects a deep level of engagement, as the participant used thematic information from the game to reflect on the intricacies of our sustainable practices. Furthermore, the participant employed the game's information to generate their original message on sustainability, which underscores the process of meaning-making that occurs during the game and highlights the power of this approach as an engagement technique. Thus, by prompting participants to envision scenarios relevant to their daily lives through questions, both engagement with and discussion about a particular topic can be facilitated, and new messages and meanings on sustainability and circular economy can be created.

TRANSCRIPT EXTRACTION: **SCHOOL TESTING SESSION 1**

Participant 21: „Ich glaube auch nicht, dass damit zusammenhängt, aber dass wir viele Probleme noch gar nicht kennen und noch gar nicht bewusst sind, was eigentlich für folgendes haben können, wie wir halt bestimmter Sachen aus der Industrie verwenden. […] Wir haben viele Probleme zu denen überhaupt keine Lösungseinsatzt haben. Zum Beispiel großer Teil des Plastiks ist ja auch, was man nicht wirklich wiederverwendet kann. Und wenn man jetzt T-Shirt erstellt aus diesem Kompostiersache komm noch Giftstoffe dazu und da wissen wir nicht so wirklich wie wir alles abbauen können.“

English translation: I don't think it's related to that, but we are not yet aware of many problems and don't realize what consequences certain actions could have, like how we use certain things from the industry. [...] We have many problems for which we don't have any solutions at all. For example, a large part of plastic is also something that cannot really be reused. And if you now create a T-shirt from this compostable material, toxic substances are added, and we don't really know how to break everything down.

Promoting discussion through challenging activities: For the second iteration of the game test, I introduced a revised version of the Material Passports activity in response to feedback suggesting that the initial version lacked engagement (Field Notes, 29.11.2023). The Material Passports activity sought to illustrate the concept of *zero waste* and underscore the significance of repurposing materials beyond their primary use. The objective was to showcase how material passes could facilitate the reuse or recycling of materials by offering insights into their history and physical and chemical properties.

Initially, players were tasked with salvaging materials from a demolished building by creating material passes to breathe new life into them. This required players to independently determine the necessary material properties for envisioning the future applications of the materials. The purpose of this activity was to gather insights into what participants considered important in a material, with no definitive right or wrong answers. However, feedback indicated that the open-ended nature of this task hampered engagement, as participants struggled to

understand expectations. In response, the subsequent version of the game addressed this feedback by simplifying the players' roles. They were now directly responsible for matching the material passports with their corresponding materials. Additionally, a supplementary task was introduced: once all materials were paired with their passports, participants were encouraged to use the information from the passports to explore alternative applications for the materials in a new building.

During the feedback session with the museum staff following this iteration, they expressed enjoyment of the revised version. They observed that only two passes were difficult to assign to their respective materials, as both materials were quite similar. However, unlike the first version of the game, this small challenge was engaging as it sparked discussions about which pass referred to which material. Furthermore, the supplementary activity entailing the envisioning of new sustainable lives for the materials within a new construction project also sparked lively group discussions regarding optimal material integration (Field Notes, 15.12.2023).

SPARKING DISCUSSION THORUGH CHALLENGING ACTIVITIES

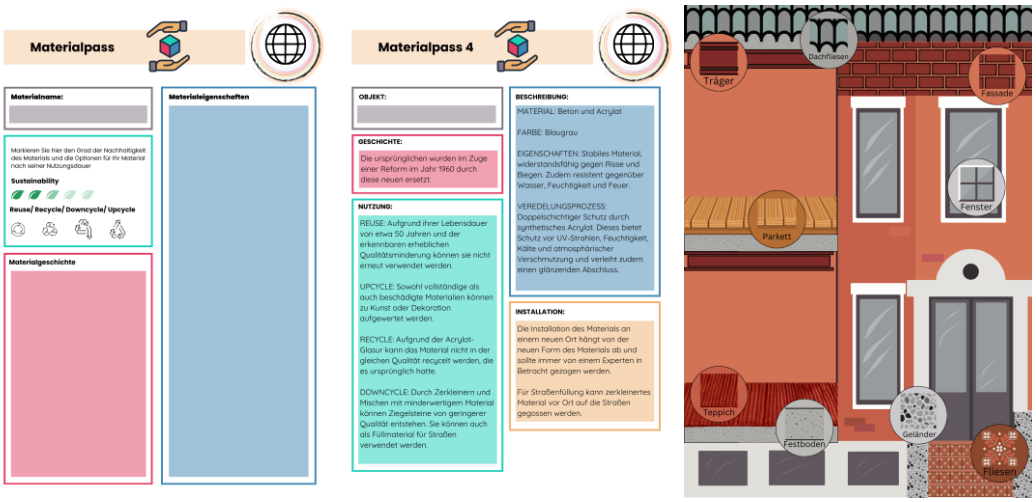

Figure 16 - Photo Collection 9. **Material Passports Activity**: On the left, the initial version of the material passports, a blank form awaiting participants' input. In the middle, the finalised version of the material passports, displaying material characteristics, with object names left blank, ready for participants to connect them with highlighted objects from the old building. On the right, an image of the old building slated for demolition showcasing the highlighted objects for participants to correlate with the material passports. Below, a photograph of the activity installation in the exhibition. For a complete translation of the activity and further details, please consult the Annex.

This activity serves as an illustration of how optimal difficulty levels can promote engagement and facilitate meaningful discussion, whereas excessive or insufficient difficulty levels can compromise both.

4.2.2.2. Discussion between groups. Building a discussion facilitator: "The Final Puzzle."

As crucial as the intra-group discussions during the game may be, I find it equally imperative to foster them among the players after the game concludes as well. Given that the game aims to convey various messages concerning sustainable development and the circular economy and considering that it is played by diverse groups with unique roles and experiences throughout the game, exchanging these insights presents a valuable opportunity to strengthen engagement with the subject matter. Consequently, in designing the game, I tailored its end to actively encourage such post-game discussions.

The primary objective of every escape room is to find a way out of the confined space. In CREISE's scenario, however, this escape room functions more metaphorically. Participants traverse distinct "rooms" represented by various islands within the exhibition. Escaping from these metaphorical rooms entails finding ways to foster a more sustainable future within your industry, drawing inspiration from the messages that the island aims to convey. The deliberate open-endedness of the game, exemplified by *The Final Puzzle* activity, serves to emphasise the intricate and multifaceted nature of this endeavour.

The Final Puzzle activity unfolds as follows: At the game's outset, participants choose an industry and embark on a mission to enhance its sustainability. They explore various islands, engaging in diverse activities aimed at discovering sustainable solutions. Consequently, participants accumulate examples of current or prospective sustainable and circular practices in the form of puzzle pieces, which they must gather and safeguard for the final activity. Once all groups have completed all activities, they come to the start of the game, and the final activity begins. During *The Final Puzzle*, participants present in front of their peers the challenges confronting their chosen industry and the solutions they have devised. Simultaneously, they collaborate to piece together the puzzle, symbolising the interconnectedness of these solutions and the collective endeavour required to achieve sustainability objectives.

However, when all groups have presented their industries, they will discover that there is no definitive solution; the puzzle they were tasked to build remains incomplete after integrating all collected solutions. This intentional incompleteness serves as a strategy to stimulate discussion. As participants observe the unfinished puzzle and are guided to understand that it symbolises the necessity for more than just chemical knowledge to attain a sustainable future, they engage in spirited conversations regarding the missing elements. Many of the proposed

solutions deviate from my initial expectations. Feedback sessions with schools yielded positive responses regarding the concept of the incomplete puzzle as a catalyst for conversation (Field Notes, 15.01.2024; 29.01.2024).

THE FINAL PUZZLE ACTIVITY

Figure 17 - Photo Collection 10: **The Final Puzzle Activity:** The first image (above) depicts the assortment of puzzle pieces displayed in the Material Passport activity, which participants collect upon completing it. The second image (below) showcases *The Final Puzzle*, with three-quarters of the circle completed using solutions gathered from different industry groups. A quarter of the puzzle remains empty, symbolising the unresolved aspects of sustainability. Through discussion, participants are tasked with filling this section using green puzzle pieces, representing their own ideas on what is essential beyond chemistry to ensure a sustainable future. This end of the game is open-ended as participants create with their beyond-chemistry solutions unique circles, illustrating the diverse pathways toward sustainability.

TRANSCRIPT EXTRACTION: **SCHOOL TESTING SESSION 2**

Person 25: „Also ich fand es echt gut, denn am Ende komm alles zusammen und schließen wir den Kreis und als Reflektion ist echt gut, weil man viel nachdenkt und die Information besser verarbeitet und als Puzzleteile, die man in der Box findet, ist ganz cool.“

English translation: Well, I thought it was really good because in the end, everything comes together, and we close the circle, and as a reflection, it is really good because you think a lot and process the information better, and as puzzle pieces that you find in the box it is quite cool.

4.3. Mechanics.

A game distinguishes itself from other visitor programs at the Deutsches Museum, such as science shows or experimental programs, by incorporating a third dimension that adds complexity and enhances its ability to engage audiences: game mechanics. Therefore, in this final section of the results, I will delve into this aspect, exploring how the communication of previous messages and engagement were intentionally reinforced through the game's mechanics.

Escape room games feature simple mechanics: participants are immersed in themed rooms where they must escape by uncovering hints, solving puzzles, and decoding riddles. The room's theme intertwines with a narrative, role(s) and a collective objective. Unlike conventional escape rooms, where the space is carefully designed for the story of the escape room, CREISE is housed within the Chemistry Exhibition of the Deutsches Museum, an already established environment. This distinction is pivotal; rather than adapting space for the escape room, the escape room is tailored to fit seamlessly within this existing context, resulting in a more “metaphorical” escape room experience.

In CREISE, each room corresponds to an island within the exhibition, and participants gather *ideas* –rather than codes– on how to make the future more sustainable and circular to escape the room –or, in this case, the island. Like traditional escape rooms, the game also assigns roles to participants, though in this case, multiple roles are designed for multiple groups rather than giving one role to a single group. Given that the game targets school classes consisting of 20 to 30 pupils, this approach ensures that the whole class can experience the game together and enhances collaboration among participants.

In the forthcoming sub-section, I explain the overarching story of the game and the interplay between this narrative, the assigned roles, and the exhibition space through the overarching mechanics of CREISE.

4.3.1. The Islands and their Industries. The story and the main roles of CREISE.

The underlying story of CREISE is simple: our current industrial system adversely impacts natural cycles, leading to environmental pollution and contributing to the urgent climate crisis we all face. Chemistry, as the science that explores changes in matter, allows us to explore sustainability at the molecular level and might help us find ways in which our industry can harmoniously co-exist with nature, helping it thrive. To achieve this, we need to rethink the way our industries operate, and the Circular Economy model is proposed. Participants must adopt an industry role, reflect on the problems of their industries, and discover through the game new ways in which chemical knowledge can assist these industries in fostering a more sustainable future.

I devised six distinct roles for participants at the onset of the game. Each role correlates with one of the exhibition's islands. In the following table, I once more showcase the seven distinct islands alongside their respective messages. However, I go one step further and present how these have been combined to create a role in the game where the message is reinforced by the role of an industry and its main environmental problems. In this table, the names of the islands in the exhibition have already been replaced by the names in the game, and to simplify the content, the messages have been condensed into concepts or concise sentences.

ISLAND NAME	MESSAGE	INDUSTRY ROLE	ENVIRONMENTAL PROBLEMS
Industry	Chemistry alone cannot make our future more sustainable	None (place where the industry roles are assigned)	Linear process production contributing to resource depletion and waste production
Nourishment	Safe return of nutrients to the soil	Food & Agriculture Industry	Soil impoverishment and biodiversity loss due to monoculture, excessive agriculture and food waste
Chemistry of today and tomorrow	Sustainable energy production	Electronics & Energy Industry	Environmental pollution from energy production, e-waste accumulation due to product obsolescence and repair difficulties
Chemistry in and around us	Sustainability is assessed locally	Hygiene & Health Industry	Pollution from toxic and non-degradable hygiene and health products, excessive use of single-use items causing environmental pollution
Construction	Waste is material without identity	Construction & Urban Planning Industry	Extraction of large amounts of raw materials, demolition practices devaluating these construction materials and contributing to pollution and resource scarcity.

High performance thanks to chemistry	Resource efficiency in plastic production and (re-)use	Polymers & Plastics Industry	Use of fossil materials, improper disposal leading to pollution and loss of material value
Analytical Chemistry	No toxicity	Water Treatment Industry	Water mismanagement and inadequate wastewater treatment leading to environmental contamination

Table 6: Creation of Industry Roles to reinforce the messages on the islands.

As illustrated in the table, the *Island of Industry* remains unassigned to a specific industry. As noted earlier, this island serves as both the starting and concluding point of the game. Functioning as the physical venue for the introduction, it is moderated via the Actionbound App. Within the digital narrative, participants embark on a quest to uncover the "Industry Cards" discreetly placed on the island. Upon discovery, participants can assume a game role by selecting one of these cards.

INDUSTRY ROLES

Figure 18 - Photo Collection 11. **Industry Cards:** On the left is an image of the *Industry Cards* display located in the Island of Industry within the Chemistry Exhibition. Participants must discover and select one of these cards, which will determine their role in the game. On the right is a screenshot of the Actionbound App, demonstrating how instructions are delivered using this digital tool, which moderates the game's storyline. For translations and more information about the activity, please refer to the Annex section 7.1 on The Actionbound Game.

INDUSTRY ROLES: **INDUSTRY CARDS AND ITS ELEMENTS**

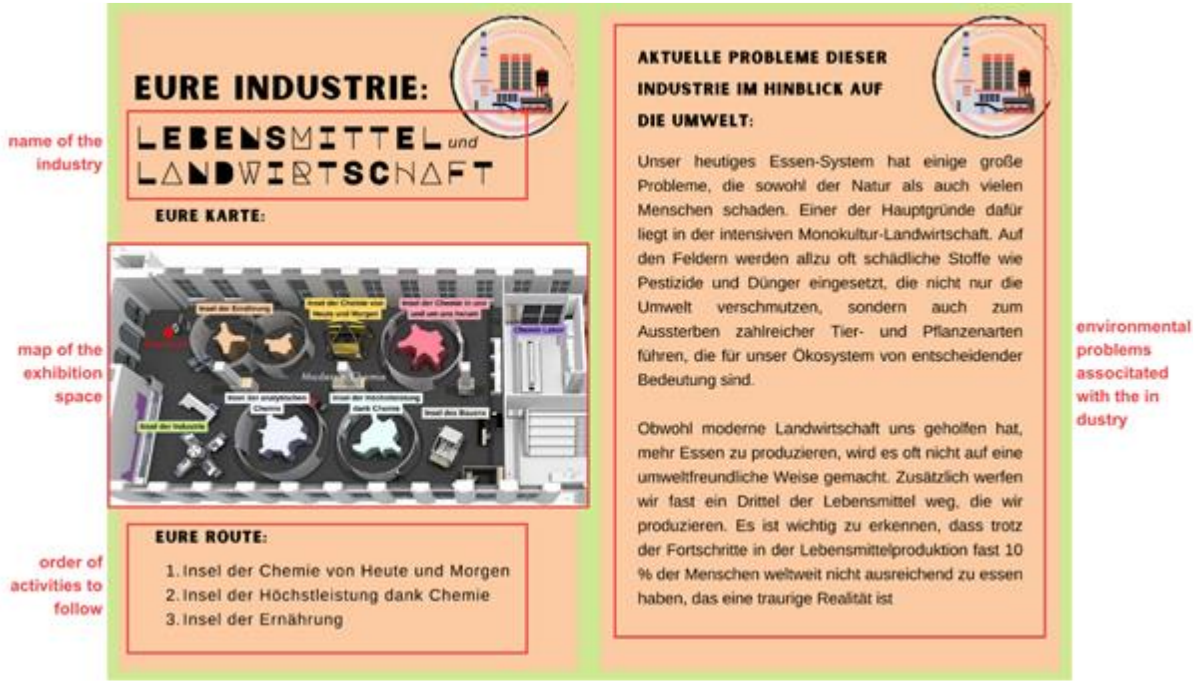

Figure 19 – The Food & Agriculture Industry Card: The following photo shows what an Industry Card looks like, using the example of the *Food & Agriculture Industry*: In the photo, various elements of the card can be identified. At first glance, what might immediately draw attention is the design of the card. As mentioned in previous sections, each thematic island in the Modern Chemistry Area has its own colour, which has been incorporated into the game's design to maintain coherence with the exhibition's overall aesthetic. This colour-coding also aims to enhance participants' gaming experience by providing visual cues. Therefore, each industry role card adopts the colour of its corresponding island, ensuring consistency. As observed in the photo, the card features a green frame matching the colour of the "Island of Industry", while the main colour of the card corresponds to the industry's island.

Turning our focus to the elements within the card: on the front side, there is the name of the industry, a route outlining the activities participants of the industry need to complete during the game, and a map of the exhibition space. This map assists participants in locating the area within the exhibition where they need to go. On the back side of the card, there is an explanation of the environmental problems associated with this industry. This information encourages players to reflect on these issues during the game and strive to find solutions - it is an extended version of the problems summarised in Table 5. For translations and more information about the "Industry Cards", consult the Annex section 7.3.2.1 on the "Industry Cards".

4.3.1.1. Roles, why? Reflecting on the roles of the Industry Roles

The strategy behind using roles in the game serves multiple purposes. Firstly, roles cultivate a profound emotional connection and engagement with the narrative, as participants are required to embrace and embody them. This heightened involvement enhances the overall interactivity of the game, providing diverse avenues through which players can engage with the experience, thereby enriching its versatility and depth. Moreover, given that CREISE's roles mirror industry sectors familiar to participants, I recognised their potential to leverage pre-existing knowledge,

rendering game content and messages more comprehensible, relatable, and pertinent within the participants' personal contexts.

MEMO EXTRACTION: ROLES AS BRIDGES BETWEEN CONTENT AND PARTICIPANTS' PERSONAL CONTEXTS

Field Notes, 29.01.2024: During post-game discussion conducted with this second school, the role of roles as facilitators between content and participants' personal contexts has become evident. Participants frequently engaged in reflections extending beyond the game's explicit content, likely influenced by sustainable narratives encountered both inside and outside the classroom. I posit that industry roles serve as catalysts for these discussions. For instance, a group assigned the *Plastics & Polymers Industry* role delved into associated problems and potential solutions presented in the game, touching upon concepts such as reusable plastics and the importance of regulatory measures to curb excessive plastic production. The second insight emerged organically from participants' national context. Furthermore, within the same group, while exploring the role of renewable resources in plastic production, another participant brought up the ability of certain bacteria capable of decomposing fossil-based plastics, reflecting on their potential in sustainability efforts. This illustrates how industry roles prompt participants to consider sustainable ideas by integrating their existing knowledge into discussions about sustainability, thus fostering deeper engagement.

TRANSCRIPT EXTRACTION: SCHOOL TESTING SESSION 2

Participant 1: „Unser Thema war die *Polymere und Kunststoffindustrie*, ein Problem ist, dass [Kunststoffe] sehr einfach herzustellen [sind], sehr robust [sind], was auch ein Nachteil ist, weil es sehr lange dauert, bis es sich zersetz und es ist nicht wirklich nachhaltig. Und dadurch das so günstig ist, wird überall verwendet, weil Profit. Wie man an diese Probleme reinkönnte, ist wiederverwendbare Kunststoffe zu verwenden, die halt einfacher wieder zu verwend sind und halt einfach, Kunststoffe reguliert, dass sie nicht in so große Maße produziert werden, wir zum Beispiel Plastiktaschenverbot in Deutschland.“

English translation: Our topic was the *Polymer and Plastics Industry*. One problem is that it's very easy to produce and very durable, which is also a disadvantage because it takes a long time to decompose and is not truly sustainable. And because it's so inexpensive, it's used everywhere for profit. One way to address these problems is to use reusable plastics, which are easier to reuse, and to regulate plastics production so that they're not produced in such large quantities, like the plastic bag ban in Germany, for example.

Secondly, roles offer logistical benefits by allowing entire groups of participants to join the game in teams, thereby promoting teamwork and collaboration within each group. Since each team has its own unique experience, roles also facilitate communication between teams during the discussion rounds, thereby enhancing the meaningful exchange of experiences among different teams. Furthermore, integrating roles ensures that each team is assigned to a distinct space within the exhibition, affording them privacy to solve the activities with their respective teams. Although occasional collisions occurred, with two teams overlapping in the same area, such instances were infrequent. Additionally, the visitors' laboratory can accommodate only 18 students at a time, requiring school classes to book regular programs in two separate sessions. The distribution of roles, along with their unique activity routes, allowed, for the first time, an entire class to participate together in a visitor program with laboratory experiments without the necessity

of booking two separate sessions. This arrangement ensured that the laboratory was used without overcrowding, as the entire class was not present simultaneously, thus preventing the laboratory from reaching maximum capacity. From a logistical standpoint, the inclusion of industry roles was a positive feature of the game.

Thirdly, and most importantly, roles offer a dual perspective for players to engage with both the main message and the smaller narratives within the game. Since the game's communication strategy involves breaking down the overarching message[39] into smaller ones, a shift in perspective is required. Here, it is important to emphasise that the sum of these smaller messages is not equivalent to the larger one, and interacting with them on the islands does not automatically guarantee engagement with the game's overarching message. Instead, these smaller messages are co-produced with the larger ones, mutually reinforcing each other. That is why having a mechanic in the game that allows for this shift is important, and the industry roles facilitate that. Participants engage with these two levels of information - the overarching message and the smaller sub-messages –simultaneously.

For instance, participants may begin engaging with the overarching message at the outset of the game since it's connected to the game's mission. The smaller messages, which are encountered later on the different islands, play a crucial role in fulfilling the mission – and therefore, they prompt participants to engage with the larger message. Likewise, keeping the mission in mind aids participants in completing the smaller activities – and that is how the overarching message promotes engagement with the smaller ones. In this layered engagement with messages, industries act as lenses through which participants view messages. Roles are closely tied to activities, thereby influencing the messages conveyed in each activity. They encourage players to expand their thinking beyond the immediate context and to apply the activities and their underlying messages to their broader industry-related issues. In the following section, I will delve into how roles intersect with activities in the game and, consequently, how they relate to the smaller messages.

4.3.1.2. The Industries and their Activities. Engaging with Messages through the "Industry Lenses"

The initial concept of the game envisioned each industry carrying out activities on every single island. Drawing inspiration from the circular layout of the museum's islands, the original plan was for industries to begin their activities on the island adjacent to their own and progress clockwise, concluding at their home island. The final activity of each industry was, therefore, the activity of their island. This journey was designed to expose participants to various messages along the

[39] *Imagining a "sustainable future" does not mean thinking about the ways to have a "chemical-free future", but engaging in a conversation about how chemical knowledge can be used to make our industries more sustainable.*

way, prompting reflection on their relevance to their industry context. The design aimed not only to emphasise the concept of circularity –by having participants literally move in circles throughout the exhibition– but also to communicate the importance of interdisciplinary collaboration in finding sustainable solutions. Participants were encouraged to explore solutions from other islands (i.e., other industries) with the intention that this would raise awareness of the significance of considering alternative approaches and drawing inspiration from them.

It might be questioned how the experience differs among industries if all participants engage in the same activities clockwise and encounter the same small messages upon completing them. The answer lies in the industries serving as lenses. When participants assume the role of an industry, they confront problems specific to their respective industries, prompting reflection on these issues and, consequently, experiencing the solutions unlocked in each activity from a different perspective. Therefore, the messages encountered on the different islands vary slightly from one industry to another due to the unique lens of each industry. This diverse perspective is further enriched by the introduction of a point system, which will be elaborated on in the next section. Upon completing activities, participants earn points based on the perceived effectiveness of the activity in fostering sustainability within their industry. To collect points using the app, participants must scan a QR code found on a card known as the Industry Points card. This card not only displays the points earned for the activity but also provides a brief description of how the activity may benefit the industry[40].

Following the first playtest of the game with Museum's staff, feedback was received indicating that the content and duration were excessive for a visitor's program and needed to be condensed. Consequently, the initial game was trimmed to include only three of the originally planned six activities. This feedback proved to be enriching for the game because reducing the number of activities to three allowed me to select the three activities that were more related to every industry – obviously, one of them was the activity corresponding to the industry's own island. In the final version of the game, only three activities are played, and the combination of activities is unique for each industry, accentuating the exclusive experience of each industry and resulting in a more compelling one. Nonetheless, the original plan demonstrated that even by including all the activities, the industries' roles and the reinforcement of them through a point system already allowed players to engage in the game in at least six different ways.

[40] For example, if both the Plastics & Polymers Industry and the Water Treatment Industry engage in the same activity on the Island of Food & Nourishment, they will encounter different solutions tailored to their respective industries. The Plastics & Polymers Industry will unlock a card explaining promising advancements in the fabrication of biodegradable plastics and plastics derived from renewable resources, while the Water Treatment Industry will discover the potential to extract fertilisers from wastewater – both solutions aligned with compost-ability and soil enrichment. On the other hand, the Food & Agriculture Industry, when undertaking the same activity, receives the general small message on the importance of designing products that can be safely returned to the soil while enriching it and earns more points than other industries because it is their home island and thus more closely linked to their primary challenges.

The table below shows the different industries and their respective combinations of activities, along with the unlocked messages at the end of each activity.

INDUSTRY ROLE →	**Food & Agriculture**	**Energy & Electronics**	**Hygiene & Health**	**Construction & Urban Planning**	**Plastics & Polymer**	**Water Treatment**
Activity 1	Chemistry of today and tomorrow	High performance thanks to chemistry	Construction	Chemistry in and around us	Analytical Chemistry	Nourishment
Message Activity 1	Bio-Batteries in agricultural practices: harnessing Earth's energy	Modular design: electronic components easily separable	Reduce disposable hygiene products: material passes to enhance reusability of products	Building in harmony with our surroundings	Reduce use of pollutants in plastic production	Use of nutrients from the wastewater
Activity 2	High performance thanks to chemistry	Construction	Analytical Chemistry	Chemistry of today and tomorrow	Nourishment	Chemistry in and around us
Message Activity 2	Correct sorting of agricultural waste for the production of plant-based products	No electro-waste: use of material passes track materials of electronic products	Reduction in the use of toxic sub-stances in hygiene and health products	Self-efficient buildings	Environment-ally friendly and biodegra-dable plastics	Decentralised and local wastewater treatment
Activity 3	Nutrition	Chemistry of today and tomorrow	Chemistry in and around us	Construction	High performance thanks to chemistry	Analytical Chemistry
Message Activity 3	Safe return of nutrients to the soil	Sustainable production of energy	Hygiene measures adapted to the diversity of the environment	No demolition waste	Resource efficiency: proper separation of plastics to maximise their useful life	No toxicity: proper wastewater management: no pollutants are discharged into the environment

Table 7: Allocation of activities to Industry Roles and the influence of Industry Roles on activity messages.

As indicated in the table, the inclusion of industry roles subtly adjusts the messages conveyed in each activity, tailoring them to the specific context of the industry. By integrating industry roles, participants are immersed in a real-world scenario where the activity's application should become tangible, thus deepening engagement with both the activity itself and its messages. This approach renders the content more relatable and relevant to the participants.

Upon completion of an activity, participants receive an *Industry Point Card* containing the summarised messages outlined in the table above. Since groups must successfully complete three activities to finish the game, participants must collect three distinct point cards. These cards collectively form a puzzle piece, contributing to the larger *Final Puzzle*. This aspect is crucial for the subsequent discussion round, where participants are required to address industry-specific problems and the solutions they have devised while assembling their puzzle pieces in front of their peers. The accompanying photo illustrates an example of a puzzle piece:

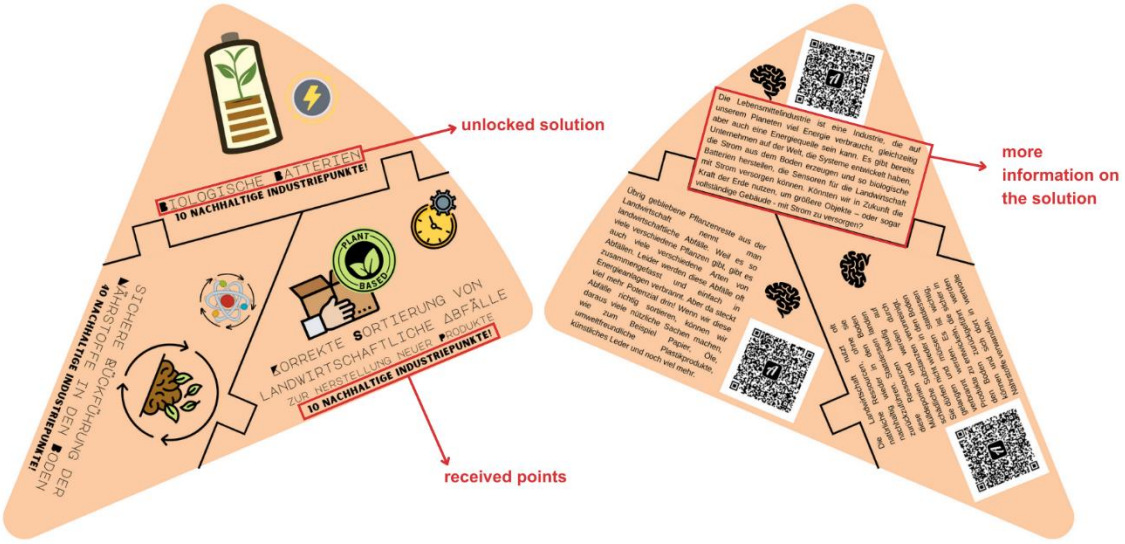

Figure 20 – The Food & Agriculture Industry Point Card: The photo displays an example of the three *Industry Point Cards* assembled together, corresponding to the *Food & Agriculture Industry*. The cards are easily identifiable by their orange colour, which matches the Industry Card and the associated thematic colour in the "Island of Nourishment". The front side of each card displays the unlocked solution along with the points earned for the solution. The reverse side offers a concise explanation of the solution and includes a QR code. Scanning the code provides participants with additional points.

Functioning as a puzzle within the larger *Final Puzzle*, these cards echo the way individual messages contribute to the broader one. During each activity, participants receive one of three puzzle parts. The cards possess varying point values, with those obtained from islands other than the participants' own yielding fewer points. This distinction acknowledges that, while all solutions are advantageous to the industry, those most closely related to the participants' specific topics—namely, those originating from their own island—hold greater significance and thus carry higher value.

To finalise this section, I shortly reflect on the observed outcomes of this mechanic. Regarding engagement with the messages, I observed that the industry roles facilitated the incorporation of participants' knowledge about the industry into the game. However, it should be acknowledged that, at times, concerns arose about the complexity of the mechanics, including the sub-messages and the use of industries and lenses to relate these sub-messages to more familiar contexts, potentially making the game challenging to engage with. As mentioned in the previous *Content* section, certain aspects of the game, particularly those associated with the

material passes, were more difficult to engage with, perhaps due to their novelty. It was observed that while the game introduced new perspectives to the participants, much of the discussion centred around sustainable knowledge that they may have already acquired in schools or through public discourse, making it challenging to assess the true extent of engagement fostered by the game on the topic. The question of how industry roles contributed to engagement with the game messages remains open, but it can be said that industry roles also positively impacted the discussions because they brought personal connections from participants to sustainability issues. Moreover, the unique set of activities associated with each industry provided each group of participants with a distinctive experience and made the final discussion in the game more meaningful.

4.3.2. The Point System of CREISE. 360 points to achieve sustainability.

The point system of CREISE was introduced as a strategy to enhance engagement with the messages by offering participants rewards and fostering competition. Consequently, it serves as a strategy to enhance overall game engagement. This system operates as follows:

- **Participants in CREISE can earn two types of points:** normal points and final industry points. Normal points are awarded for correctly completing the small activities designed for each island. Final industry points, akin to bonus points, are obtained upon completing the island's main activity. These points can be earned by scanning a QR code located on the back of the Industry Points Card. The amount of final industry points varies based on both the industry and the specific activity involved.
- **Each industry undertakes three activities:** two on external islands and one on their designated island. Given that the activities on external islands are not directly aligned with their respective industries, they yield fewer points compared to activities on the participants' own islands. Participants earn 10 industry points for activities on external islands and 40 industry points for activities on their home islands.

The implementation of bonus points, along with their notable contrast between *foreign activities* and those on participants' home islands, aims to make participants aware of the most important concepts related to their industry. Simultaneously, it underscores the significance of exploring and incorporating external approaches within their respective fields. Participants noticed this difference in points, with many of them being surprised to receive so many points at the end of the game once they had completed their own industry-related activity (Field Notes, 04.03.2024). During the discussion round with the schools, I also observed that while participants occasionally did not comment on all solutions found, they consistently engaged with solutions tied to their own

industry activity (Field Notes Winter 2024). This observation might not be solely due to the higher point value; other factors, such as the information provided in the industry cards or the influence of sustainable narratives, likely played a role as well. However, through my observations, I believe the points system certainly enhanced participants' awareness of their main industry message, fostering engagement with it. Even though it is difficult to assess to what extent a different number of points contributed, these reflections demonstrate how point systems can help reinforce particular messages in games.

Additionally, in exploring the role of points in conveying messages within games, it has been observed that points can evoke emotional reactions that establish a connection with the game's content. The choice of Actionbound as the platform to facilitate the game's narrative was primarily influenced by its point system, which plays a crucial role in fostering engagement with the story in various ways. The design of the point system in the application is user-friendly and offers both visual and auditory feedback. Correct answers trigger the appearance of a piggy bank symbol accompanied by a cashing-out sound, providing a sense of satisfaction. Conversely, incorrect answers prompt the display of a neutral face along with a two-note descending interval, signalling disappointment. This combination of visual and auditory stimuli proves to be impactful; correct answers generate satisfaction, while incorrect ones can result in disillusionment. Participant reactions have provided evidence of the effectiveness of this point system. In multiple tests, correct answers have elicited celebratory reactions from participants, even when the tablet volume is turned off, while in situations where they answered incorrectly, I observed the discontentment on their faces (Field Notes, 15.01.2024; 29.01.2024; 04.03.2024). This illustrates a potent means of emotional engagement.

Moreover, it has been observed how this emotional engagement is linked to the game's content, thereby fostering engagement with the game's messages. An illuminating example of this connection is evident in the case of incorrect answers. Incorrect answers have tended to generate higher levels of engagement with the game's content, making them an intriguing strategy to consider when designing engaging activities.

ENGAGING THROUGH WRONG ANSWERS

Field Notes, Winter 2024: I became aware of this phenomenon while listening to the discussion rounds in the different tests of the game. One of the designed chemical experiments was about filtration. In this experiment, participants needed to filter dirty water with different particle-size filters. At the end of the experiment, participants were confronted with the question: "Is the water after the last filtration completely clean?" The answer was multiple-choice based, requiring participants to choose either "yes" or "no." Most participants answered this question incorrectly, believing that the water is clean because it appears clear after filtration. Following this question, a brief explanation clarified that although the water may seem clear, because only physical size-based filters were used, there might still be small contaminants present that require extraction using more powerful methods.

ENGAGING THROUGH WRONG ANSWERS

Figure 21 - A screenshot depicting the results of the question, "Is the water completely clean after filtration?

As evident, the majority of recorded answers are incorrect. However, during the final discussion round, nearly all participants who conducted the chemical experiment noted that the water remained impure.

TRANSCRIPT EXTRACTION: SCHOOL TESTING SESSION

Participant 3: „Als letztes haben wir noch dem Punkt, wenn man in der Industrie oder so, bestimmte Reinigungsmittel verwenden hat, das Wasser danach viel verschmutz werden kann und haben wir auch ein Versuch gemacht, wo verschmutztes Wasser durch verschiedene Filterart laufen lassen haben und am Ende war das Wasser trotzdem nicht sauber.“

English translation: “Finally, we also addressed the point that when using certain cleaning agents in the industry or elsewhere, the water can become heavily polluted afterward. We also conducted an experiment where we passed contaminated water through various types of filters, and in the end, the water still wasn't clean.”

TRANSCRIPT EXTRACTION: SCHOOL TESTING SESSION 3

Participant 1: „Dann haben wir noch ein weiteres Experiment, […] wie schwer ist die Microteile von Plastik auszufiltern. Wir hatten Erde das sollten wir aus Wasser rausfiltern, dann haben wir dann verschiedene Arten von Filter benutz, vom grobsten bis zu feinsten und am Schluss haben wir ein 5 Picometer Filter benutz, der dann aber noch nicht alles rausgefiltert hat, weil noch Bakterien auch an einer kleineren Ebene sind.“

English translation: „Then we conducted another experiment, [...] to see how difficult it is to filter out microplastic particles. We had soil that we needed to filter out of water. We used various types of filters, from the roughest to the finest, and in the end, we used a 5 picometer filter. However, it still didn't filter out everything because bacteria are also present at a smaller level. “

On a final note, regarding the role of points in reinforcing messages, the point system was also used to highlight the theme of the game: circularity. Thus, the point system is structured so that the maximum number of points a participant can achieve is 360, a number that resonates with the 360 degrees of a circle, enhancing the thematic coherence of the game. While this may seem like a mere stylistic detail with minimal impact on participants, it contributes to the overall

harmony of the concept. Additionally, some participants were curious about the maximum number of points attainable in the game. At the game's conclusion, only their position and total accumulated points are displayed, omitting this information. When I revealed that the maximum points attainable were 360, it elicited smiles from some participants who perhaps found it poetic (Field Notes, 04.03.2024). This design choice may not directly enhance engagement in the game, but it exemplifies the cohesion I aimed to achieve across all levels, reinforcing the concept of circularity. I endeavoured to convey circularity through numerous subtle design choices, which may go unnoticed by many participants but serve as small nods to those with a keen eye who can appreciate them.

5. Discussion & Conclusion

Contemporary discourse in the field of science communication advocates for more applied dialogue and participation-driven initiatives to engage the public in contested issues of science and technology. This study addresses current claims and contributes to the broader discourse and understanding of such practical interventions by creating a gamified intervention embedded within a museum exhibition. The intervention is specifically designed to engage the public with topics such as sustainable development and the circular economy while also encouraging discussions about how chemistry can contribute to creating a more sustainable world. Hence, this research extends its relevance to intersecting domains, notably museum studies and games for sustainability development. On the one hand, museum studies can benefit from the insights that gamified interventions offer in understanding their audiences and their ways of engaging in these settings. On the other hand, this study underscores the roles of games for sustainability purposes and provides practical examples of different formats that can be introduced for such novel and interactive approaches. It is within this interdisciplinary convergence that the novelty of this research lies, as it addresses various gaps within these fields, thereby advancing scholarship in science communication, museum studies, and games for sustainability.

The primary focus of this study is on science communication; thus, the discussion will mainly consider discourses in this field. Nevertheless, it is also important to mention that the supportive institutional environment in which this work was developed not only facilitated the implementation of the intervention but also established it as a regular visitor program available for booking after the course of this research. This continuity adds value to the game by addressing a gap in the literature on gamified interventions for sustainability, which often notes that such interventions are not studied over extended periods. Although the short duration of a master's thesis did not allow for reflection on the long-term impact of this intervention, the sustained presence of CREISE as an official visitor program at the Deutsches Museum[41] suggests promising avenues for future research. Thus, this continuity invites further investigation into the lasting effects of such interventions on science communication within museum contexts.

In this final discussion, I explore both the empirical findings that contribute to the existing literature on science communication and the potential future research avenues stemming from this study. In the first part of the discussion, I introduce a novel framework for science communication that better describes the particular process of ideation, creation and implementation of CREISE within the Chemistry Exhibition of the Deustches Museum: science *communication as a symbiosis*. The consideration of a new framework tailored to this specific

[41] For more information about CREISE as an official visitor program at the Deutsches Museum, please visit: Deutsches Museum - Chemische Reise (Kreislaufwirtschaft)

case study inevitably prompts a brief reflection on the potential extension of this understanding to broader contexts.

In the second part of the discussion, I elaborate on the limitations of this research and the potential lines of research unlocked by the sustained presence of this intervention in a public space in Munich, Germany.

5.1. Science Communication as Symbiosis.

The execution of a practical approach to science communication at the Chemistry Exhibition of the Deutsches Museum has been thoroughly examined in this ethnographic study. While the process of ideating, creating, and implementing these interventions is highly context-specific, the reflective nature of the study allows for the extraction of valuable insights that might be useful and help the development of such practical approaches. In this section, I argue that these insights show that such approaches can thrive through symbiotic relationships among the stakeholders involved. Therefore, I propose and discuss a new framework for practical science communication: science communication as symbiosis.

The concept of science communications as symbiosis stems from reflections on how CREISE thrived, which provided a holistic understanding of the collaborative relationship between the museum and me. This realisation suggested a framework for fostering fruitful collaborations in science communication interventions. When an external researcher creates a science communication intervention, a process of negotiation occurs between the parties involved. These negotiations are complex and merit their own study. However, in the case of CREISE, transparent and cooperative negotiations with Deutsches Museum staff made me aware of the symbiotic reality underlying the intervention. This reflection led to the consideration that science communication, understood as a symbiotic relationship, could serve as a holistic framework to guide the sound development of such practical interventions for science communication in public spaces like museums.

In short, my ethnographic journey has led me to conceptualise science communication in a new light: as a symbiosis. The new proposed framework more accurately describes my personal experience in creating an intervention that benefits both the museum and me. Therefore, in this first subsection, I present this new lens for navigating the creation of science communication interventions, drawing on how it complements existing Science and Technology Studies literature on science communication frameworks. Moreover, I theorise how this can also be applied in understanding engagement in practical approaches of science communication when communication is seen as a force shaping the parties involved.

5.1.1. My symbiotic relationship with the museum: Science Communication in the context of CREISE.

The site where science communication practices unfold is crucial for fostering sound communication, but it is not enough to understand the development of a practical science communication approach. Davies & Horst (2016) introduced *science communication as culture* to precisely reflect on the space of communication and its influences on the type of communication being created. The cultural lens, with its emphasis on examining institutional practices and traditions within science communication, sheds light on how images of the site are created, and institutional reputations maintained (Davies et al., 2019; Davies & Horst, 2016). For this reason, science communication as culture has been helpful in understanding the practices of the Deutsches Museum and the Chemistry Exhibition. However, despite these valuable insights, when applied to the entirety of the case study of CREISE, the cultural framework only explains one aspect of the communication occurring in this intervention—the aspect belonging to the museum. Consequently, it falls short of holistically capturing the broader complexity of crafting a science communication intervention when an external party, such as myself, is engaged.

Throughout this work, it has become evident that the successful implementation of a science communication intervention in the Chemistry Exhibition relied heavily on a thorough evaluation of the site's characteristics, as well as the traditions and requirements of the Deutsches Museum as an institution: their “culture”. Nonetheless, upon critical examination, I noticed that while the cultural framework was crucial for ensuring alignment between the objectives of this study and the museum's expectations, this alignment also implied a negotiated process that cannot be solely explained through the cultural framework. The process involved a mutual consensus on developing a program that would remain integrated into the exhibition with the aim of enhancing its visibility to wider audiences[42]. This shared objective at the heart of our collaboration drove us to create an intervention that *mutually benefited* both parties—expanding the museum’s educational program while furthering my academic inquiries. Such collaborative relationship mirrors a symbiotic relationship akin to those observed in biological studies. It has inspired me to reassess how participatory approaches to science communication can be executed in institutional settings, considering science communication as a mutually beneficial relationship, as a symbiosis.

In biological studies, a symbiotic relationship is broadly defined as the close association of two different species coexisting together (de Bary, 1879). Such associations typically entail consequences for the fitness of individuals during the period in which the organisms interact

[42] Described in the Chapter 3 section 3.4.2 dedicated to the Museum’s Stakeholders

(Paramentier & Michel, 2013). Generally, the association between two organisms can be distilled into two main factors: the impact on the host and the relative duration of the association (Ibid.). It is important to note that not all symbiotic relationships necessarily result in a fitness increase – namely *benefit*; the outcome also depends on the environment of both the host and the symbiont. Therefore, there exists a wide range of symbiotic relationships, which can also fluctuate over time and in response to environmental factors. As a result, experts often encounter difficulties in precisely delineating the boundaries between different forms of symbiosis.

Science communication as a symbiotic association frames the coexistence – the working together over a period of time– of different stakeholders in the creation of a science communication intervention. As in its biological classification, this association can unfold on a broad spectrum of *fitness* and *time*. In the context of CREISE, the Chemistry Exhibition at the Deutsches Museum surfaced as an exceptionally favourable setting for the intervention. The museum's dedication to integrating modern principles of science communication resulted in the new Chemistry Exhibition, which vividly fostered the public's engagement in the field of chemistry by bringing them closer to the manifold manifestations of chemistry in their everyday life. This alignment with theories of engagement rendered the exhibition a meaningful locus for the intervention (host), fostering a symbiotic relationship wherein I (the symbiont) benefited from the institution's infrastructure and expertise while the exhibition garnered increased audience engagement, enhanced its promotional efforts and educative content.

Several instances exemplify this symbiotic relationship, with personal learnings serving as vivid illustrations. Observing the exhibition's engagement strategies has profoundly informed my approach to crafting compelling communication. The museum experience has equipped me with strategies for devising engaging narratives, including the meticulous structuring of messages, the integration of diverse communication formats, and the incorporation of relevant and relatable content to captivate audiences. Furthermore, the gamified intervention transcended logistical challenges encountered with traditional visitor programs, such as standard chemical experimental workshops. Unlike conventional formats that necessitate sequential bookings due to laboratory capacity constraints, the innovative game format facilitated the simultaneous engagement of entire school groups and brought a novel approach for such programs. These practical examples underscore the intricate symbiosis between the museum and me, the external researcher, showcasing the fitness – in this particular case, our mutual benefits – derived from collaborative endeavours.

In conclusion, I believe that the framework of symbiosis can inspire sound interdisciplinary collaborations in developing practical approaches to science communication. In this framework, the involved parties should foster mutual benefit for their interventions to thrive.

5.1.2. Extending the framework of Symbiosis beyond the case study of CREISE.

Science communication as a symbiosis has yielded fresh insights into the process of crafting and executing a practical approach to science communication in relation to the intervention site and the stakeholders involved. This prompts a reconsideration of practical exercises in science communication as a symbiotic endeavour, emphasising the need for involved parties to collaborate in a mutually beneficial manner for these interventions to thrive. However, could this framework be extended as a responsible framework for science communication and public engagement?

The overall format of CREISE, the game itself, is a participatory communication format. While dissemination and dialogical formats were employed within the game, its informal and open setting aligns with the participatory communication model defined by Bucchi and Trench (2021). As Horst and Michael (2011) noted, communication in participatory science communication formats does not follow a singular direction but rather functions as a dynamic force that shapes all parties involved. Similarly, in this section, I argue that responsible science communication in highly participatory formats can benefit from understanding the communication process through the framework of symbiosis, where communication is considered a symbiotic force. The concept of symbiosis refers to the coexistence and association of two entities over a period of time – over the course of the science communication event. Once the symbiotic association takes place, the entities are transformed, having been shaped by the force of coming together. This resonates with Horst and Michael's (2011) understanding of participatory events, viewing the communicative process as a force that shapes entities. If this force is understood as symbiotic, it can trigger responsible communication and public engagement by prompting consideration of how communication can be directed in a way that benefits the public.

Previous discussions emphasised that this work's collaboration, where the mutual benefit shaped the involved parties, generated a symbiotic force—or association—that positively influenced both the museum and the researcher in the fruitful creation of a science communication intervention. However, since communication itself is a shaping force, participants in the game and the game itself are also influenced by the communicative event, warranting further evaluation. Observations from participants' engagement in post-game discussions demonstrate how participants have shaped the game and how this, in turn, has shaped participants. The results suggest that achieving high engagement in science communication may depend on establishing a symbiotic relationship—a mutually beneficial connection—between the public and the participatory format of communication, exemplified here by CREISE.

For instance, different meanings of CREISE were created in the discussion rounds; participants highlighted the importance of customer responsibility, while I tried to create messages that went beyond this kind of statement and underpinned the importance of industrial responsibility. At the same time, the game brought new insights and shaped participants' understandings as well, and this becomes evident thanks to a reflection prompted by a chemical experiment in the game. Chemical experiments were particularly interesting to include due to their immersive nature, which provides participants with all-round engagement through the laboratory experience. Detailed in the results was the reflection of a participant who noted how the chemical experiment involving plastic separation prompted a new contemplation on the real-life implications and costs of such processes.

Even though further research is needed to refine this framework, viewing science communication through the lens of symbiosis could offer a valuable perspective for managing highly participatory formats responsibly. In these contexts, communication is not merely a passive flow but a transformative force that shapes all parties involved. Recognising this force as symbiotic may cultivate more responsible engagement because the symbiotic lens should encourage reflection on communication that benefits the public by examining how interactions unfold over time within specific environments and how they shape the entities involved in science communication events. Such reflections prompt a deeper exploration of how these interactions alter our *fitness* — including our knowledge, competencies, abilities, values, beliefs– and ultimately transform us through the communicative process. Science communication, viewed as a symbiosis, should aim to enhance this *fitness* in a positive manner.

5.2. Strengths and Limitations, Future Lines of Research.

Due to the study's limited timeframe and resources, a thorough analysis of the participants' meaning-making processes during their engagement in the game, as well as a deeper exploration of how such interventions co-create publics within museum spaces, could not be fully conducted, as originally intended. Consequently, the research focused shifted primarily on documenting the ideation, creation, and implementation process of a practical approach to science communication in a museum setting. The methodology used and the results are consistent with this shift and the study has been an ethnographic journey through the process, bringing valuable reflections on how more practical and dialogical approaches to science communication can be created in museums.

I view this shift as beneficial and the strength of this study, as it has brought many insights into how such interventions can be responsibly conducted, serving as a guide for science communication scholars seeking to bridge theoretical claims with practical application. By focusing on the process rather than the outcomes of the game, I have detailed various strategies

used to foster engagement in practical communication endeavours. These findings can hopefully inspire individuals working in fields such as science communication, museum studies, and games for sustainability. Moreover, a focus on the process allowed for reflection on the nature of collaboration and the success of the intervention, leading to a new understanding of science communication as symbiosis. I sincerely wish that this reflection can encourage more sound interdisciplinary collaborations in science communication, rooted in the mutual benefit of all parties involved, which has always been at the core of CREISE.

However, there are inherent limitations to this study, primarily related to the small sample size of three schools. While this data sufficed for the design and implementation process of the game and allowed for a comprehensive reflection on its engagement elements, it fell short in providing an in-depth analysis of the participants' meaning-making processes during the game and the co-creation of the public in museums. Although initial coding of the school discussion material was conducted, exploring this research inquiry through this practical intervention would require achieving data saturation and, therefore, further complementation and a more extensive coding process would be imperatively needed. Nonetheless, this initial coding process has unveiled promising avenues for further exploration, which could be pursued through a deeper analysis of the discussion rounds with the schools. I believe that additional data collection from participants involved in these discussions could yield more insights into participants' meaning-making processes and the co-creation of publics in museums through science communication interventions. Thus, I identified three intriguing avenues for future research that stem from this work.

Firstly, there is potential for a study examining the prevailing narratives of sustainability that shape public perceptions of a sustainable future and pathways to achieve it. Insights gleaned from the discussion sessions suggest that there may be a collective understanding of sustainable development that influences post-game discussions. A detailed analysis of these discussions could offer valuable insights into these collective ideas and enable the identification of major sustainable narratives.

Secondly, a detailed study of the game discussions could shed light on the diverse nature of the public in museums. Building upon Hetland's (2019) classification of museum publics, this study seemed to target what Hetland defines as the *pure public*. Therefore, the target audience for the game may initially seem homogeneous. However, observations from the discussion rounds have suggested that this *pure public* might be more complex and less homogeneous than it seems. Through their meaning-making process, participants of the game have shown different patterns of engagement. These different reactions prompt consideration of various subgroups within the audience and potential types of the public that are co-created through the intervention in the museum. In this line, it is noteworthy that some teenagers demonstrated a strong pre-

existing interest in sustainability topics, actively contributing to discussions from an *activist* standpoint. Conversely, other participants showed enthusiasm for the innovative solutions proposed by the game, expressing interest in exploring and implementing them on a larger scale. For instance, one participant suggested the use of bio-batteries to power agricultural machinery. Although the feasibility of such a solution is currently limited, the fact that a participant proposed this idea suggests a *techno-positive* and innovative mindset among some participants. Therefore, further investigation into how the game shapes these diverse audience segments promises to yield valuable insights into the study of the public in museums.

Thirdly, a more exhaustive analysis of the framework of symbiosis is required and would benefit further explorations on how this framework can be understood beyond the case study. The symbiosis lens suited the context of this work describing the particular science communication intervention that took place in the Chemistry Exhibition of the Deutsches Museum and how this intervention came to be out of negotiations between the museum and myself to create something that benefited both of us. Therefore, I believe that the framework of science communication as symbiosis can be a valuable perspective for navigating the creation and implementation processes of practical science communication interventions, guiding sound collaborations where such interventions can thrive. Although the framework of the symbiosis has been theorised further to explain responsible communication and engagement in highly participative science communication formats, where communication is a force shaping parties at play, I acknowledge that this is a first theorisation and more research on this direction would be needed as well. Therefore, a deeper exploration of the framework is necessary.

To conclude, this thesis provided an ethnographic reflection on how more dialogical and participatory approaches to science communication can be developed in museum settings, focusing on the themes of sustainable development, the circular economy, and the role of chemistry in shaping sustainable futures. Despite its limitations, this study represents an important step toward understanding the creation and execution of practical, participatory science communication strategies and the dynamics of science communication events in museums. By proposing a new framework—science communication as a symbiosis—this study underscores the importance of developing practical approaches and fostering collaborations that benefit all parties involved. Moreover, by theorising further on how the symbiosis framework may serve as lenses for responsible science communication and public engagement, this work demonstrates that transitioning from theoretical concepts to practical applications can advance science communication discourses. Therefore, this thesis illustrates the iterative nature of academic research, highlighting the significance of practical interventions in science communication. Responsible science communication must certainly be built in circles, through the iterative process between theory and practice.

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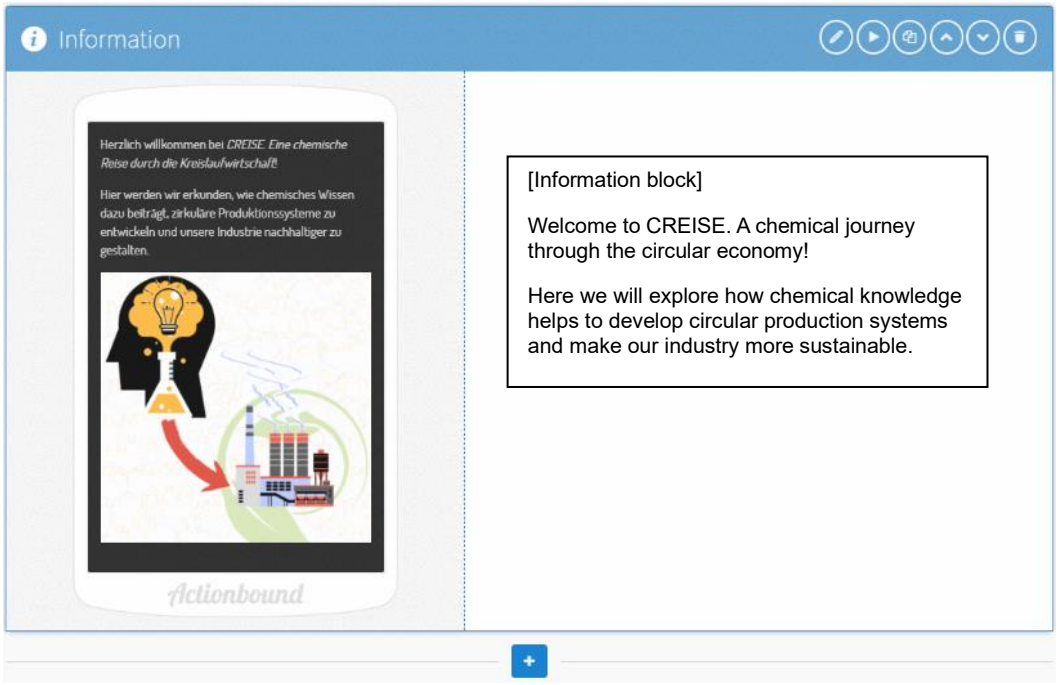
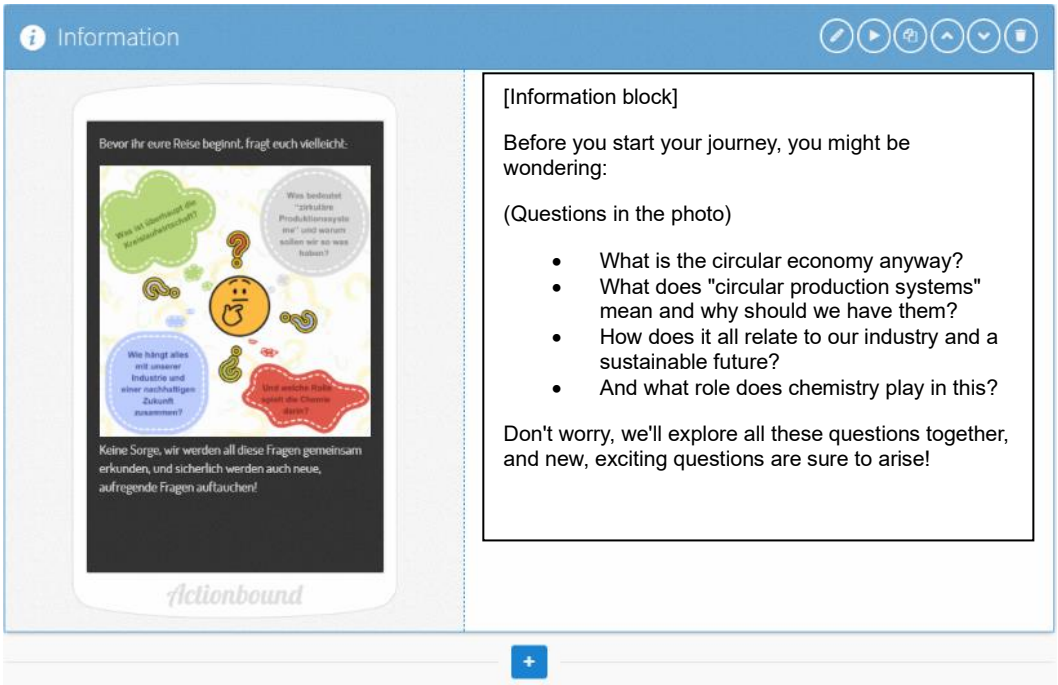
7. Annex

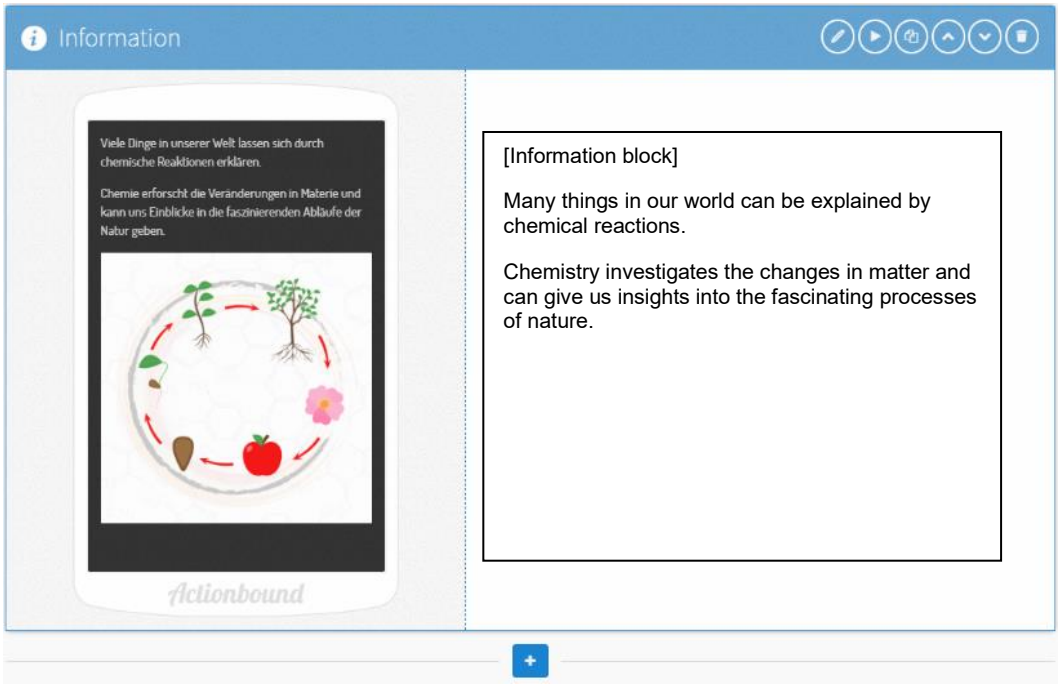
7.1 The Actionbound Game.

The game was developed using Actionbound, a platform specifically designed to create treasure hunts and guided tours with ease. The following images are screenshots[1] from the Creator page, where the game was constructed using Actionbound's intuitive building blocks.

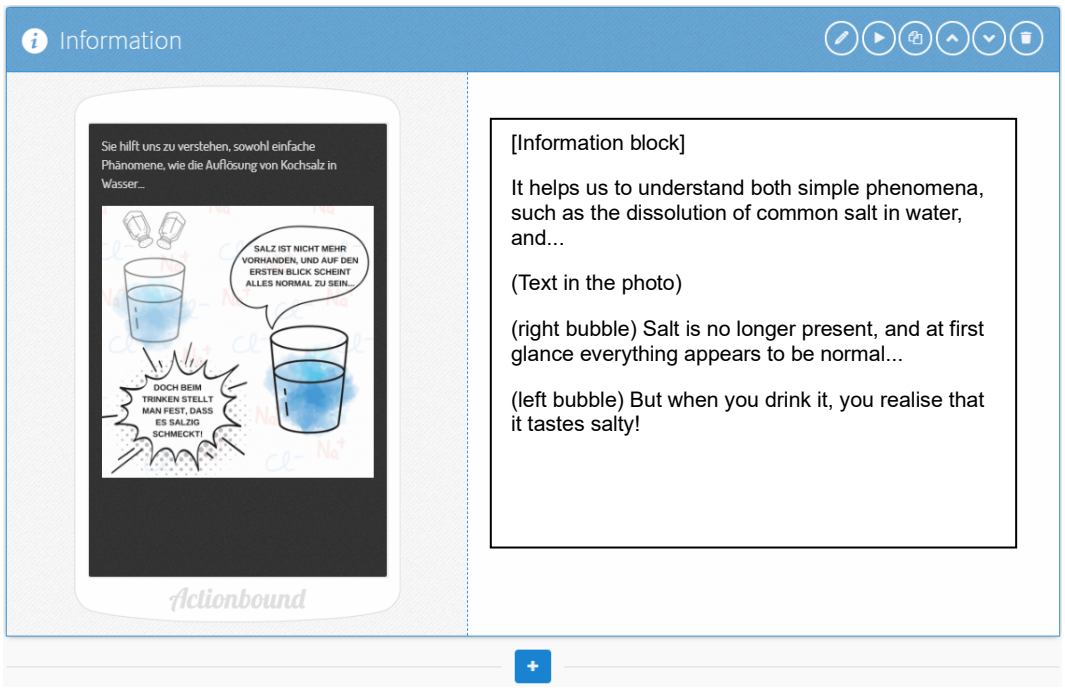




[1] The following images are screenshots captured from the creator page of Actionbound. This approach has been chosen to better illustrate the design and creation process behind the game. For those interested in exploring the smartphone version, you can download the Actionbound app from this link and search for "CREISE" within the app.
All images uploaded in the game were originally created by the author using the online graphic design tool Canva.

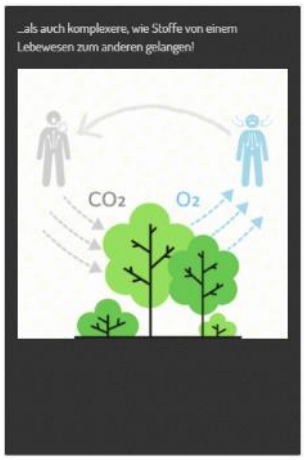


Information Block[2]



[2] The Information block permits the presentation of content in written form, or through video, pictures, or audio.

Information



[Information block]

...as well as more complex ones, such as how substances pass from one living being to another!

Information

[Information block]

When we observe the chemical processes in nature, we realise that there is no waste; everything is food and everything is in balance.

Information

[Information block]

Take a look at this part of the exhibition and you will see how chemical knowledge has contributed to a more comfortable life.

Information

[Information block]

But at the same time, it also poses threats to our environment. That's why some people think that chemistry and sustainability don't go together.

Information

[Information block]

But is that really the case?

If chemistry helps us to understand the secrets of nature, could we design our industry in such a way that it acts in harmony with nature?

Information

[Information block]

Now go to the right onto the industrial island and find the area shown in the photo.

There you will find various industry cards that assign you your roles in the game.

Information

[Information block]

The industry map contains:

- an overview of the exhibition
- the route you have to follow during the game
- important information about your industry!

Choose a map and always keep it during the game!

The photo is only an example! Your map could look different.

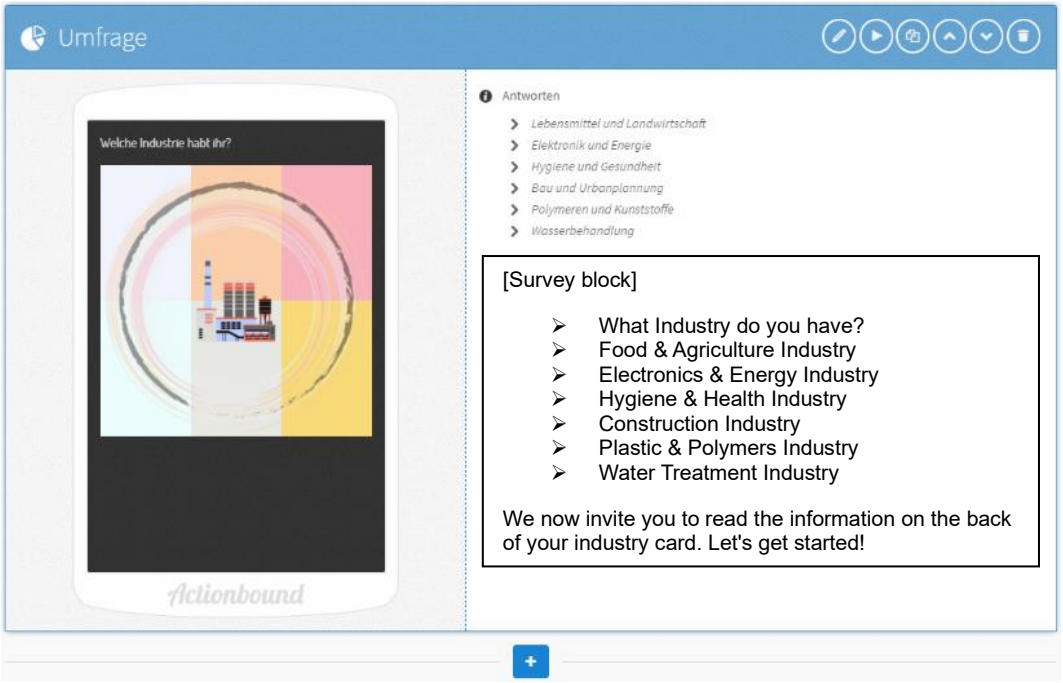
Information

[Information block]

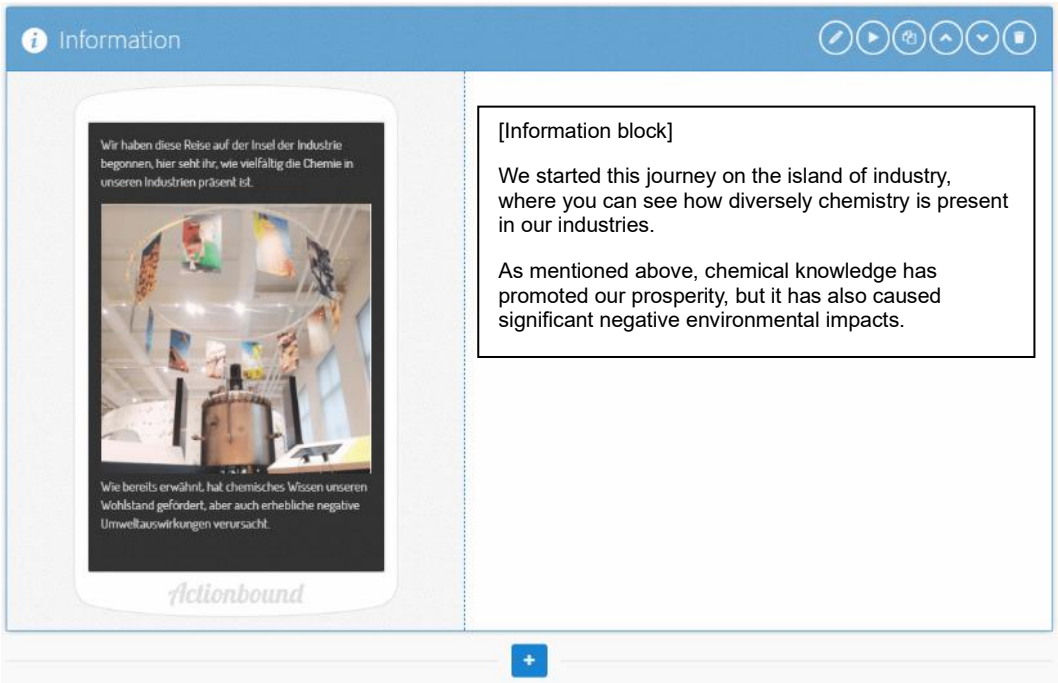
Your mission in this escape room:

- To find out how you can make your industry more sustainable!

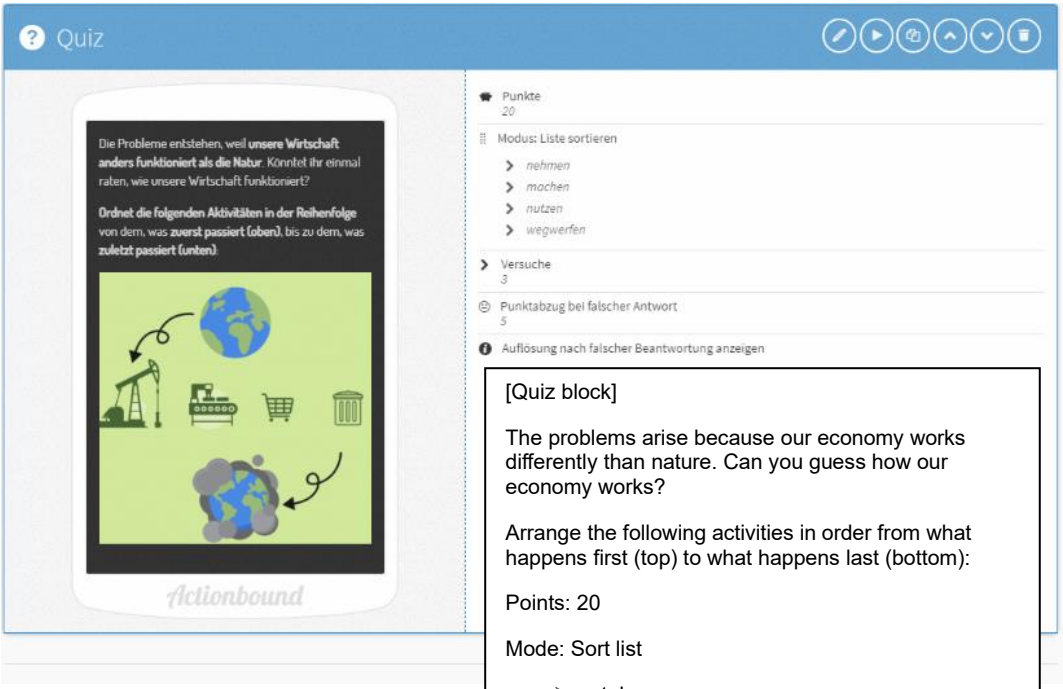
We now invite you to read the information on the back of your industry card. Let's get started!



Survey Block[3]



[3] The Survey Block is designed to create surveys where participants can respond freely, with no right or wrong answers. In this case, it is intentionally used in conjunction with the Switch Block to present tailored information based on the specific industry each group represents.



[Quiz block]

The problems arise because our economy works differently than nature. Can you guess how our economy works?

Arrange the following activities in order from what happens first (top) to what happens last (bottom):

Points: 20

Mode: Sort list

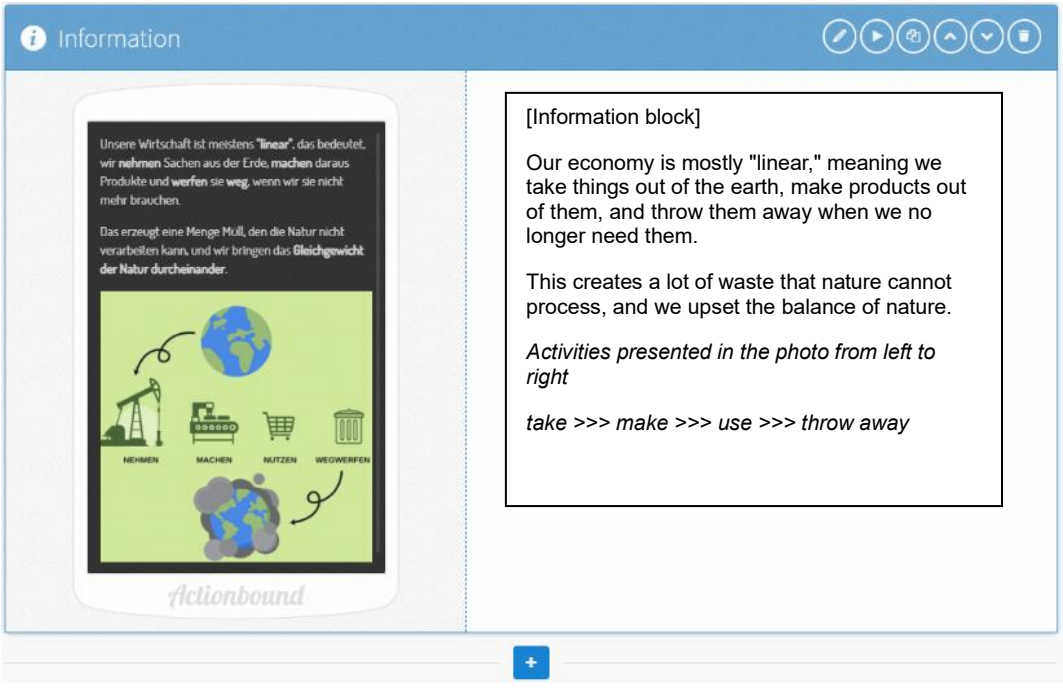
- take
- make
- use
- throw away

Attempts: 3 / Penalty for incorrect answer: 5

Show solution if answered incorrectly

Quiz Block[4]

Sort List Mode[5]



[Information block]

Our economy is mostly "linear," meaning we take things out of the earth, make products out of them, and throw them away when we no longer need them.

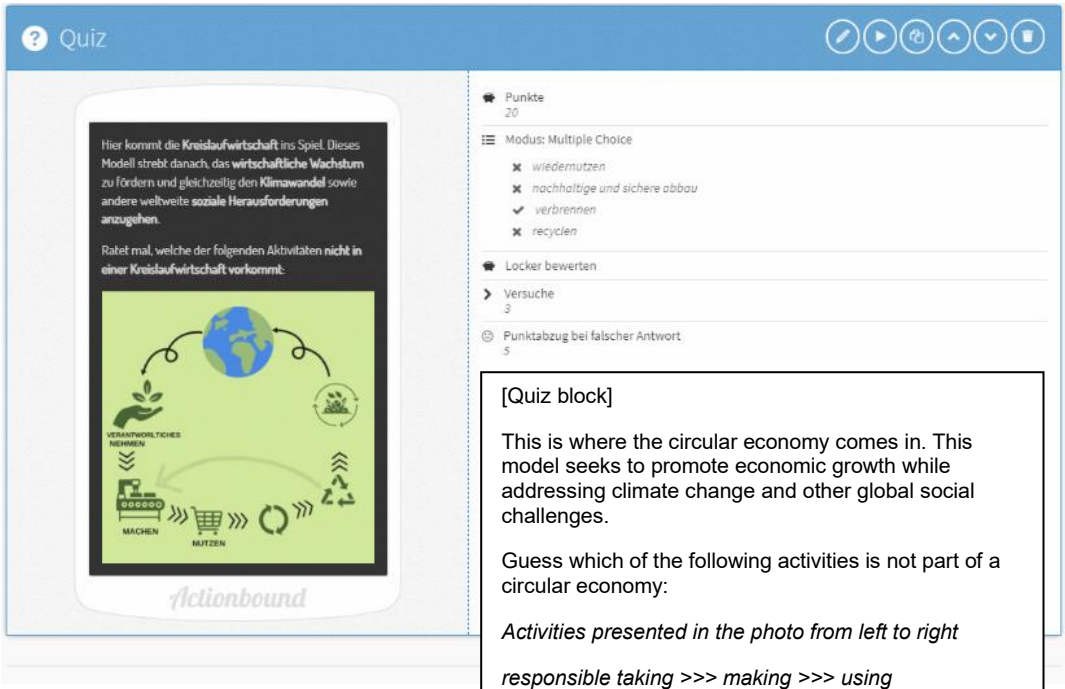
This creates a lot of waste that nature cannot process, and we upset the balance of nature.

Activities presented in the photo from left to right

take >>> make >>> use >>> throw away

[4] The Quiz Block is used to create activities that assign points based on participants' performance. In the Quiz Block, there are right and wrong answers, and participants earn points according to their good work. Various quiz modes are available and will be introduced as they appear. Each Quiz Block includes options for the number of attempts, penalties for incorrect answers, and hints. The use of these variables affects the number of points participants can earn per activity.

[5] The Sort List Mode is an activity where participants are required to arrange a series of items in the correct order. These items are always presented in a randomized sequence.



Multiple Choice Mode[6]

[Quiz block]

This is where the circular economy comes in. This model seeks to promote economic growth while addressing climate change and other global social challenges.

Guess which of the following activities is not part of a circular economy:

Activities presented in the photo from left to right

responsible taking >>> making >>> using

Points: 20

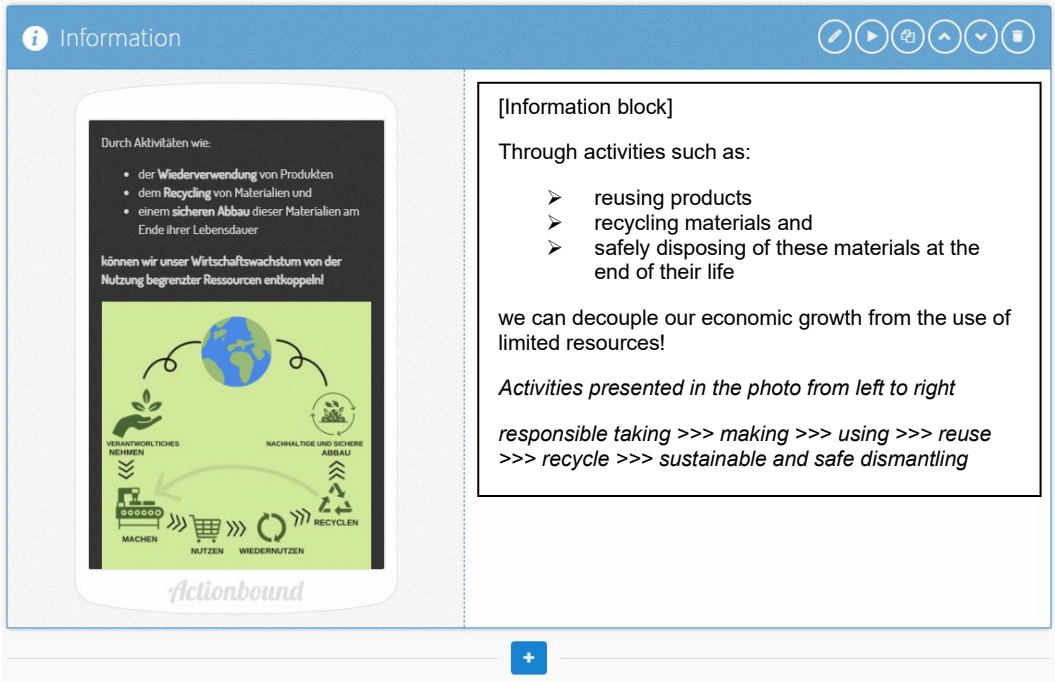
Mode: Multiple choice

- reuse
- sustainable and safe dismantling
- burn (correct answer)
- recycle

Relaxed scoring

Attempts: 3 / Penalty for incorrect answer: 5

Show solution if answered incorrectly



[Information block]

Through activities such as:

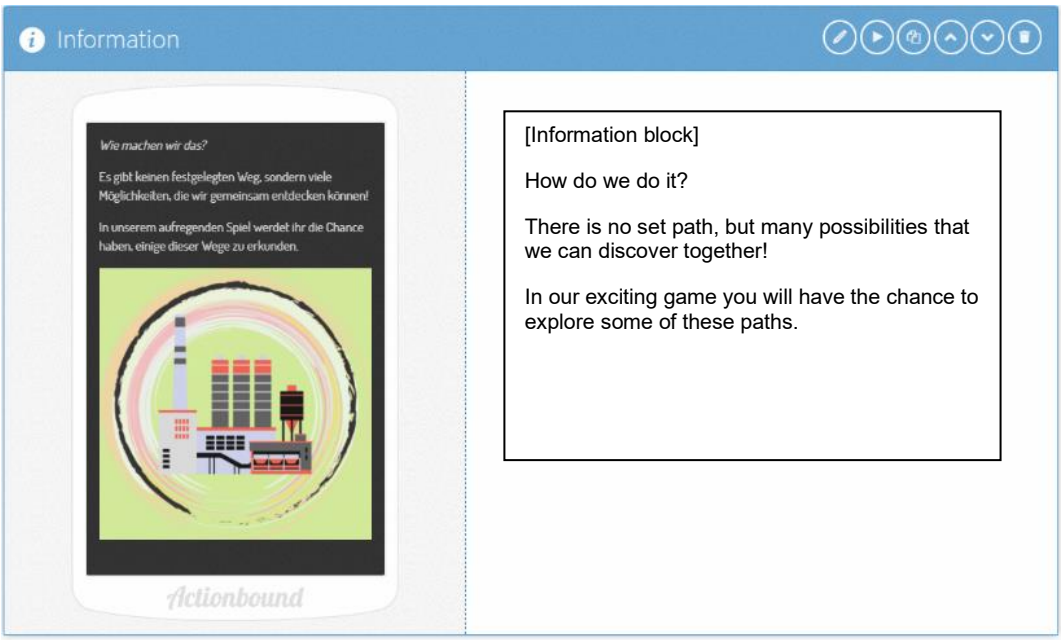
- reusing products
- recycling materials and
- safely disposing of these materials at the end of their life

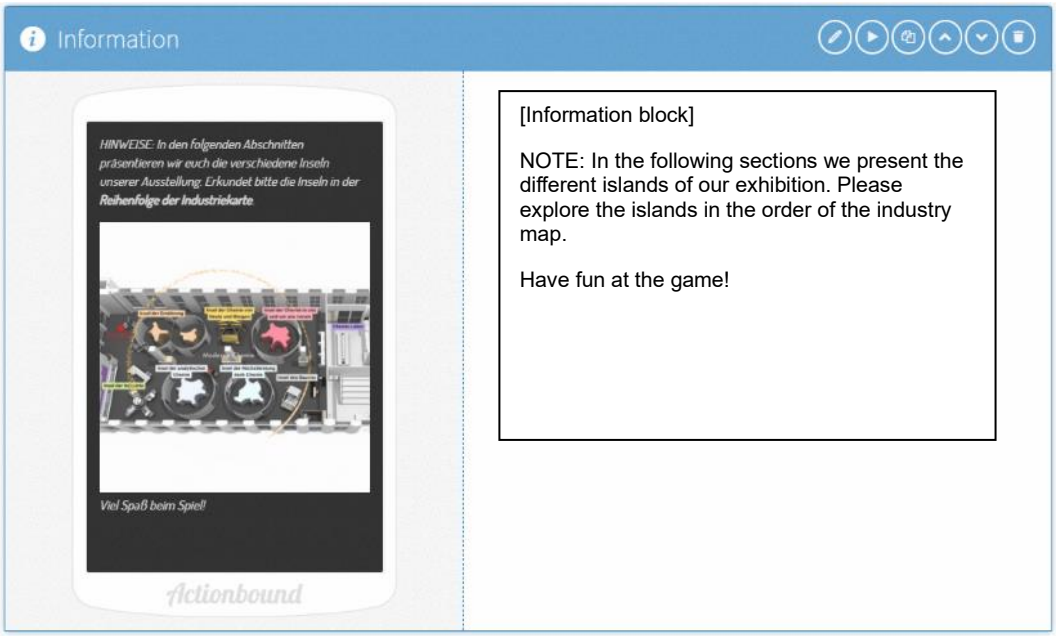
we can decouple our economic growth from the use of limited resources!

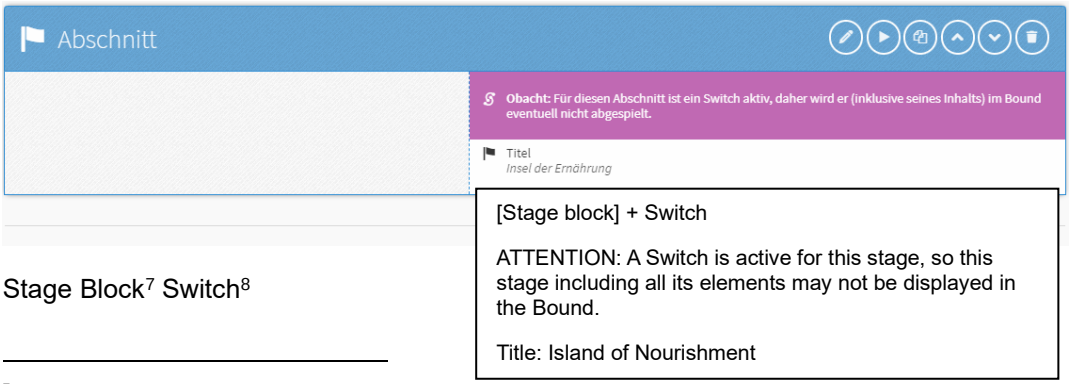
Activities presented in the photo from left to right

responsible taking >>> making >>> using >>> reuse >>> recycle >>> sustainable and safe dismantling

[6] The Multiple Choice Mode is an activity where participants are required to select the right answer.



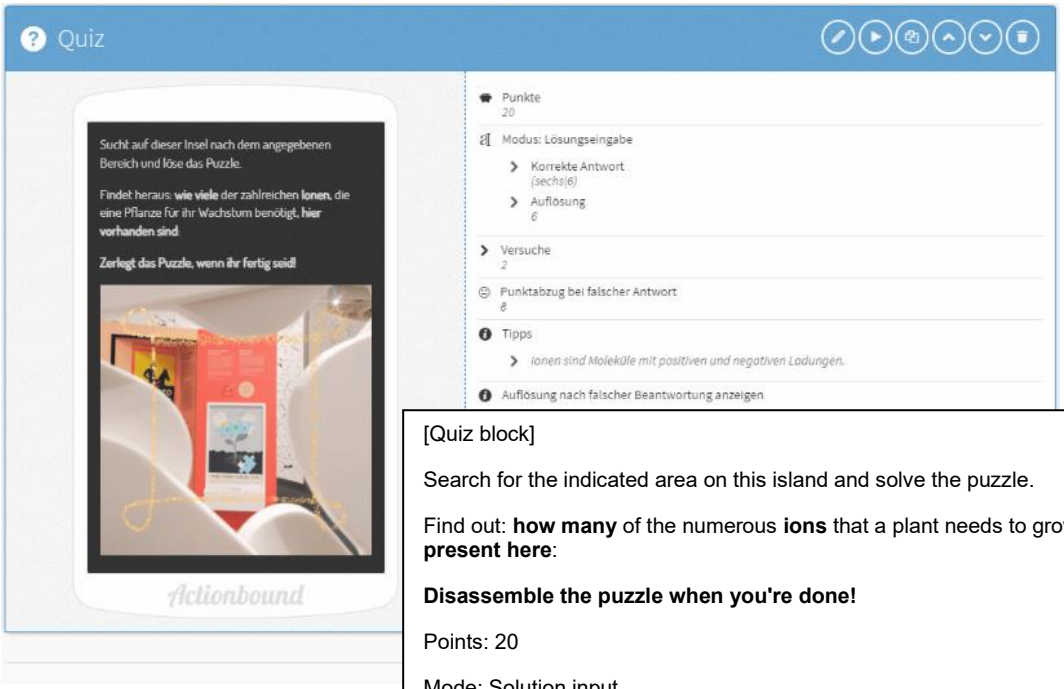




Stage Block[7] Switch[8]

[7] The Stage Block is a feature that enables the organization of sections within the Bound, allowing various activities and information to be grouped together. In this case, the Stage Block is used to represent different thematic islands within the exhibition. Each stage is named after a specific island and contains the activities that participants need to complete in order to "escape" the island.

[8] The Switch is a feature that sets conditions for displaying elements within the Bound. In this case, it is connected to the initial survey, ensuring that a stage appears only to participants who need to complete that specific island to progress in the game.



Solution Input Mode[9]

[Quiz block]

Search for the indicated area on this island and solve the puzzle.

Find out: **how many** of the numerous **ions** that a plant needs to grow **are present here**:

Disassemble the puzzle when you're done!

Points: 20

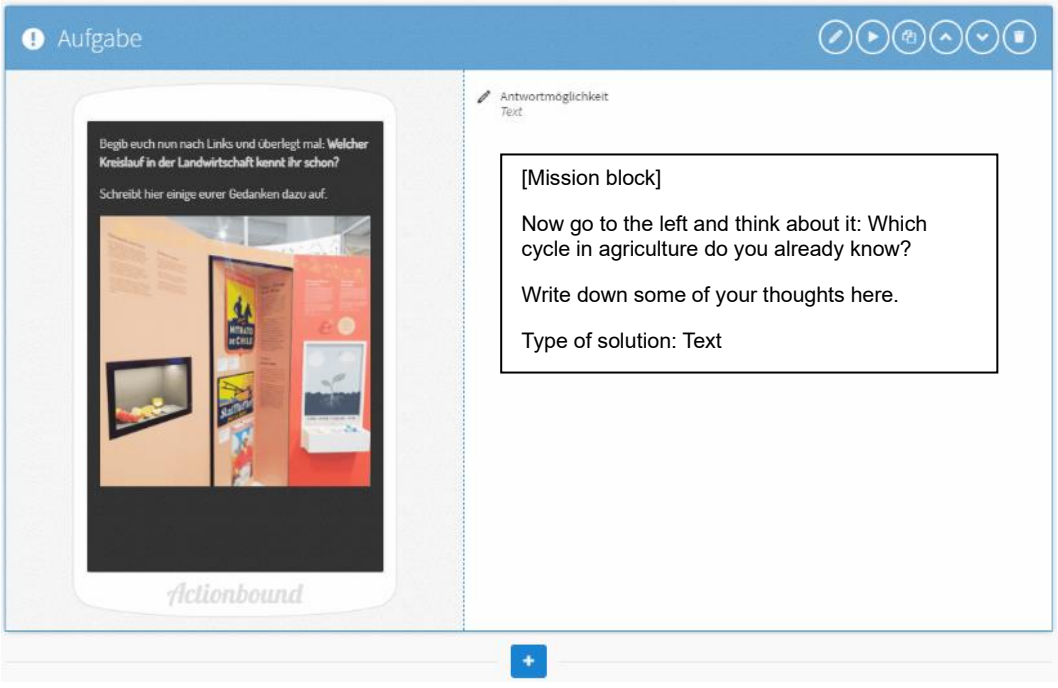
Mode: Solution input

- Correct answer: (six|6)
- Solution: 6

Attempts: 2 / Penalty for incorrect answer: 8

Hints: Ions are molecules with positive and negative charges.

Show solution if answered incorrectly



[Mission block]

Now go to the left and think about it: Which cycle in agriculture do you already know?

Write down some of your thoughts here.

Type of solution: Text

Mission Block[10]

[9] The Solution Input Mode requires providing the correct answer. In this context, multiple answers can be programmed to be accepted as correct if the solution can be expressed in various ways.

[10] The Mission Block challenges participants to creatively solve tasks where there are no right or wrong answers. Tasks may involve providing written responses, videos, photos, or audio recordings.

Information

[Information block]

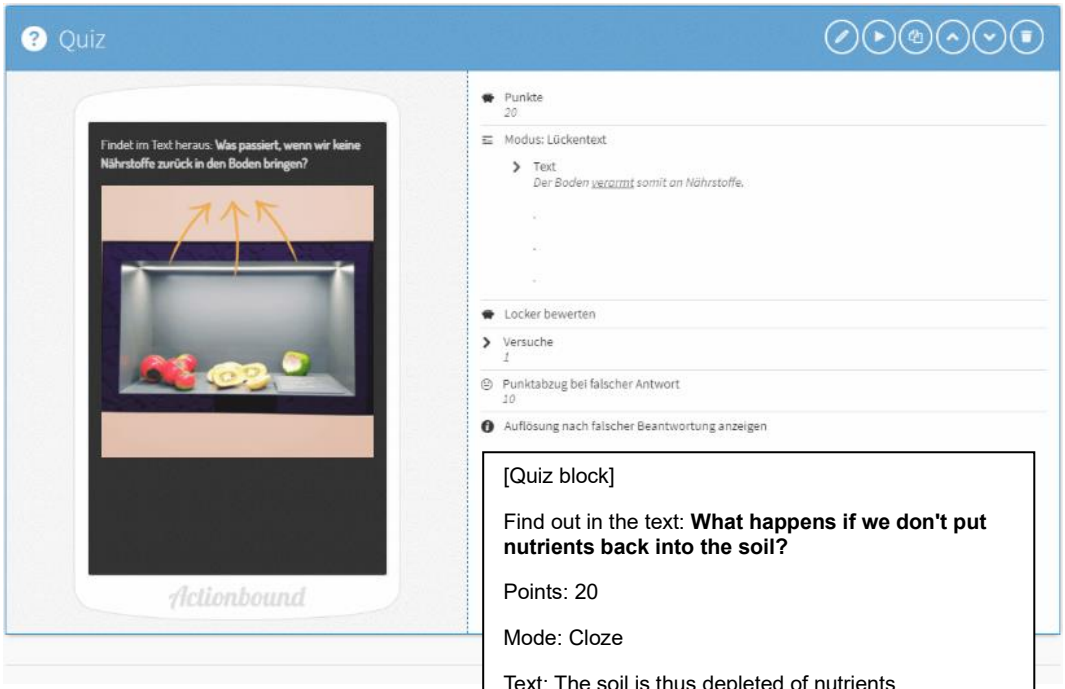
Put the puzzle together using only the orange pieces to discover one of the most common circles in our everyday lives!

Information

[Information block]

Composting is a circular practice in our everyday lives:

If we properly separate cooking waste, we can use it to make compost, which contains numerous nutrients necessary for the growth of plants for food production.



[Quiz block]

Find out in the text: **What happens if we don't put nutrients back into the soil?**

Points: 20

Mode: Cloze

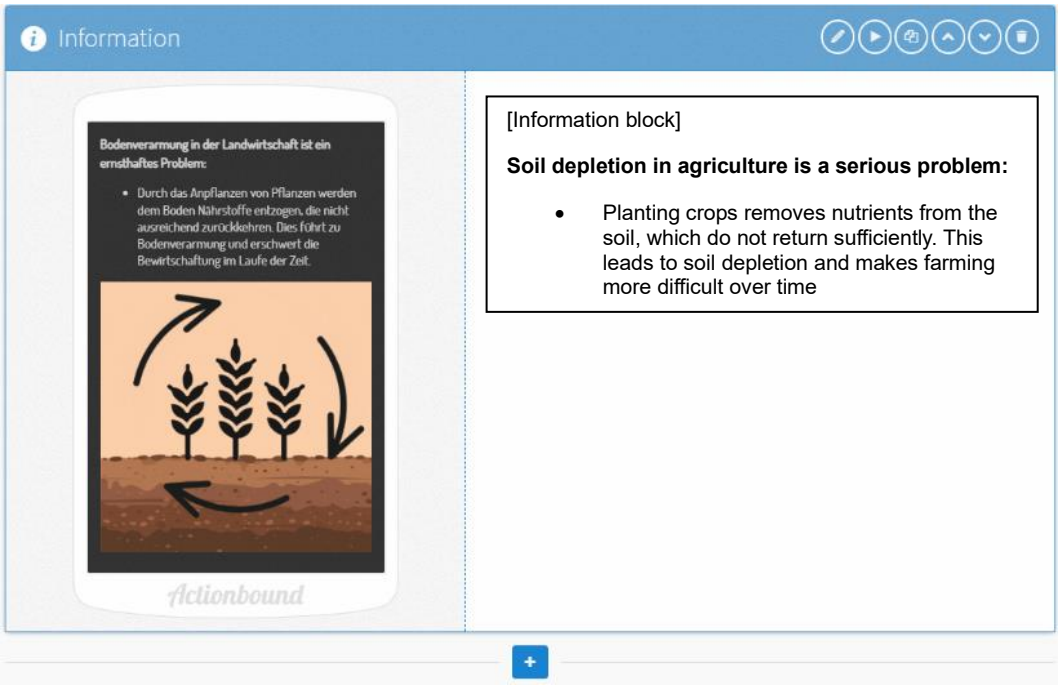
Text: The soil is thus depleted of nutrients.

Relaxed scoring

Attempts: 1 / Penalty for incorrect answer: 10

Show solution if answered incorrectly

Cloze Mode[11]

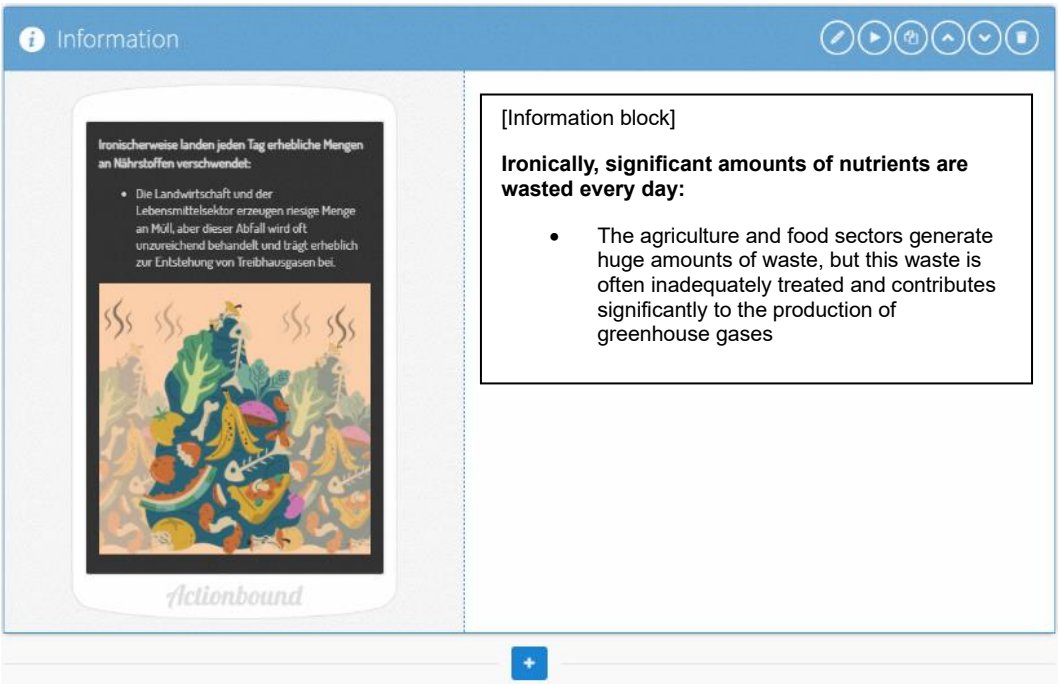


[Information block]

Soil depletion in agriculture is a serious problem:

- Planting crops removes nutrients from the soil, which do not return sufficiently. This leads to soil depletion and makes farming more difficult over time

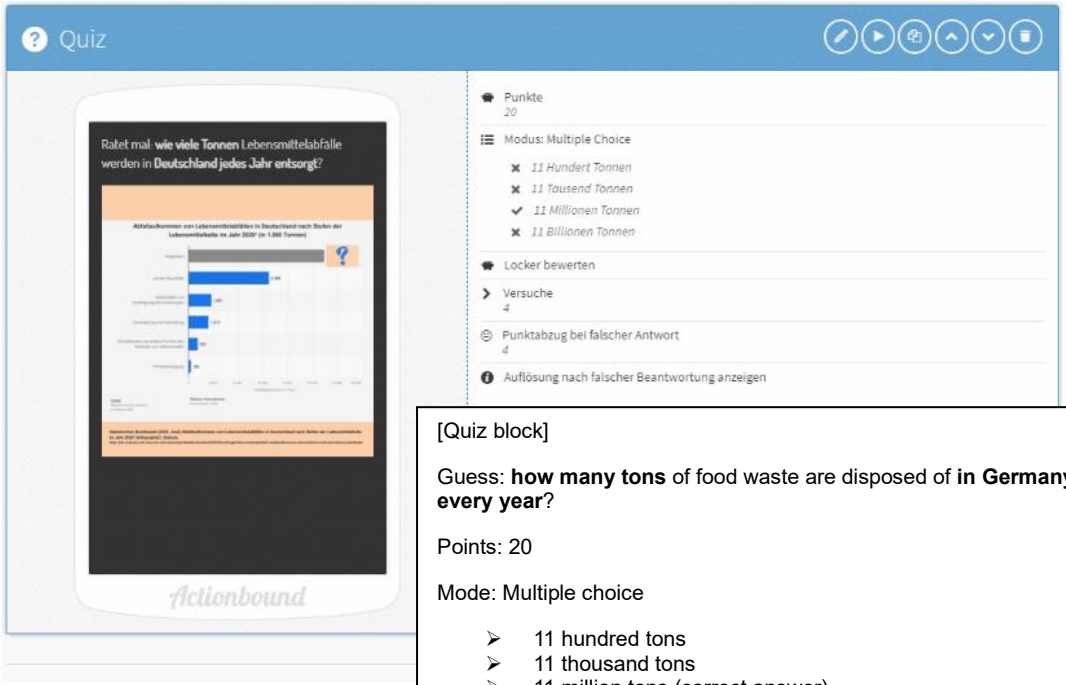
[11] The Cloze Mode involves filling in missing words in a sentence or text with the correct term. In this instance, the sentence is derived from the exhibition, and participants are required to complete it with the exact word from the exhibit. The photo with the arrows provides a clue to locate this specific sentence.



[Information block]

Ironically, significant amounts of nutrients are wasted every day:

- The agriculture and food sectors generate huge amounts of waste, but this waste is often inadequately treated and contributes significantly to the production of greenhouse gases



[Quiz block]

Guess: **how many tons** of food waste are disposed of **in Germany every year**?

Points: 20

Mode: Multiple choice

- 11 hundred tons
- 11 thousand tons
- 11 million tons (correct answer)
- 11 billion tons

Relaxed scoring

Attempts: 4 / Penalty for incorrect answer: 4

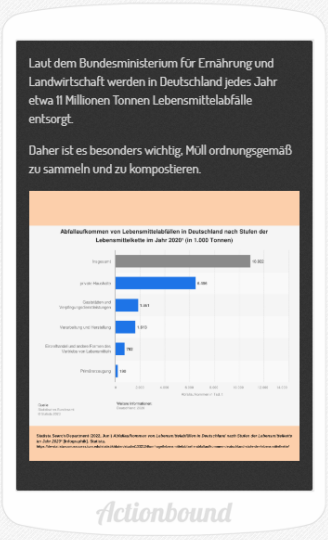
Show solution if answered incorrectly

The photo shows a graphic about the Food waste generation in Germany by stage of the food chain in 2020 (in 1000 tonnes).

Y- axis: The different sources of food waste are categorised as follows: Total, Private Households, Restaurants and Catering Services, Processing and Manufacturing, Retail and Other Forms of Food Distribution, and Primary Production.

X- axis: waste generation in thousand tons

Information



[Information block]

According to the Federal Ministry of Food and Agriculture, around 11 million tons of food waste are disposed of in Germany every year.

Therefore, it is particularly important to collect and compost waste properly.

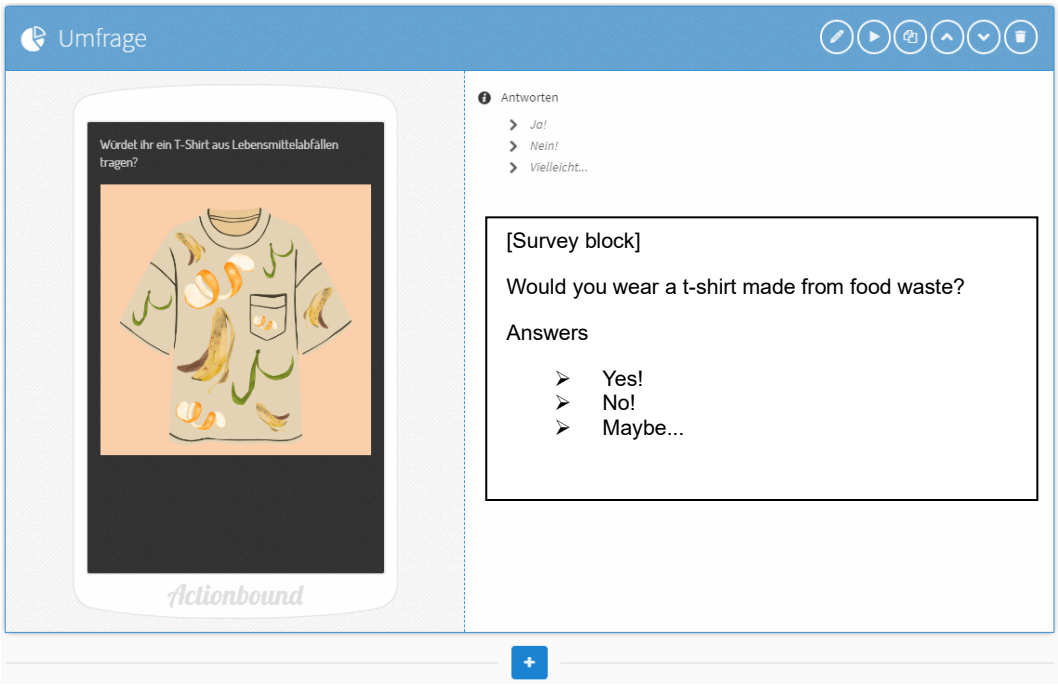
Information

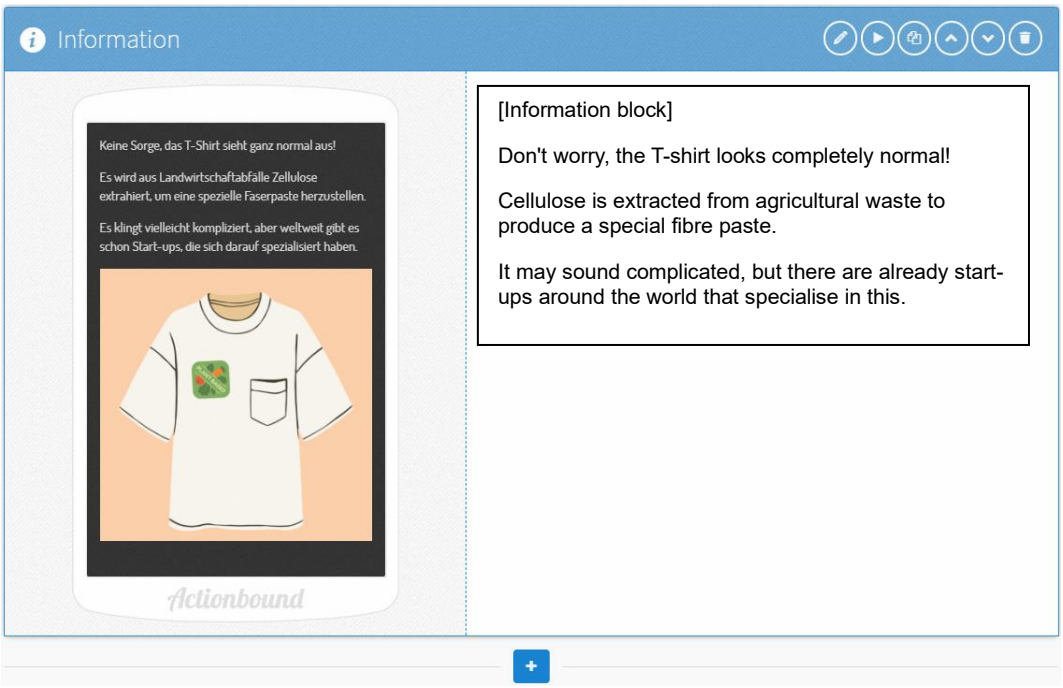
[Information block]

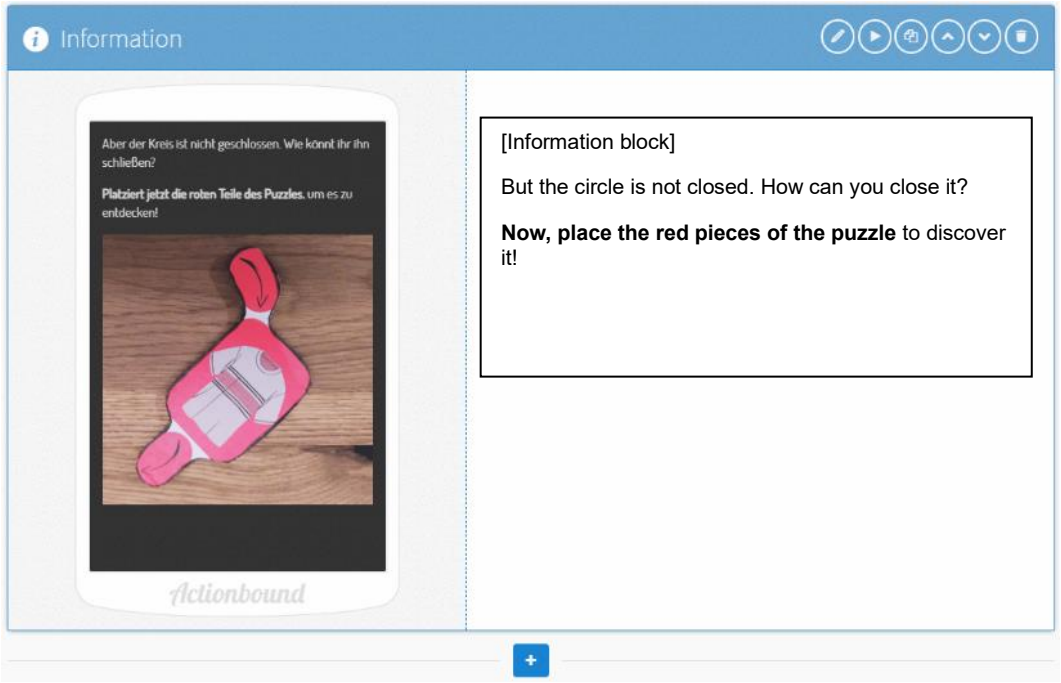
But could we perhaps get more out of this huge food waste?

Can we extend the loop?

Now put the puzzle together with the yellow pieces to discover an innovative way to use food waste!


Umfrage
Würdet ihr ein T-Shirt aus Lebensmittelabfällen tragen?
Actionbound
Antworten
Ja!
Nein!
Vielleicht...
[Survey block]
Would you wear a t-shirt made from food waste?
Answers
Yes!
No!
Maybe...

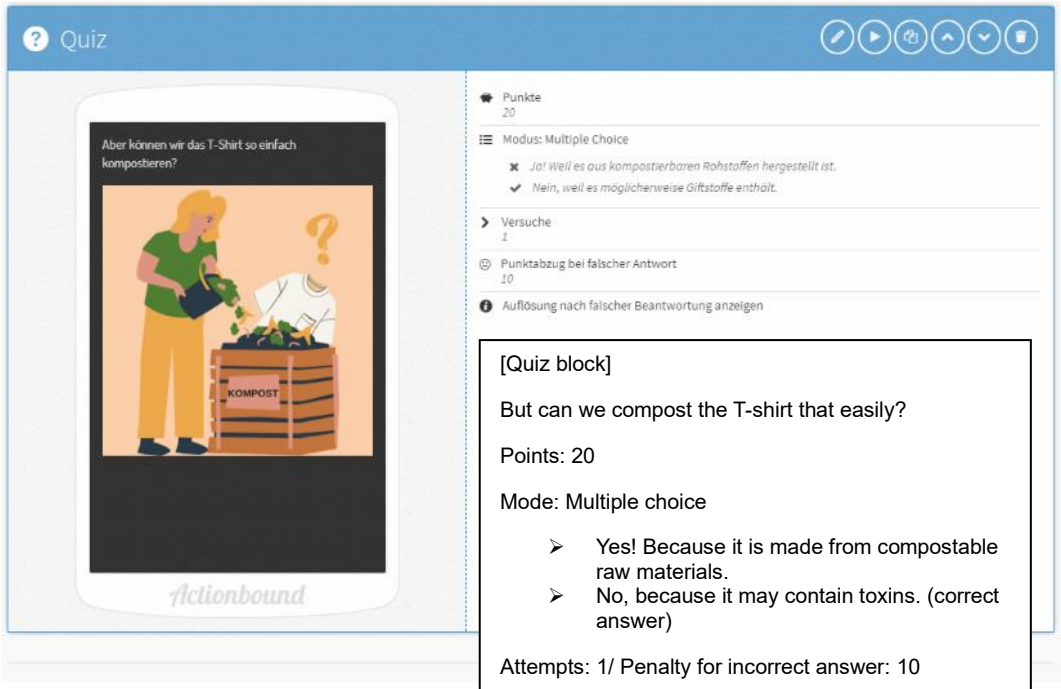

Information
Keine Sorge, das T-Shirt sieht ganz normal aus!
Es wird aus Landwirtschaftabfälle Zellulose extrahiert, um eine spezielle Faserpaste herzustellen.
Es klingt vielleicht kompliziert, aber weltweit gibt es schon Start-ups, die sich darauf spezialisiert haben.
Actionbound
[Information block]
Don't worry, the T-shirt looks completely normal!
Cellulose is extracted from agricultural waste to produce a special fibre paste.
It may sound complicated, but there are already start-ups around the world that specialise in this.



[Information block]

But the circle is not closed. How can you close it?

Now, place the red pieces of the puzzle to discover it!



[Quiz block]

But can we compost the T-shirt that easily?

Points: 20

Mode: Multiple choice

- Yes! Because it is made from compostable raw materials.
- No, because it may contain toxins. (correct answer)

Attempts: 1/ Penalty for incorrect answer: 10

Show solution if answered incorrectly

Information

[Information block]

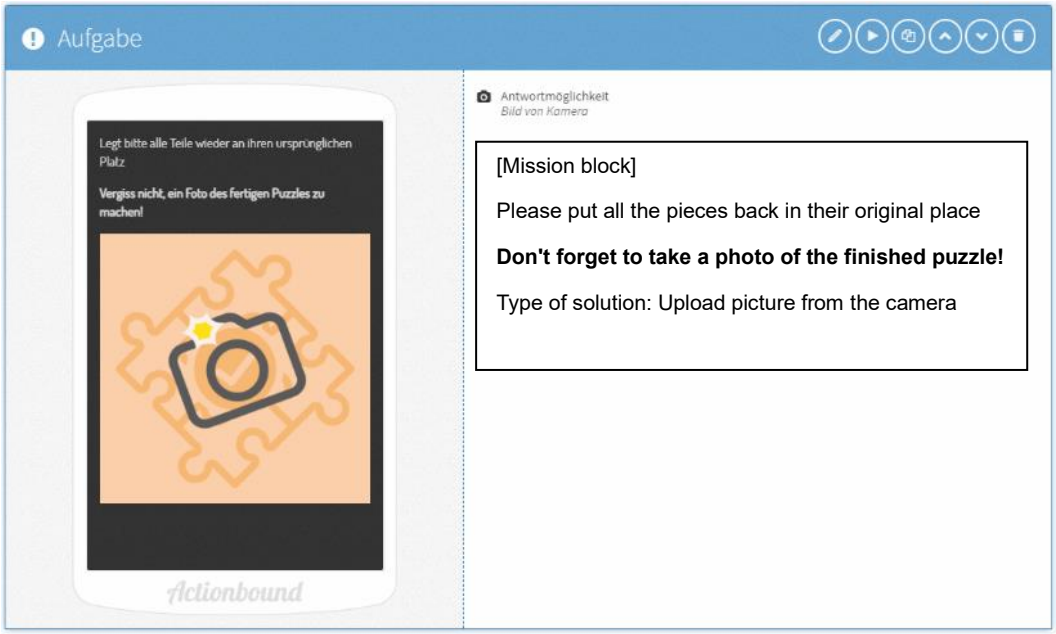
We can't just compost this t-shirt!

- synthetic dyes and fibers are sometimes added during production
- these must not be returned to the environment!

Information

[Information block]

If **only natural dyes and fibres** were used in the production of the t-shirt, **it could be returned to the soil** it came from, thus completing the circle!

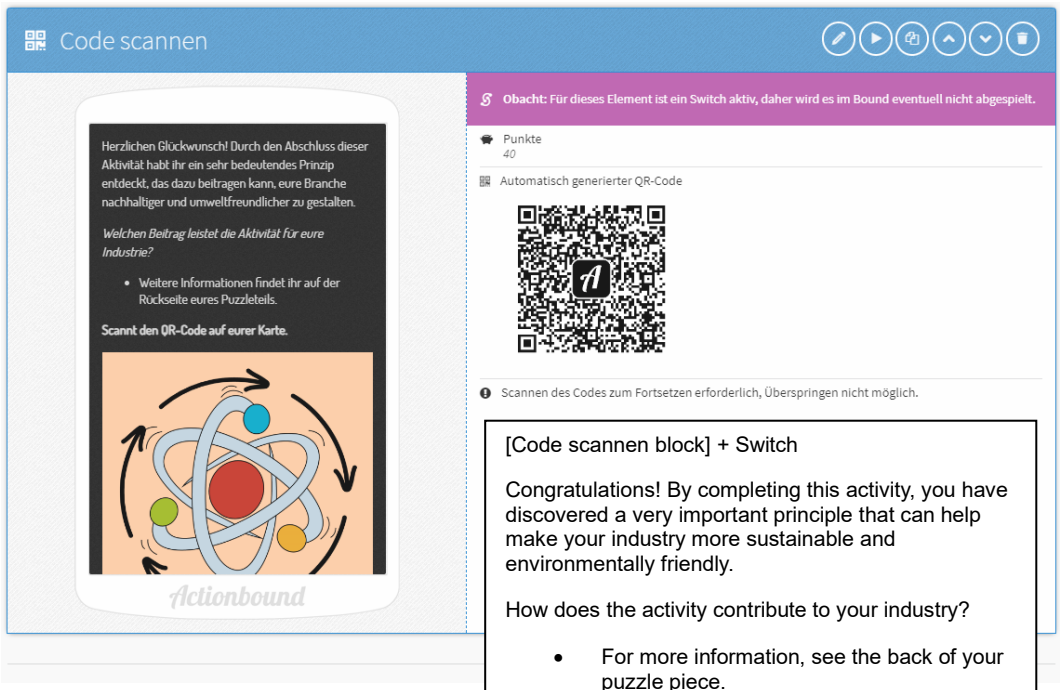


[Mission block]

Please put all the pieces back in their original place

Don't forget to take a photo of the finished puzzle!

Type of solution: Upload picture from the camera



Code Scannen Block[12]

[Code scannen block] + Switch

Congratulations! By completing this activity, you have discovered a very important principle that can help make your industry more sustainable and environmentally friendly.

How does the activity contribute to your industry?

- For more information, see the back of your puzzle piece.

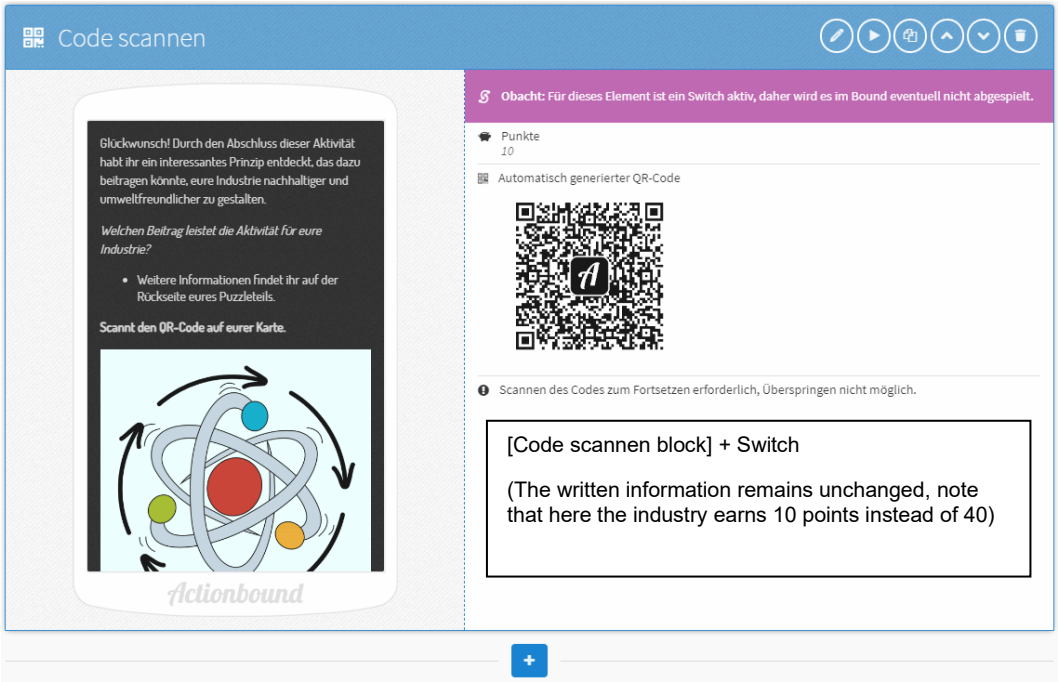
Scan the QR code on your card.

Points: 40

Automatically generated QR code

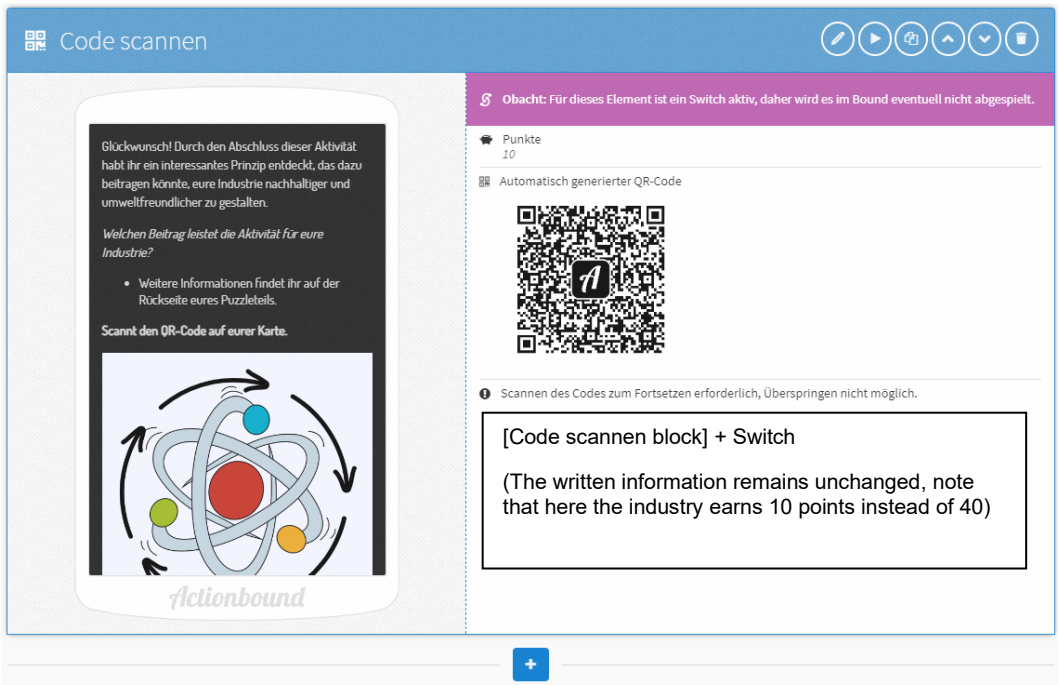
Players must scan the QR code before they are allowed to continue. This step cannot be skipped.

[12] The Code Scannen Block generates a QR code that participants must locate and scan to earn extra points. This feature was implemented to reward participants upon completing an entire island. The points awarded, known as Industry Card Points, are a game mechanic designed to reflect the value of information discovered on the island to their respective industries, regarding sustainability. A switch is used to match the correct QR code with each industry since not all industries receive the same points after completing an island. The Food & Agriculture Industry receives the maximum points, as it pertains directly to their island and contains highly relevant information. In contrast, the Plastic & Polymers Industry and Water Treatment Industry receive fewer points, acknowledging the useful but less directly applicable knowledge they gained.



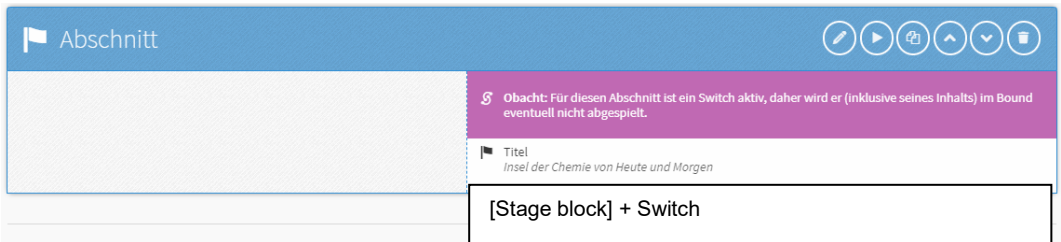
[Code scannen block] + Switch

(The written information remains unchanged, note that here the industry earns 10 points instead of 40)



[Code scannen block] + Switch

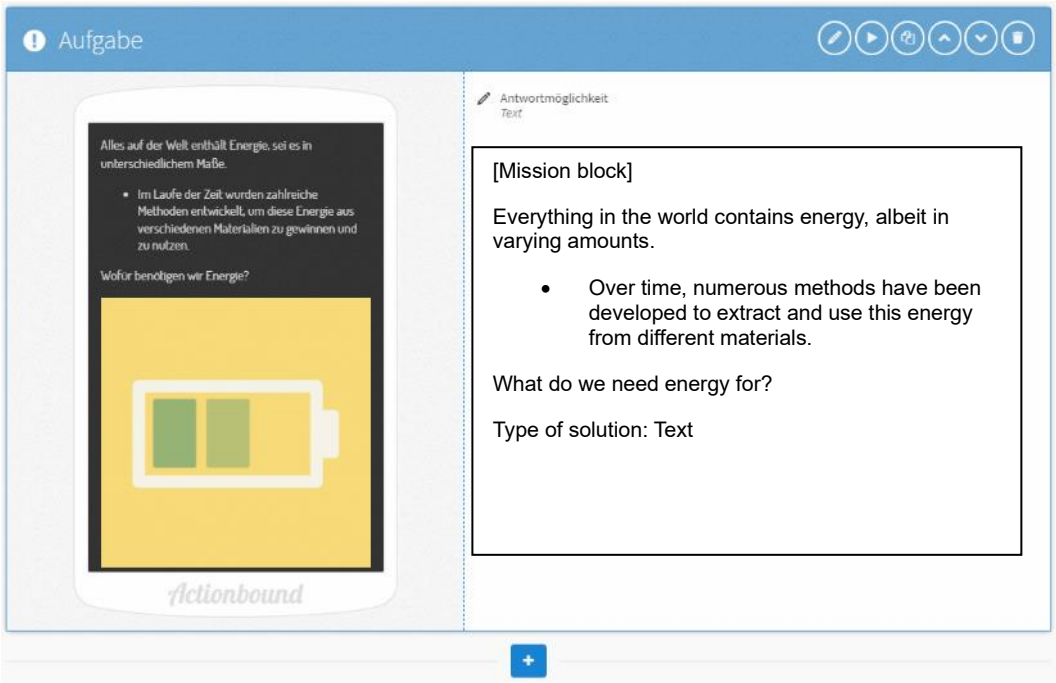
(The written information remains unchanged, note that here the industry earns 10 points instead of 40)

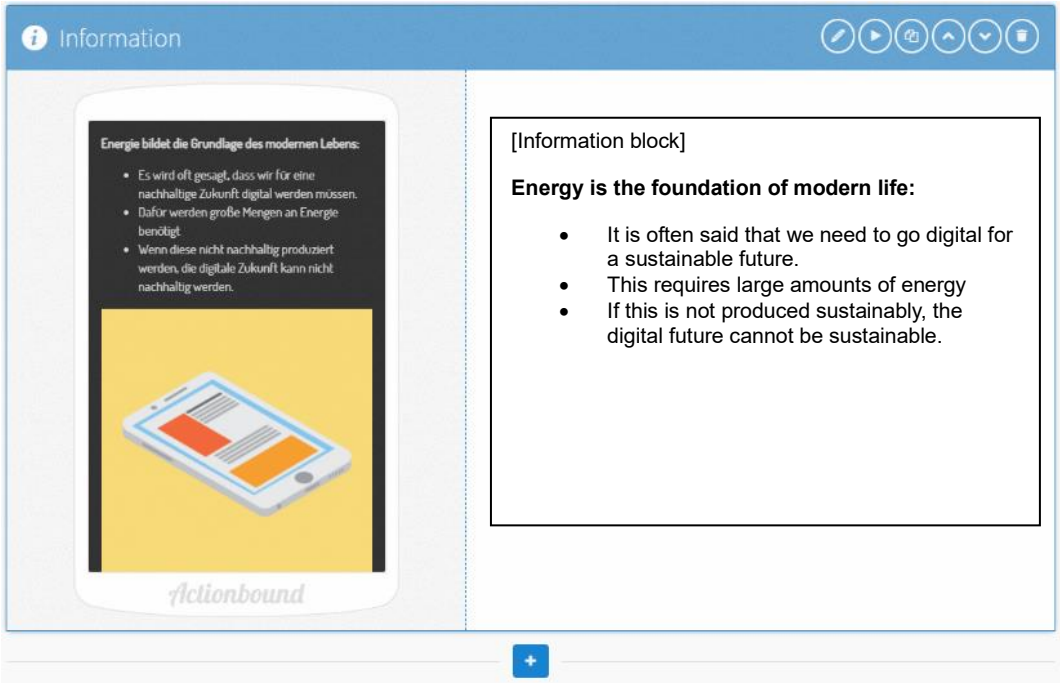


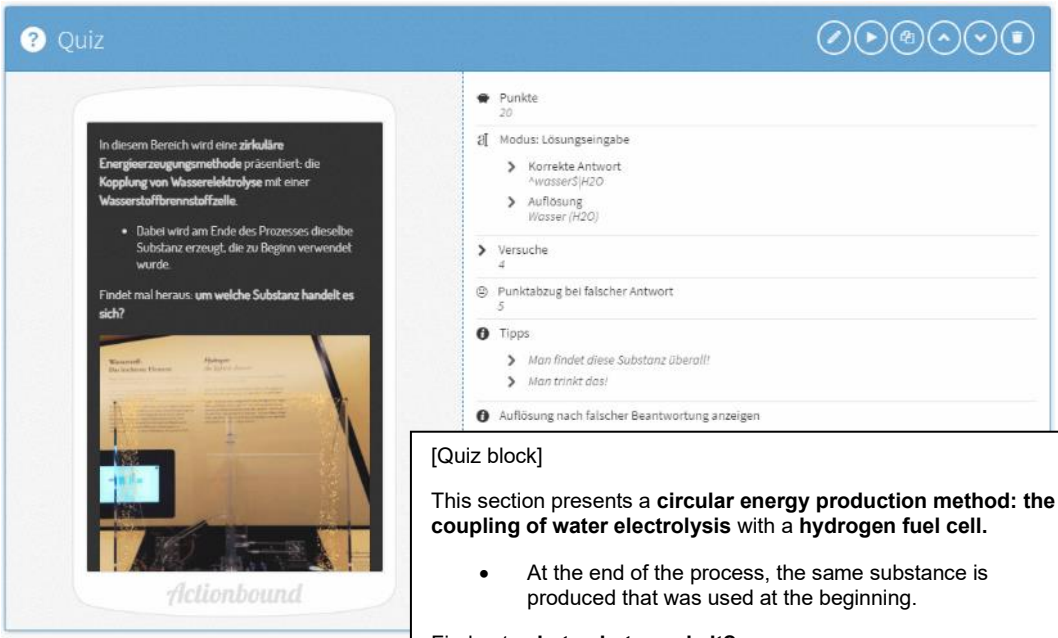
[Stage block] + Switch

ATTENTION: A Switch is active for this stage, so this stage including all its elements may not be displayed in the Bound.

Title: Island of Chemistry of Today and Tomorrow


Aufgabe
Alles auf der Welt enthält Energie, sei es in unterschiedlichem Maße.
• Im Laufe der Zeit wurden zahlreiche Methoden entwickelt, um diese Energie aus verschiedenen Materialien zu gewinnen und zu nutzen.
Wofür benötigen wir Energie?
Actionbound
Antwortmöglichkeit
Text
[Mission block]
Everything in the world contains energy, albeit in varying amounts.
• Over time, numerous methods have been developed to extract and use this energy from different materials.
What do we need energy for?
Type of solution: Text


Information
Energie bildet die Grundlage des modernen Lebens:
• Es wird oft gesagt, dass wir für eine nachhaltige Zukunft digital werden müssen.
• Dafür werden große Mengen an Energie benötigt.
• Wenn diese nicht nachhaltig produziert werden, die digitale Zukunft kann nicht nachhaltig werden.
Actionbound
[Information block]
Energy is the foundation of modern life:
• It is often said that we need to go digital for a sustainable future.
• This requires large amounts of energy
• If this is not produced sustainably, the digital future cannot be sustainable.



[Quiz block]

This section presents a **circular energy production method: the coupling of water electrolysis** with a **hydrogen fuel cell.**

- At the end of the process, the same substance is produced that was used at the beginning.

Find out: **what substance is it?**

Points: 20 / Mode: Solution input

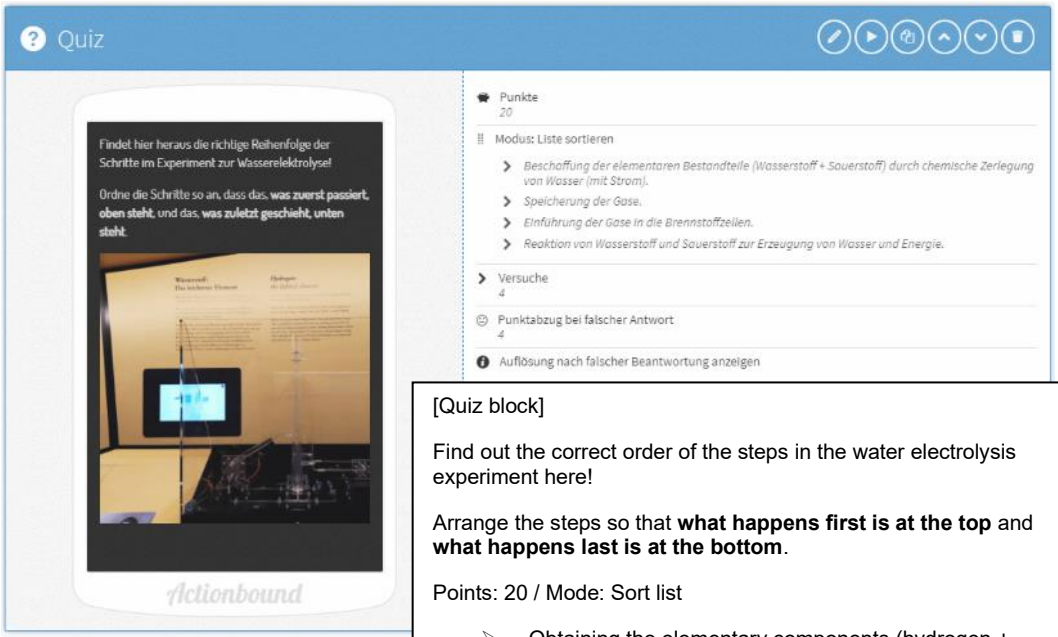
Correct answer: ^water$|H2O / Solution: Water (H2O)

Attempts: 4 / Penalty for incorrect answer: 5

Hints

- You find this substance everywhere!
- You drink it!

Show solution if answered incorrectly



[Quiz block]

Find out the correct order of the steps in the water electrolysis experiment here!

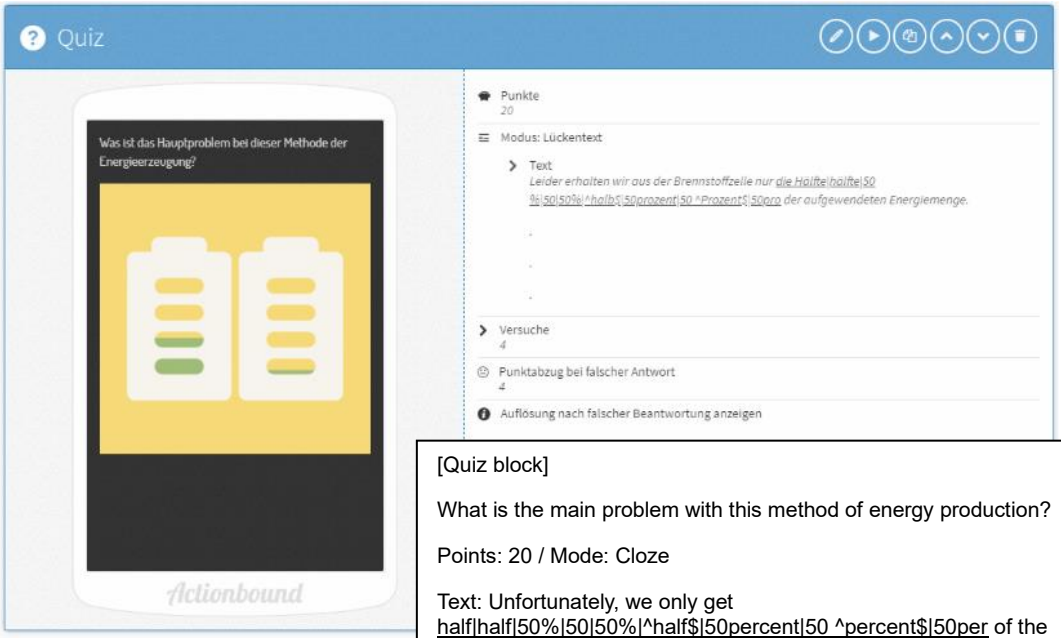
Arrange the steps so that **what happens first is at the top** and **what happens last is at the bottom**.

Points: 20 / Mode: Sort list

- Obtaining the elementary components (hydrogen + oxygen) by chemically breaking down water (using electricity).
- Storing the gases.
- Introducing the gases into the fuel cells.
- Reaction of hydrogen and oxygen to produce water and energy.

Attempts: 4 / Penalty for incorrect answer: 4

Show solution if answered incorrectly



[Quiz block]

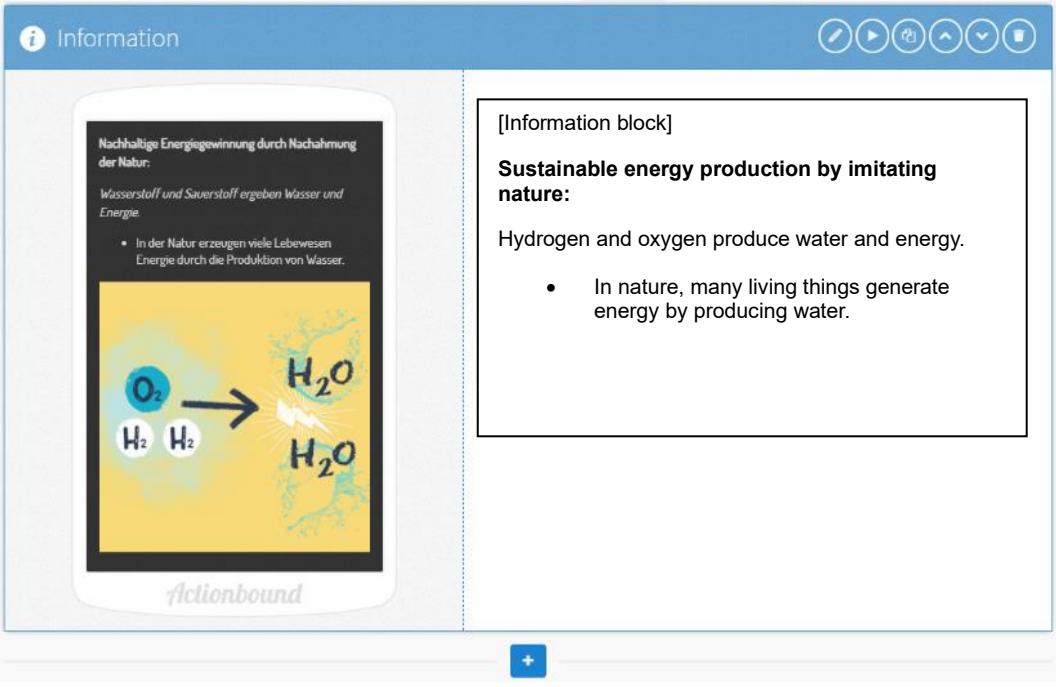
What is the main problem with this method of energy production?

Points: 20 / Mode: Cloze

Text: Unfortunately, we only get half|half|50%|50|50%|^half$|50percent|50 ^percent$|50per of the energy used from the fuel cell.

Attempts: 4 / Penalty for incorrect answer: 4

Show solution if answered incorrectly



[Information block]

Sustainable energy production by imitating nature:

Hydrogen and oxygen produce water and energy.

- In nature, many living things generate energy by producing water.

Information

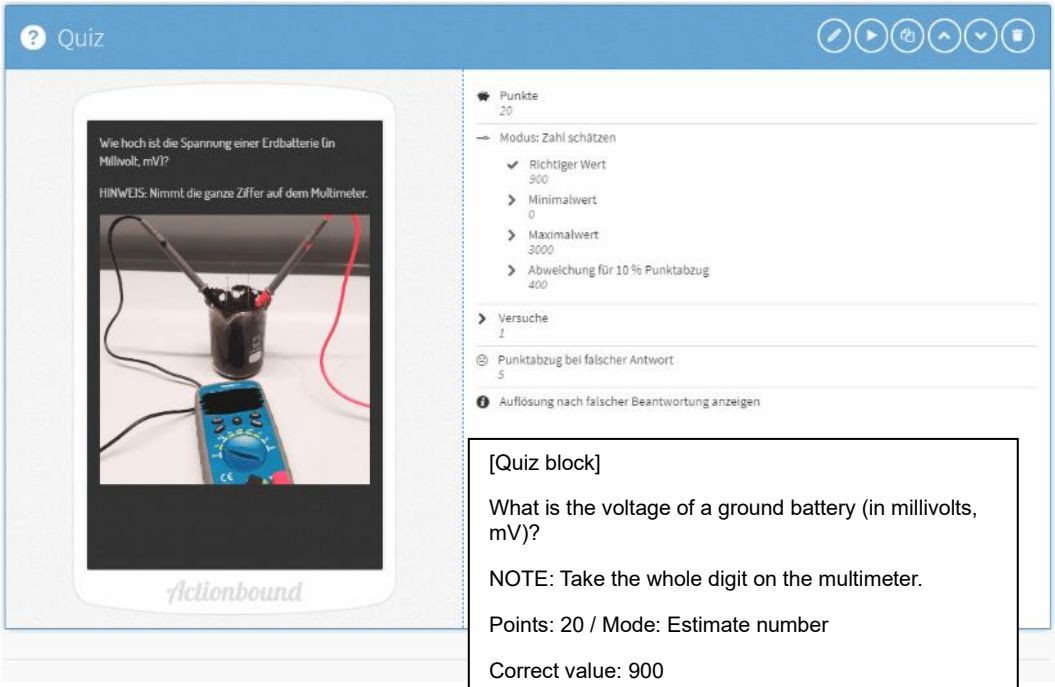
[Information block]

- However, living beings have found ways to make this profitable.
- Therefore, research into hydrogen production using water electrolysis is of great importance and promising

Information

[Information block]

- To generate large amounts of green energy, we need to be creative and think outside the box.
- To discover an innovative and sustainable method of energy production, go to the chemistry lab.



[Quiz block]

What is the voltage of a ground battery (in millivolts, mV)?

NOTE: Take the whole digit on the multimeter.

Points: 20 / Mode: Estimate number

Correct value: 900

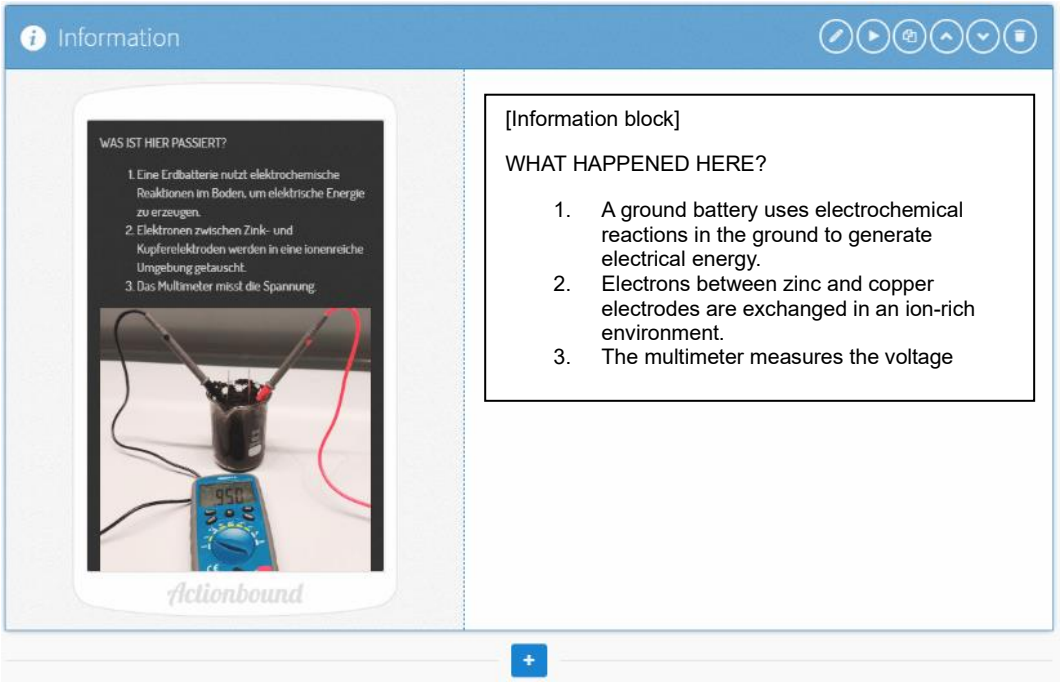
Minimum value: 0 / Maximum value: 3000

Deviation for 10%-point deduction: 400

Attempts: 1 / Penalty for incorrect answer: 5

Show solution if answered incorrectly

Estimate Number Mode[13]

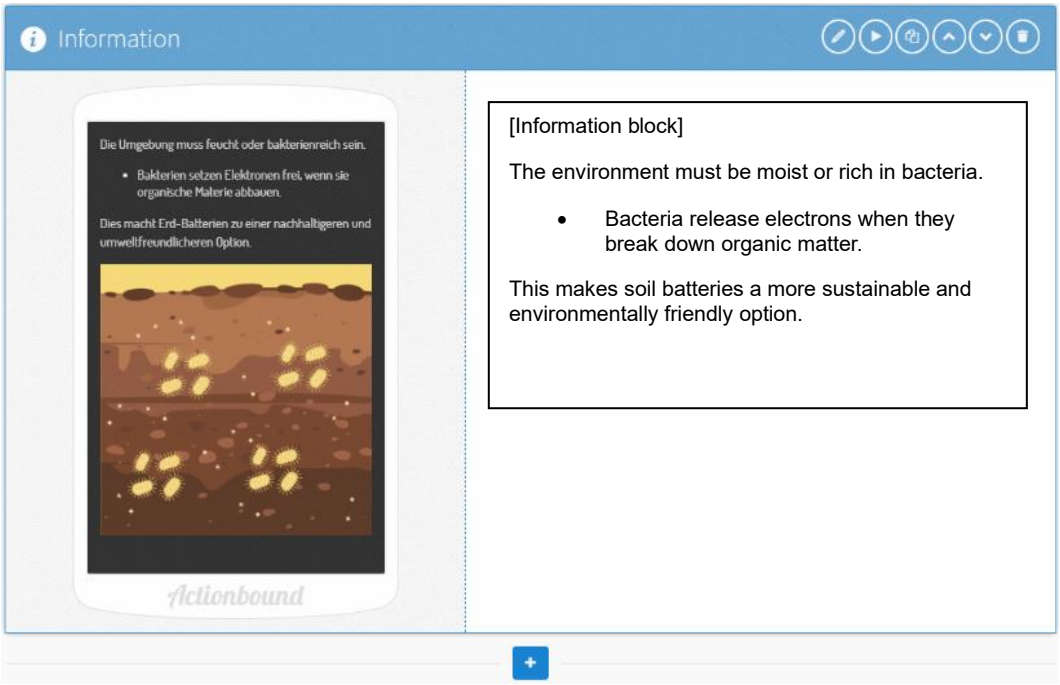


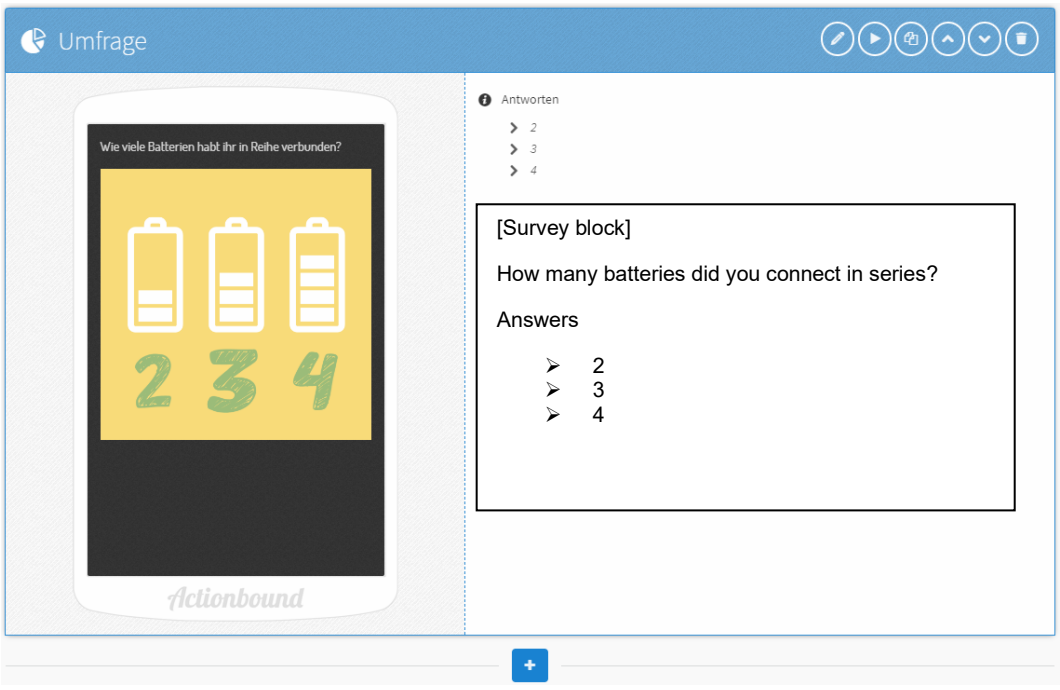
[Information block]

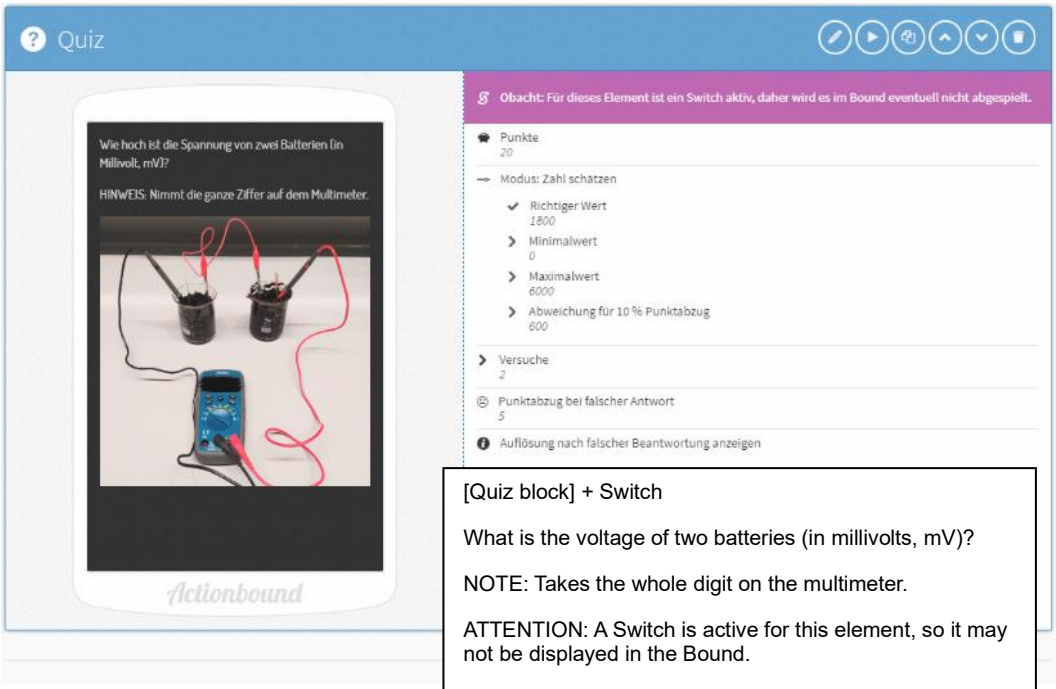
WHAT HAPPENED HERE?

1. A ground battery uses electrochemical reactions in the ground to generate electrical energy.
2. Electrons between zinc and copper electrodes are exchanged in an ion-rich environment.
3. The multimeter measures the voltage

[13] The Estimate Number Mode requires participants to adjust an indicator within a specified interval to estimate the solution's value. Since the voltage solution can vary between batteries, this mode accommodates multiple values within the correct voltage range of the battery.


Information
Die Umgebung muss feucht oder bakterienreich sein.
• Bakterien setzen Elektronen frei, wenn sie organische Materie abbauen.
Dies macht Erd-Batterien zu einer nachhaltigeren und umweltfreundlicheren Option.
Actionbound
[Information block]
The environment must be moist or rich in bacteria.
• Bacteria release electrons when they break down organic matter.
This makes soil batteries a more sustainable and environmentally friendly option.


Umfrage
Wie viele Batterien habt ihr in Reihe verbunden?
2 3 4
Actionbound
Antworten
2
3
4
[Survey block]
How many batteries did you connect in series?
Answers
➢ 2
➢ 3
➢ 4



Switch[14]

[Quiz block] + Switch

What is the voltage of two batteries (in millivolts, mV)?

NOTE: Takes the whole digit on the multimeter.

ATTENTION: A Switch is active for this element, so it may not be displayed in the Bound.

Points: 20 / Mode: Estimate number

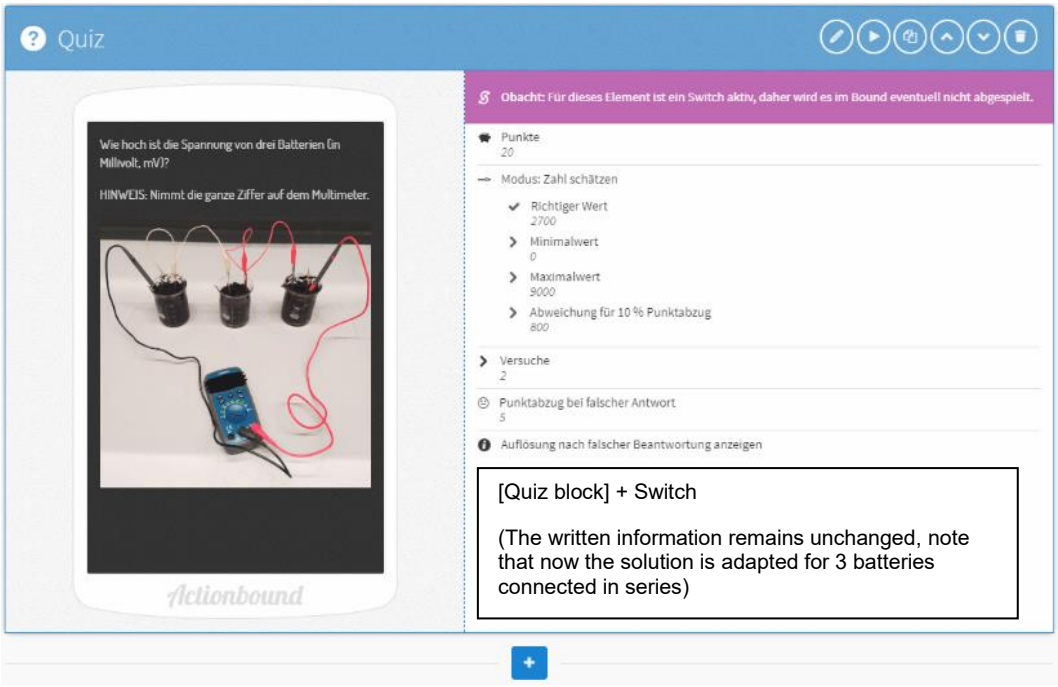
Correct value: 1800

Minimum value: 0 / Maximum value: 6000

Deviation for 10%-point deduction: 600

Attempts: 2 / Penalty for incorrect answer: 5

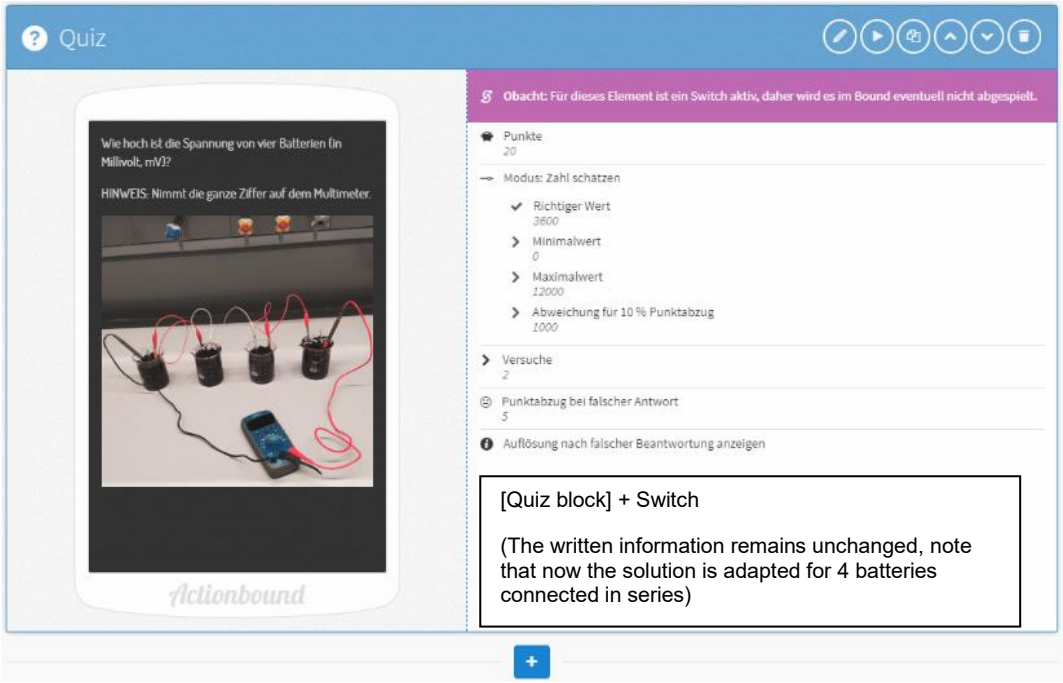
Show solution if answered incorrectly



[Quiz block] + Switch

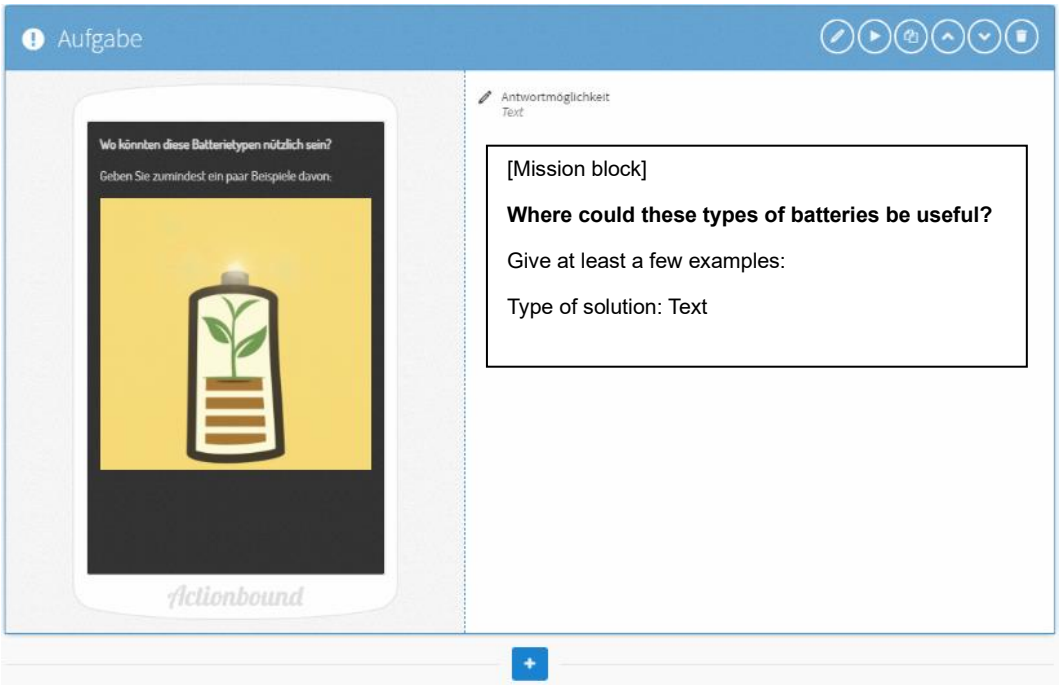
(The written information remains unchanged, note that now the solution is adapted for 3 batteries connected in series)

[14] The switch here is used in conjunction with the survey. Depending on the number of batteries selected by the participant, the solution voltage displayed will vary. Thus, the switch ensures that only the solution corresponding to the number of batteries connected in series is shown.



[Quiz block] + Switch

(The written information remains unchanged, note that now the solution is adapted for 4 batteries connected in series)

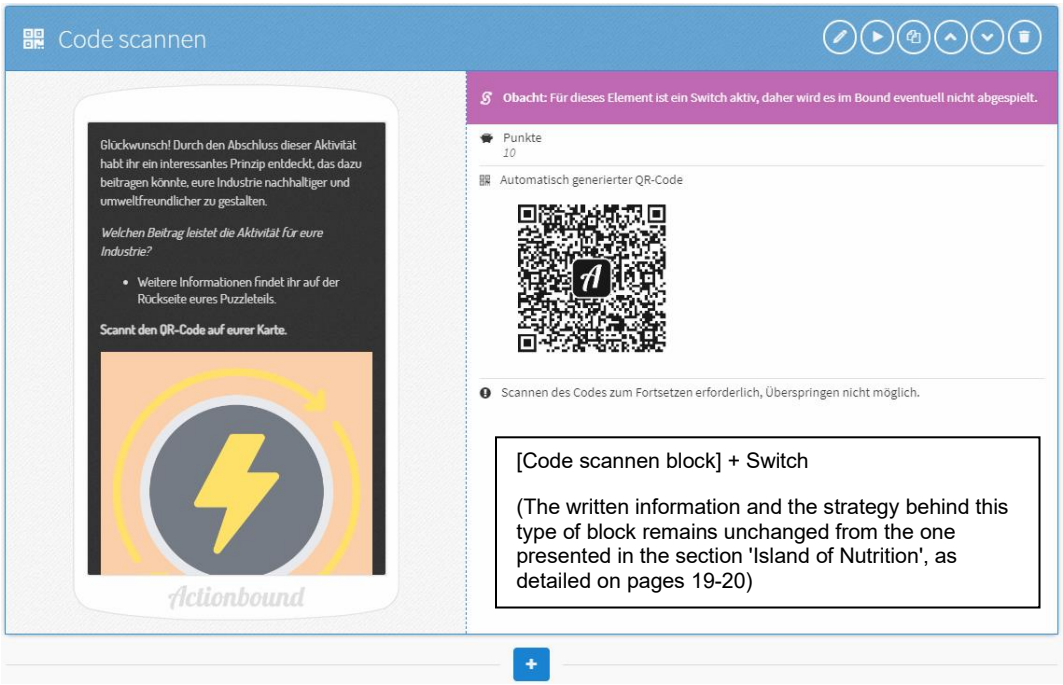


[Mission block]

Where could these types of batteries be useful?

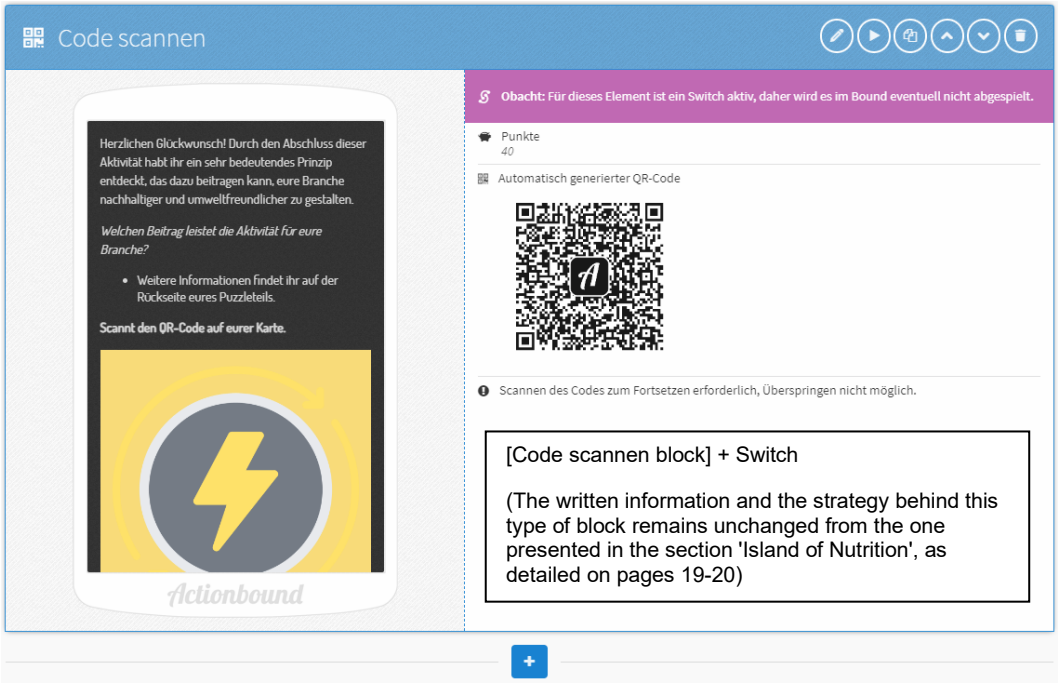
Give at least a few examples:

Type of solution: Text



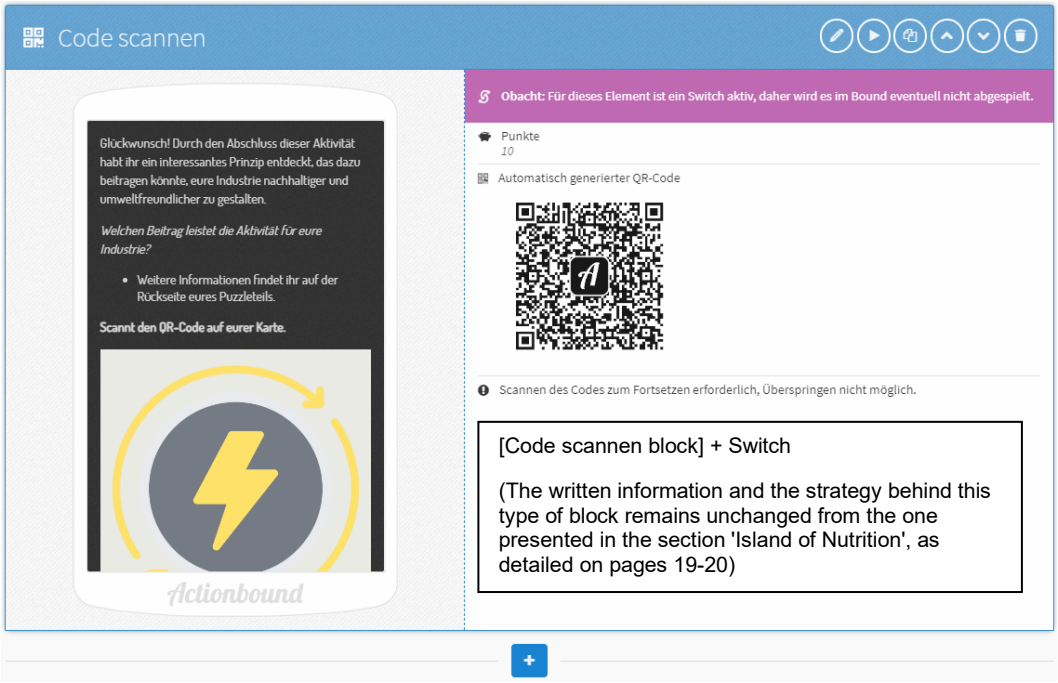
[Code scannen block] + Switch

(The written information and the strategy behind this type of block remains unchanged from the one presented in the section 'Island of Nutrition', as detailed on pages 19-20)



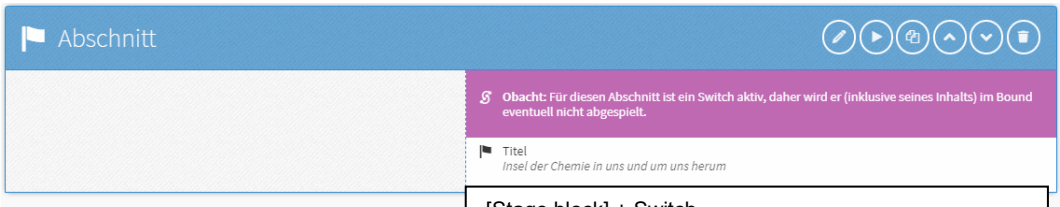
[Code scannen block] + Switch

(The written information and the strategy behind this type of block remains unchanged from the one presented in the section 'Island of Nutrition', as detailed on pages 19-20)



[Code scannen block] + Switch

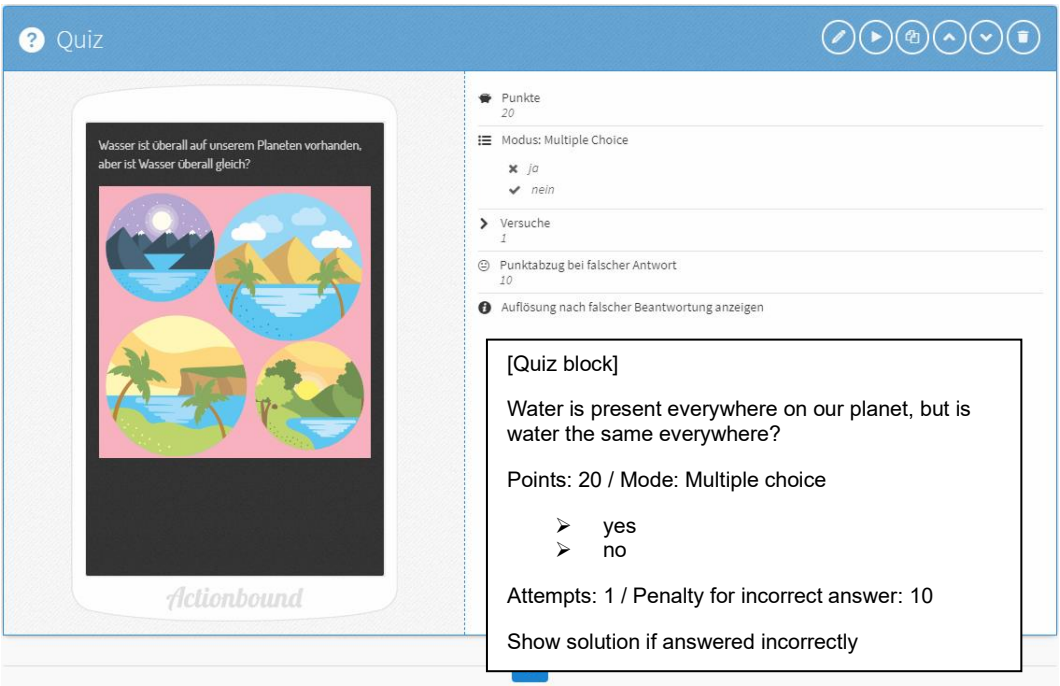
(The written information and the strategy behind this type of block remains unchanged from the one presented in the section 'Island of Nutrition', as detailed on pages 19-20)



[Stage block] + Switch

ATTENTION: A Switch is active for this stage, so this stage including all its elements may not be displayed in the Bound.

Title: Island of chemistry in and around us



[Quiz block]

Water is present everywhere on our planet, but is water the same everywhere?

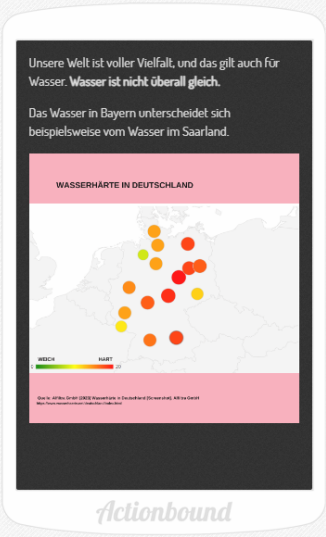
Points: 20 / Mode: Multiple choice

- yes
- no

Attempts: 1 / Penalty for incorrect answer: 10

Show solution if answered incorrectly

Information



[Information block]

Our world is full of diversity, and that also applies to water. **Water is not the same everywhere.**

For example, the water in Bavaria is different from the water in Saarland.

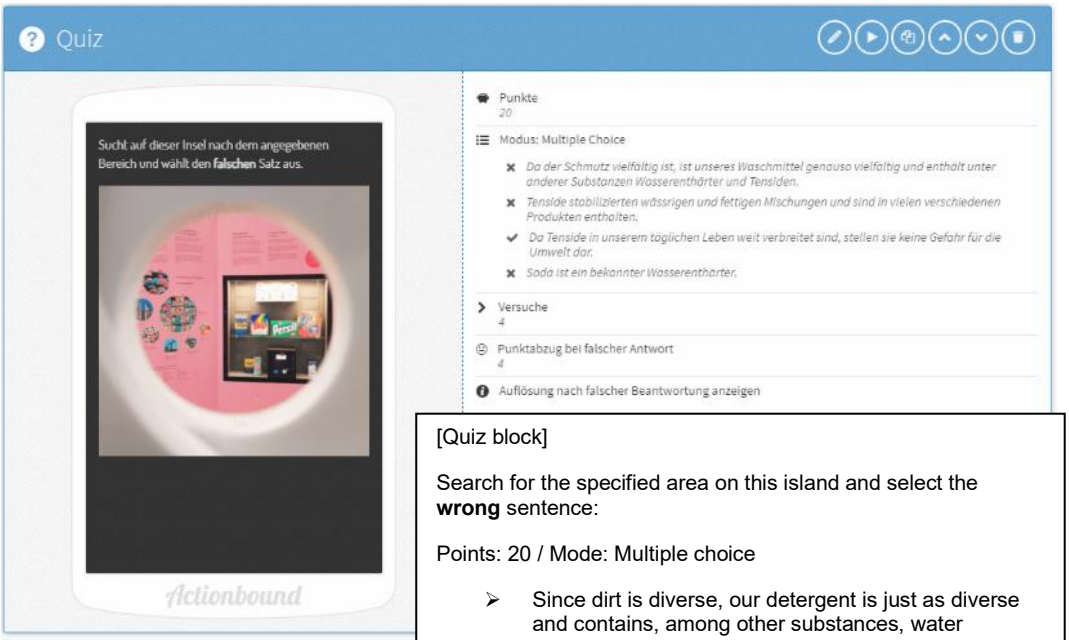
Photo depicting the water hardness levels in Germany

Information

[Information block]

Different types of water often mean different environmental conditions.

- Therefore, it makes sense to promote sustainable thinking at the local level.



[Quiz block]

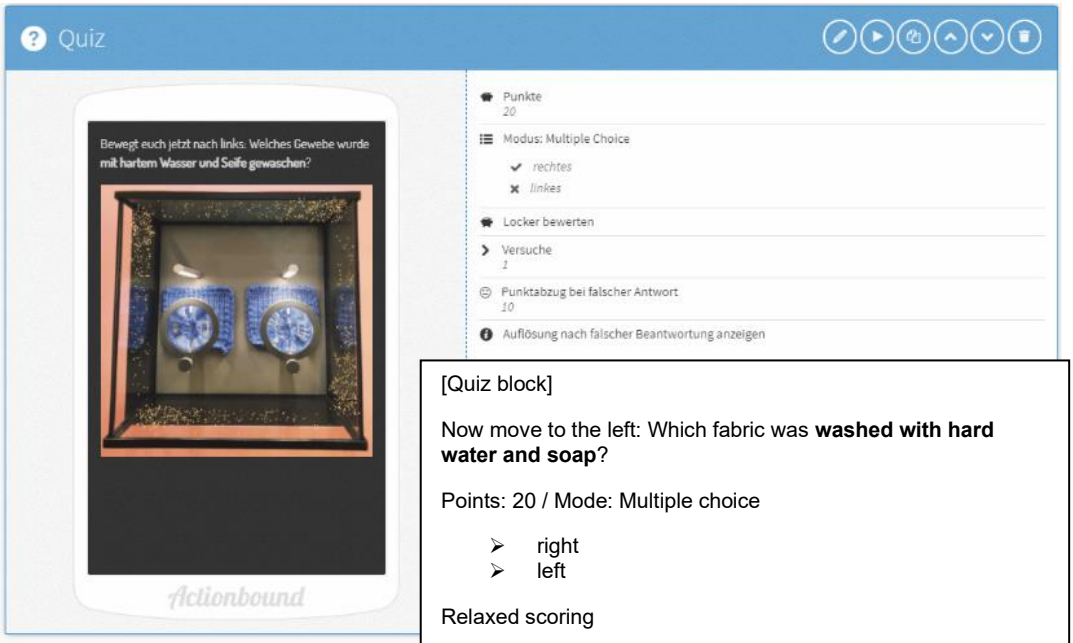
Search for the specified area on this island and select the **wrong** sentence:

Points: 20 / Mode: Multiple choice

- Since dirt is diverse, our detergent is just as diverse and contains, among other substances, water softeners and surfactants.
- Surfactants stabilise aqueous and fatty mixtures and are contained in many different products.
- Since surfactants are widely used in our daily lives, they do not pose a threat to the environment. (correct answer)
- Soda is a well-known water softener.

Attempts: 4 / Penalty for incorrect answer: 4

Show solution if answered incorrectly



[Quiz block]

Now move to the left: Which fabric was **washed with hard water and soap**?

Points: 20 / Mode: Multiple choice

- right
- left

Relaxed scoring

Attempts: 1 / Penalty for incorrect answer: 10

Show solution if answered incorrectly

Information

[Information block]

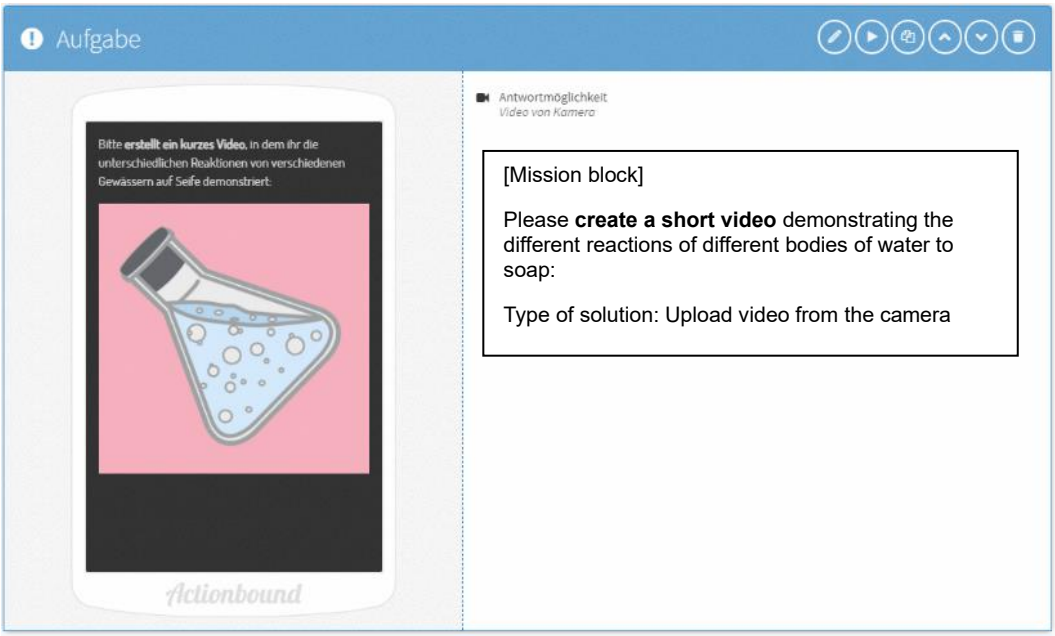
Hygiene and health are directly related to water and our environment.

- Not all hygiene measures are equally effective everywhere.
- It is of utmost importance to take regional differences into account.

Information

[Information block]

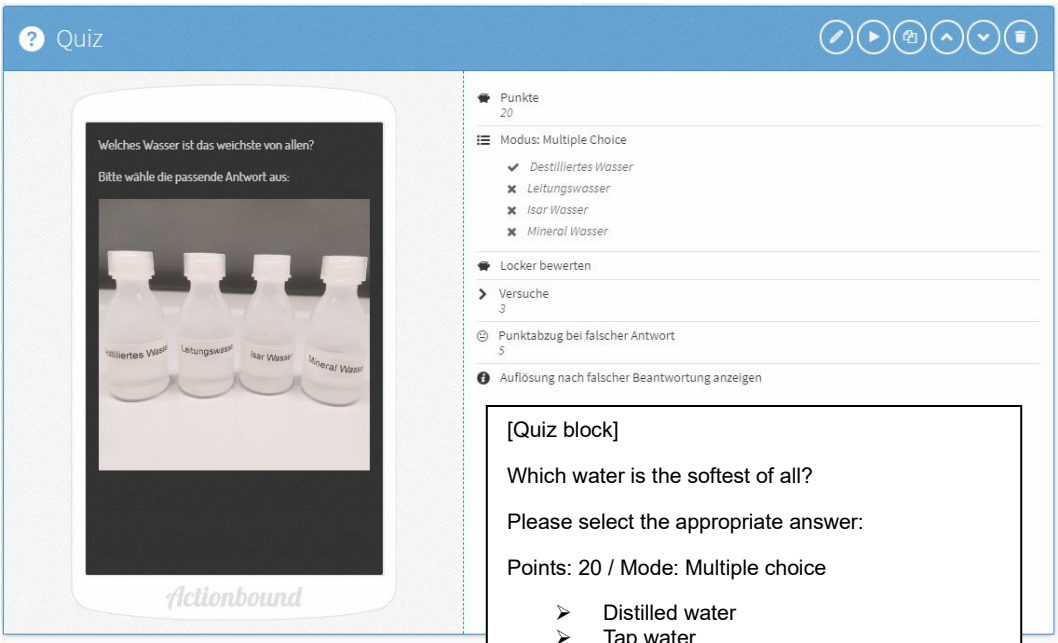
To find out how soap reacts differently in different waters and how it can be adapted**, go to the chemistry lab.**



[Mission block]

Please **create a short video** demonstrating the different reactions of different bodies of water to soap:

Type of solution: Upload video from the camera



[Quiz block]

Which water is the softest of all?

Please select the appropriate answer:

Points: 20 / Mode: Multiple choice

- Distilled water
- Tap water
- Isar water
- Mineral water

Relaxed scoring

Attempts: 3 / Penalty for incorrect answer: 5

Show solution if answered incorrectly

Information

[Information block]

WHAT HAPPENED HERE?

Not all water is the same.

Some, called "hard water," contain a lot of calcium and magnesium salts, which leave limescale deposits when they come into contact with soap.

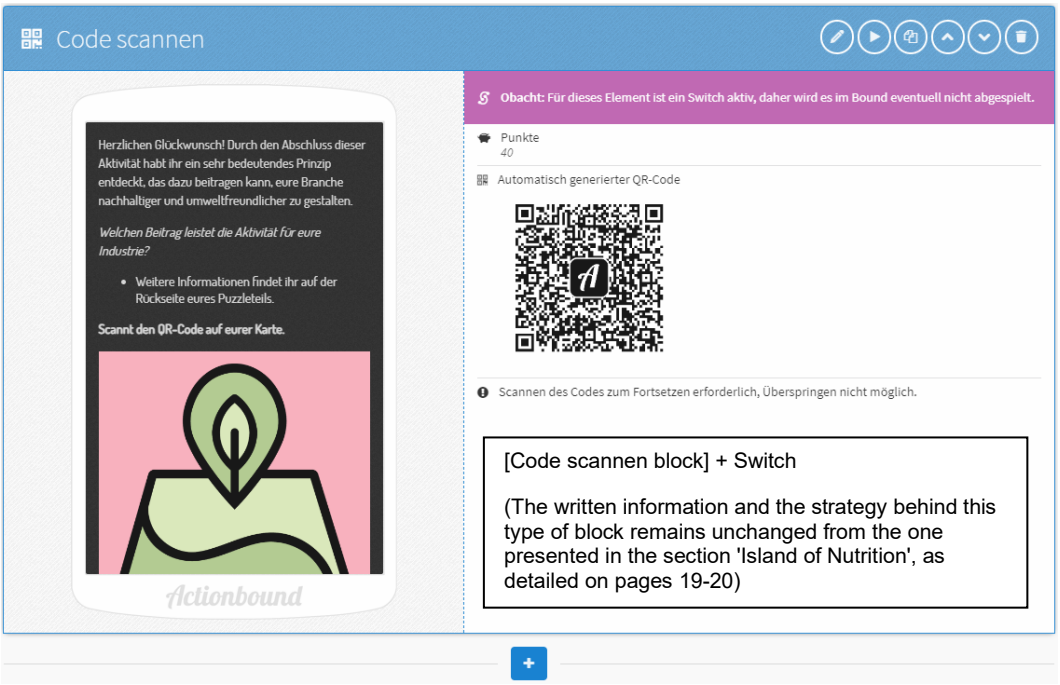
Limestone formation on the wall of the Erlenmeyer flask

Information

[Information block]

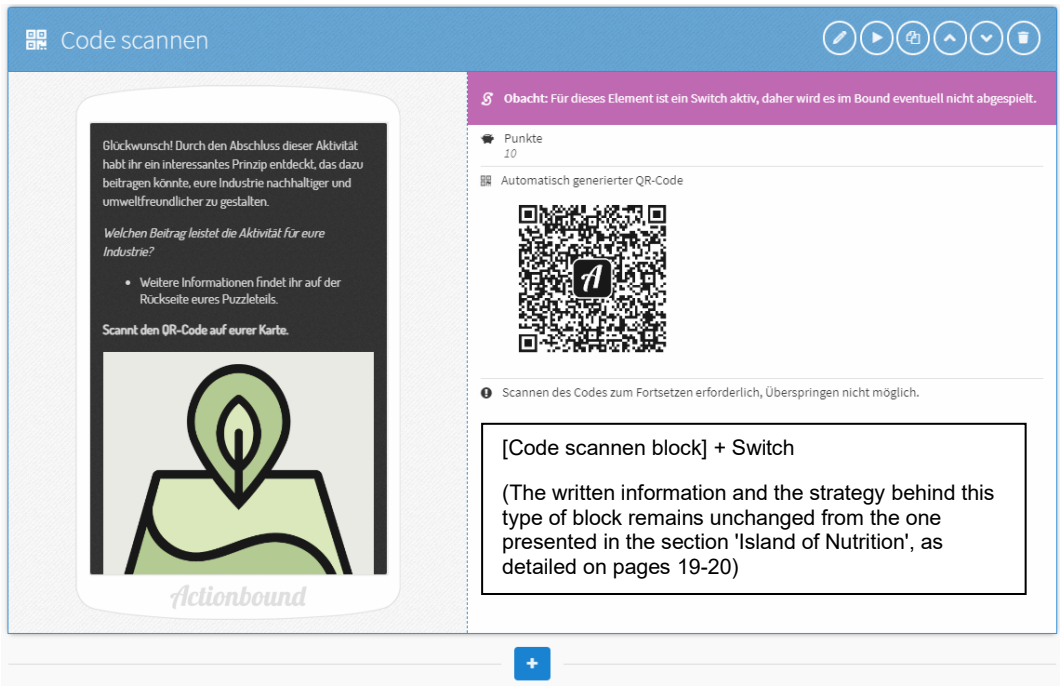
Using soda helps to loosen these deposits and bind the calcium and magnesium molecules.

This allows soap to react better with the water and create a lather.



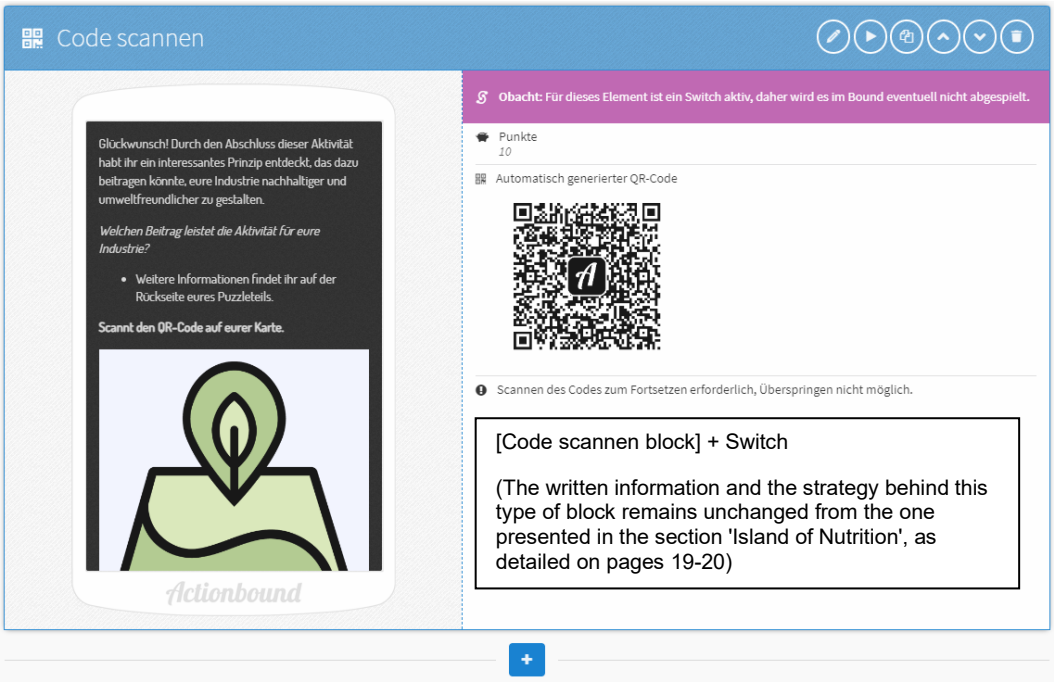
[Code scannen block] + Switch

(The written information and the strategy behind this type of block remains unchanged from the one presented in the section 'Island of Nutrition', as detailed on pages 19-20)



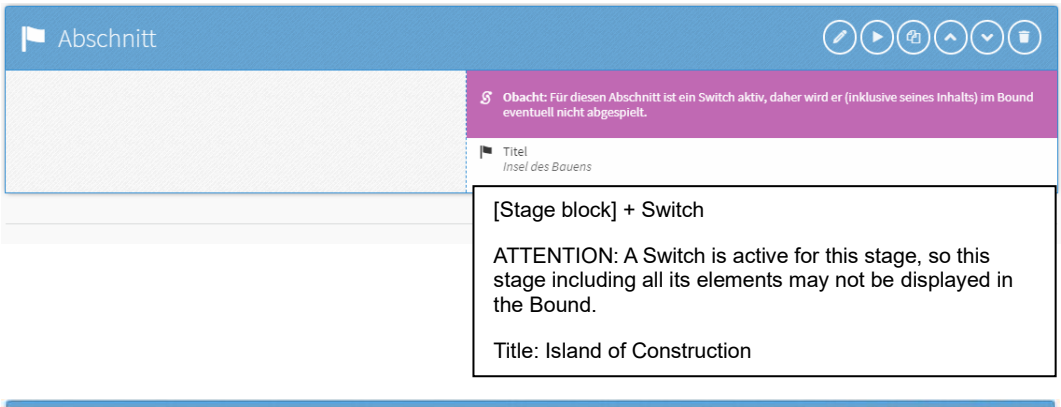
[Code scannen block] + Switch

(The written information and the strategy behind this type of block remains unchanged from the one presented in the section 'Island of Nutrition', as detailed on pages 19-20)



[Code scannen block] + Switch

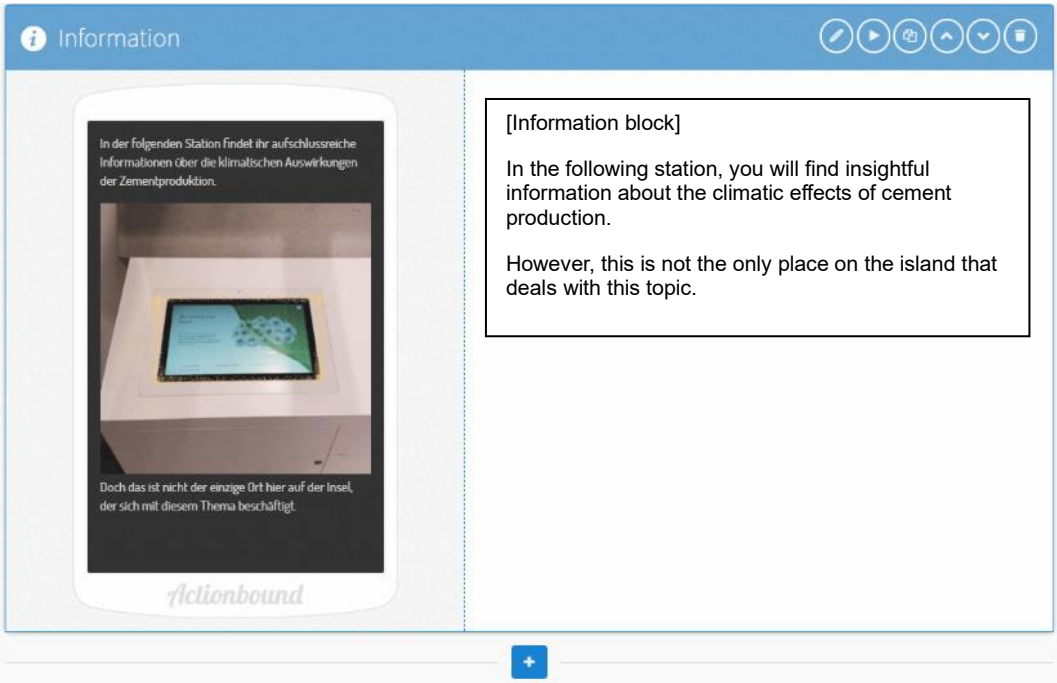
(The written information and the strategy behind this type of block remains unchanged from the one presented in the section 'Island of Nutrition', as detailed on pages 19-20)



[Stage block] + Switch

ATTENTION: A Switch is active for this stage, so this stage including all its elements may not be displayed in the Bound.

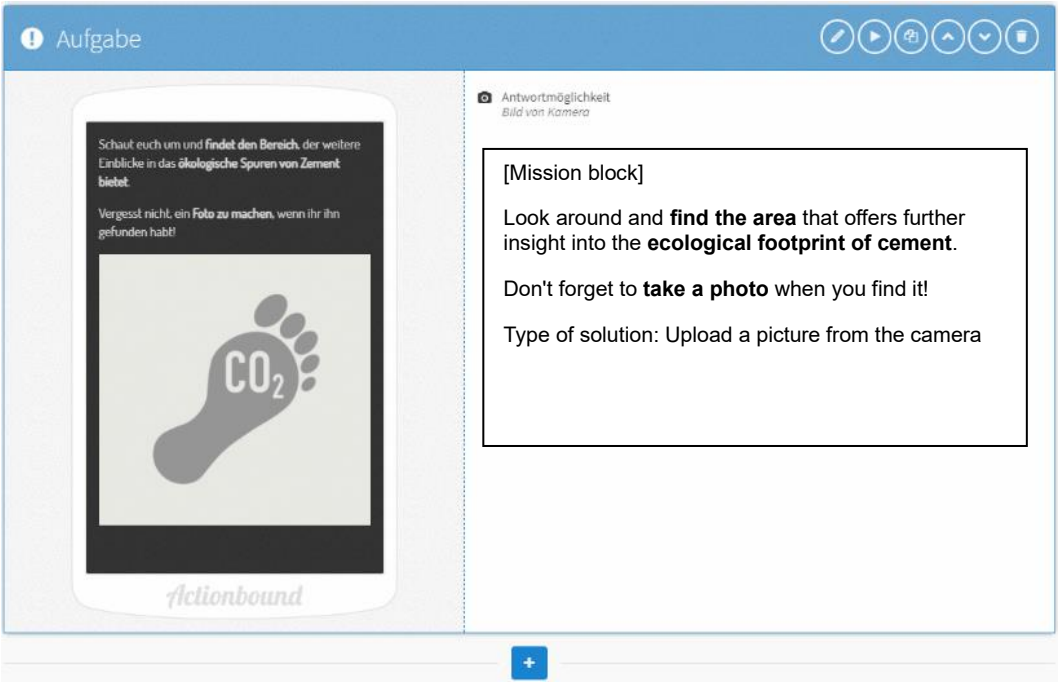
Title: Island of Construction



[Information block]

In the following station, you will find insightful information about the climatic effects of cement production.

However, this is not the only place on the island that deals with this topic.

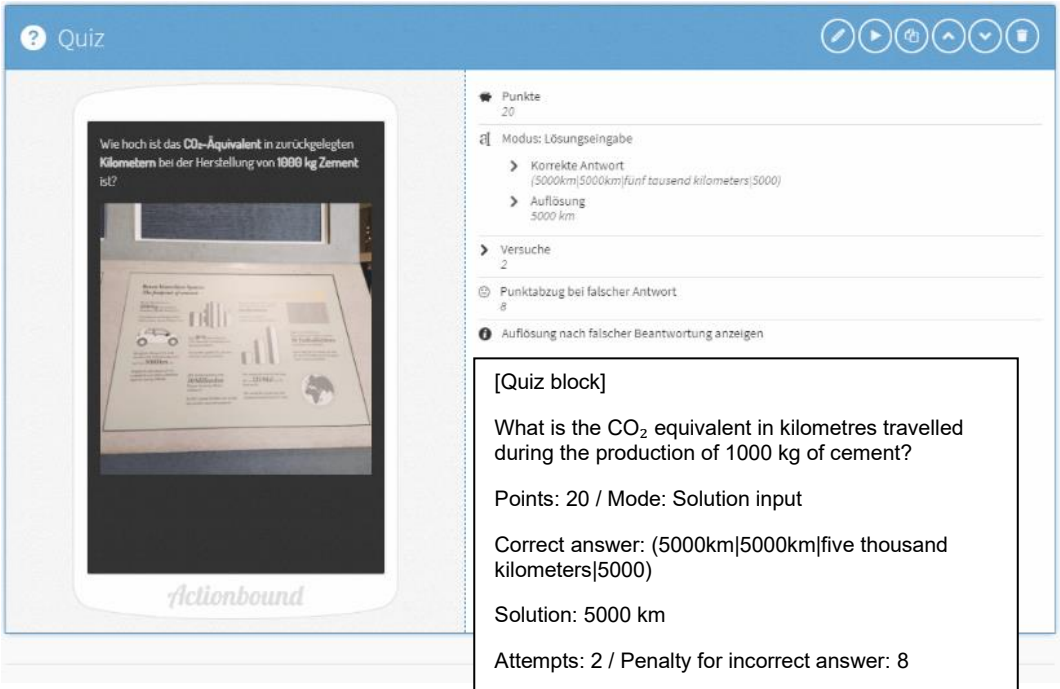


[Mission block]

Look around and **find the area** that offers further insight into the **ecological footprint of cement**.

Don't forget to **take a photo** when you find it!

Type of solution: Upload a picture from the camera



[Quiz block]

What is the CO_2 equivalent in kilometres travelled during the production of 1000 kg of cement?

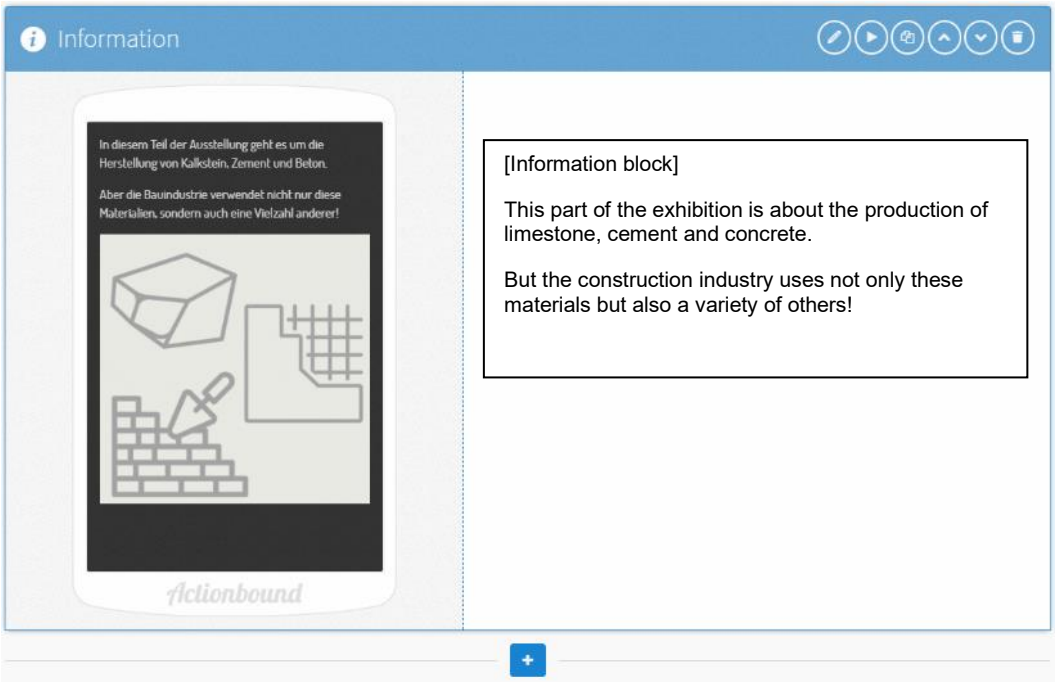
Points: 20 / Mode: Solution input

Correct answer: (5000km|5000km|five thousand kilometers|5000)

Solution: 5000 km

Attempts: 2 / Penalty for incorrect answer: 8

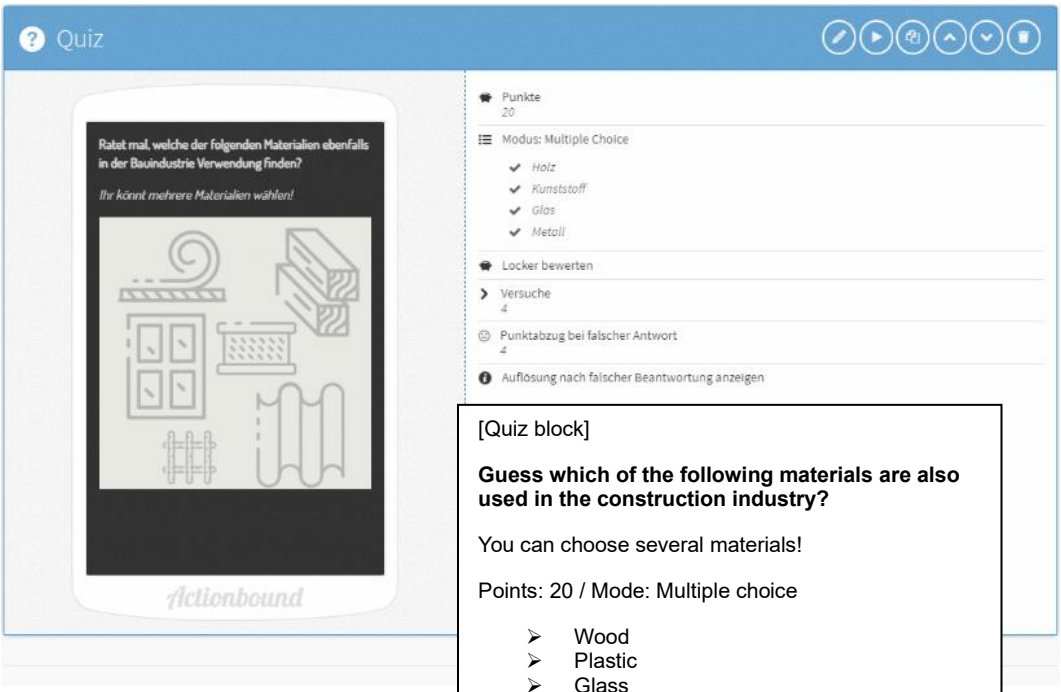
Show solution if answered incorrectly



[Information block]

This part of the exhibition is about the production of limestone, cement and concrete.

But the construction industry uses not only these materials but also a variety of others!



[Quiz block]

Guess which of the following materials are also used in the construction industry?

You can choose several materials!

Points: 20 / Mode: Multiple choice

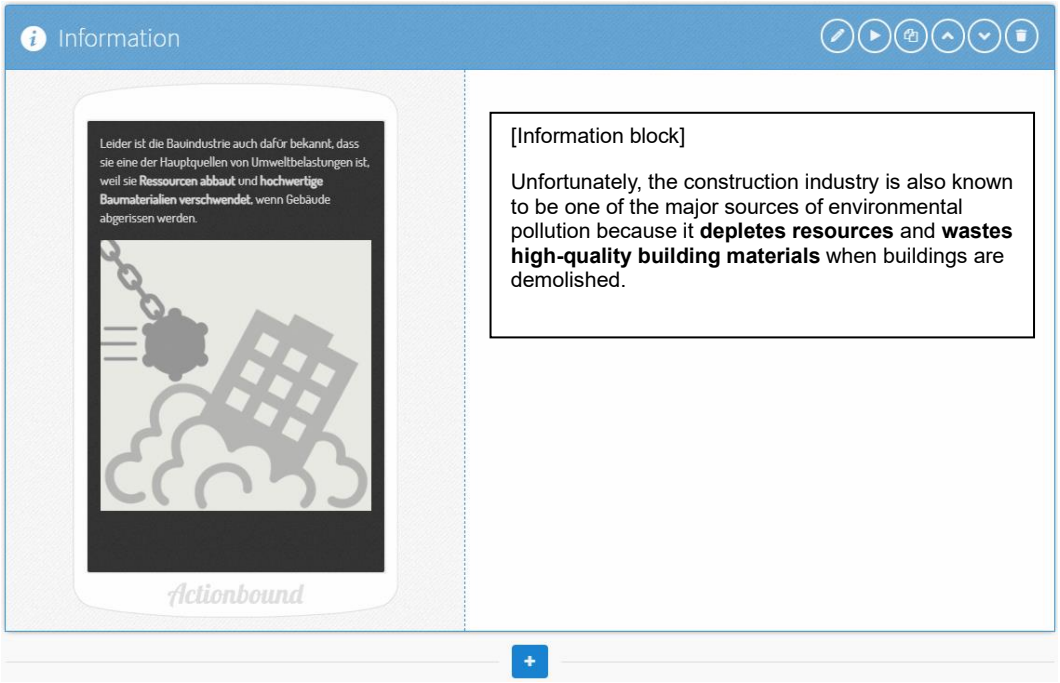
- Wood
- Plastic
- Glass
- Metal

(all answers are correct)

Relaxed scoring

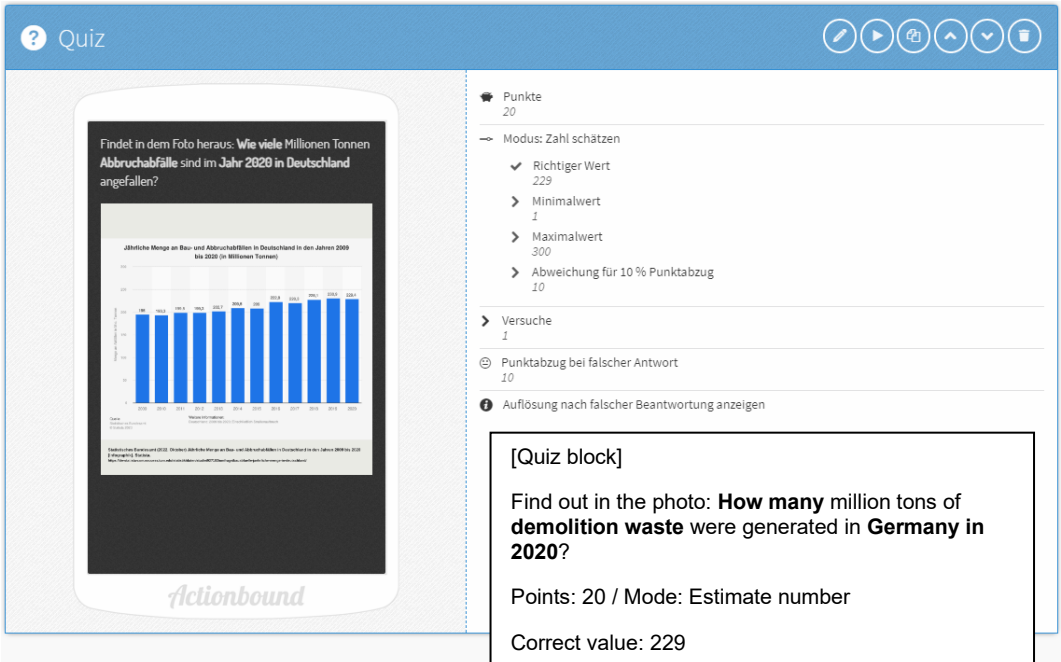
Attempts: 4 / Penalty for incorrect answer: 4

Show solution if answered incorrectly



[Information block]

Unfortunately, the construction industry is also known to be one of the major sources of environmental pollution because it **depletes resources** and **wastes high-quality building materials** when buildings are demolished.



[Quiz block]

Find out in the photo: **How many** million tons of **demolition waste** were generated in **Germany in 2020**?

Points: 20 / Mode: Estimate number

Correct value: 229

Minimum value: 1 / Maximum value: 300

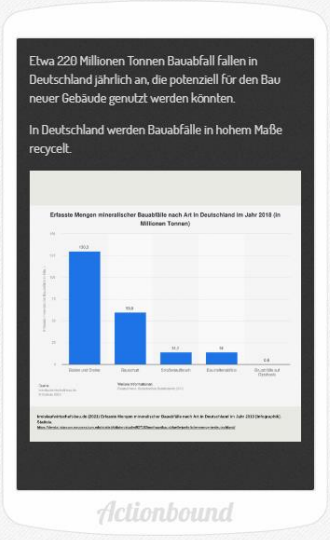
Deviation for 10%-point deduction: 10

Attempts: 1 / Penalty for incorrect answer: 10

Show solution if answered incorrectly

Graphic depicting the annual amount of construction and demolition waste in Germany from 2009 to 2020, measured in million tons.

Information



[Information block]

Around 220 million tons of construction waste are generated in Germany every year, which could potentially be used to build new buildings.

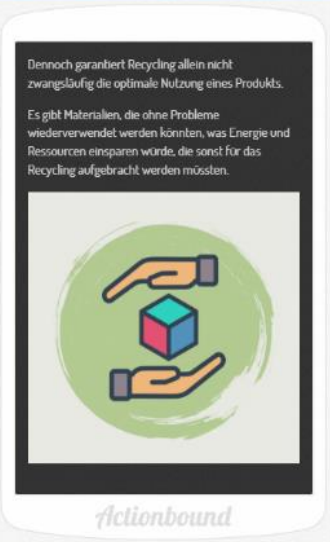
In Germany, construction waste is recycled to a large extent.

Graphic depicting the recorded quantities of mineral construction waste by type in Germany in 2018 (in million tons).

Y-axis: recorded mineral construction waste in million tons.

X-axis: types: soil and stones, building rubble, road demolition waste, construction site waste, gypsum-based construction waste

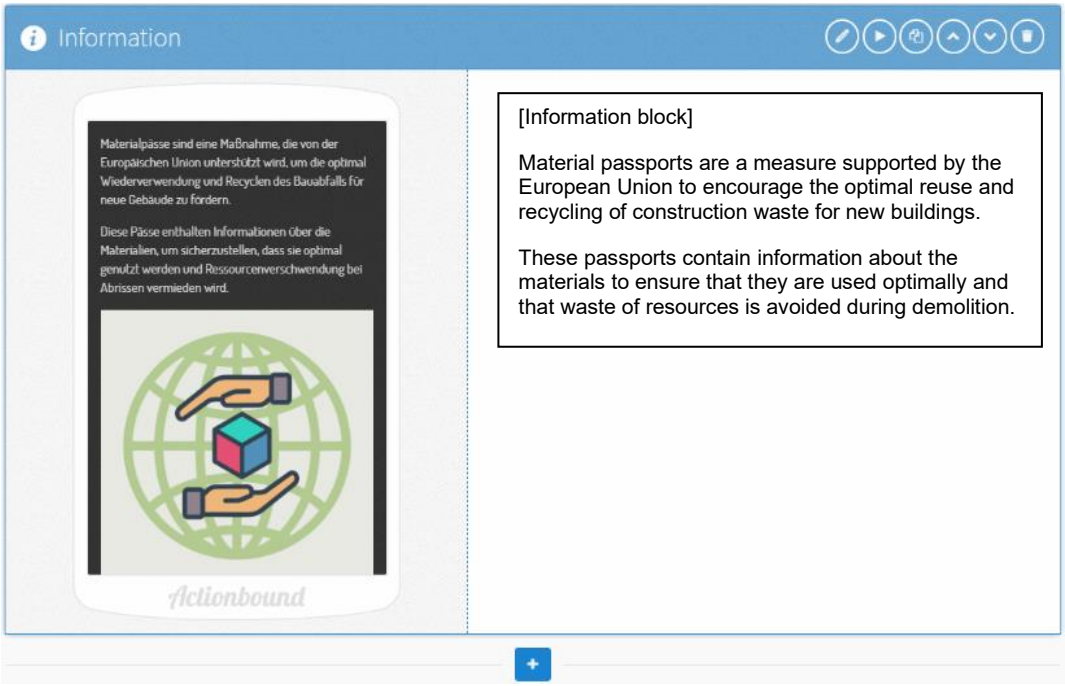
Information

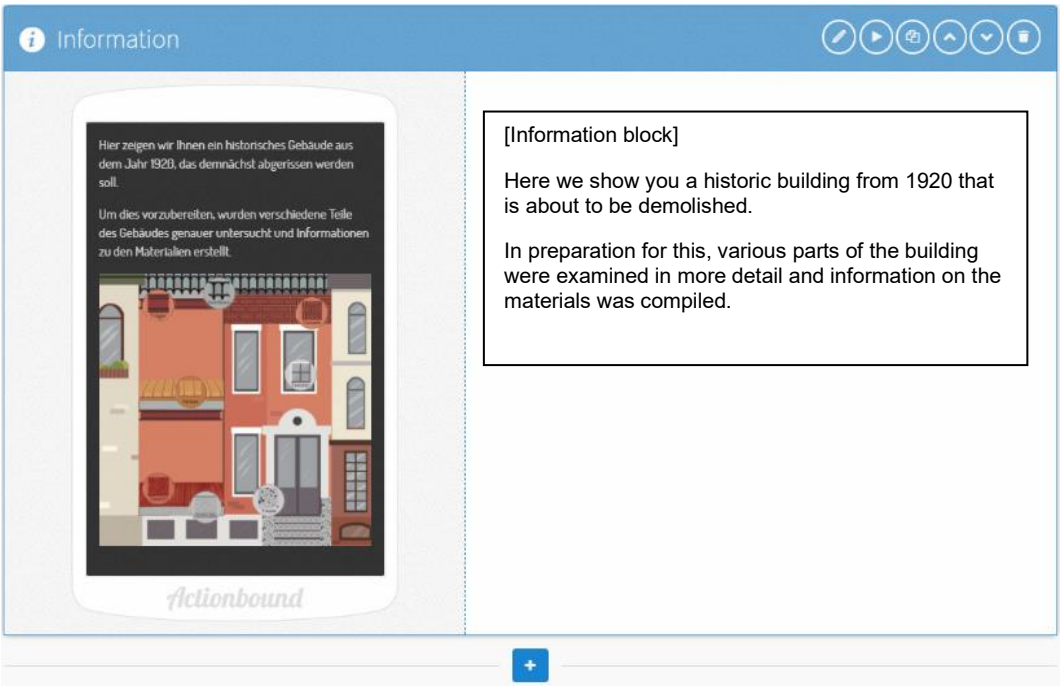


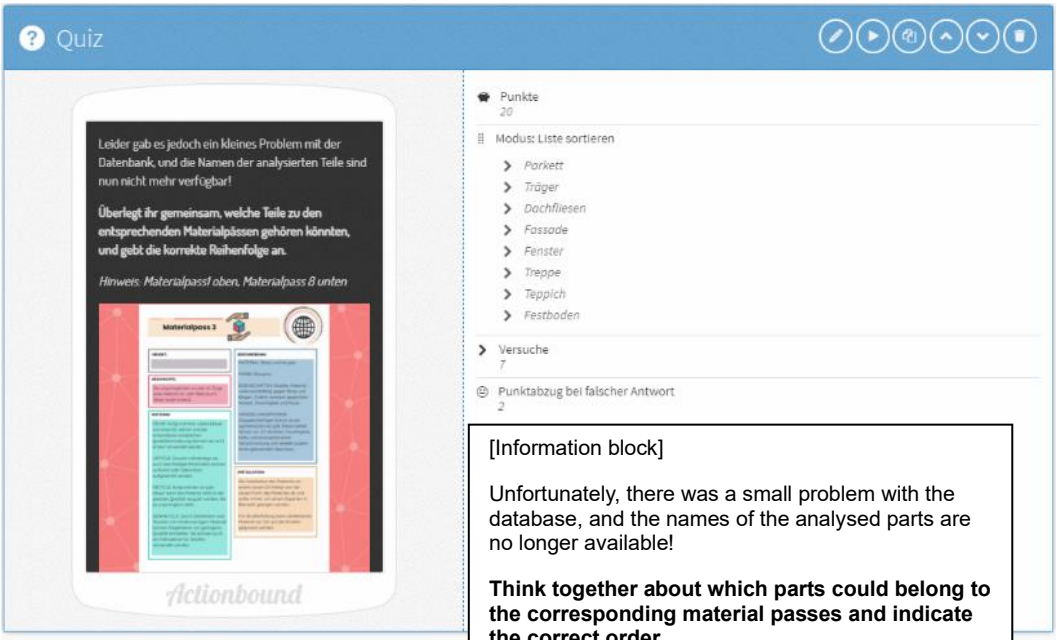
[Information block]

However, recycling alone does not necessarily guarantee the optimal use of a product.

There are materials that could be reused without any problems, which would save energy and resources that would otherwise have to be used for recycling.


Information
Materialpässe sind eine Maßnahme, die von der Europäischen Union unterstützt wird, um die optimal Wiederverwendung und Recyclen des Bauabfalls für neue Gebäude zu fördern.
Diese Pässe enthalten Informationen über die Materialien, um sicherzustellen, dass sie optimal genutzt werden und Ressourcenverschwendung bei Abrissen vermieden wird.
Actionbound
[Information block]
Material passports are a measure supported by the European Union to encourage the optimal reuse and recycling of construction waste for new buildings.
These passports contain information about the materials to ensure that they are used optimally and that waste of resources is avoided during demolition.


Information
Hier zeigen wir Ihnen ein historisches Gebäude aus dem Jahr 1920, das demnächst abgerissen werden soll.
Um dies vorzubereiten, wurden verschiedene Teile des Gebäudes genauer untersucht und Informationen zu den Materialien erstellt.
Actionbound
[Information block]
Here we show you a historic building from 1920 that is about to be demolished.
In preparation for this, various parts of the building were examined in more detail and information on the materials was compiled.



[Information block]

Unfortunately, there was a small problem with the database, and the names of the analysed parts are no longer available!

Think together about which parts could belong to the corresponding material passes and indicate the correct order.

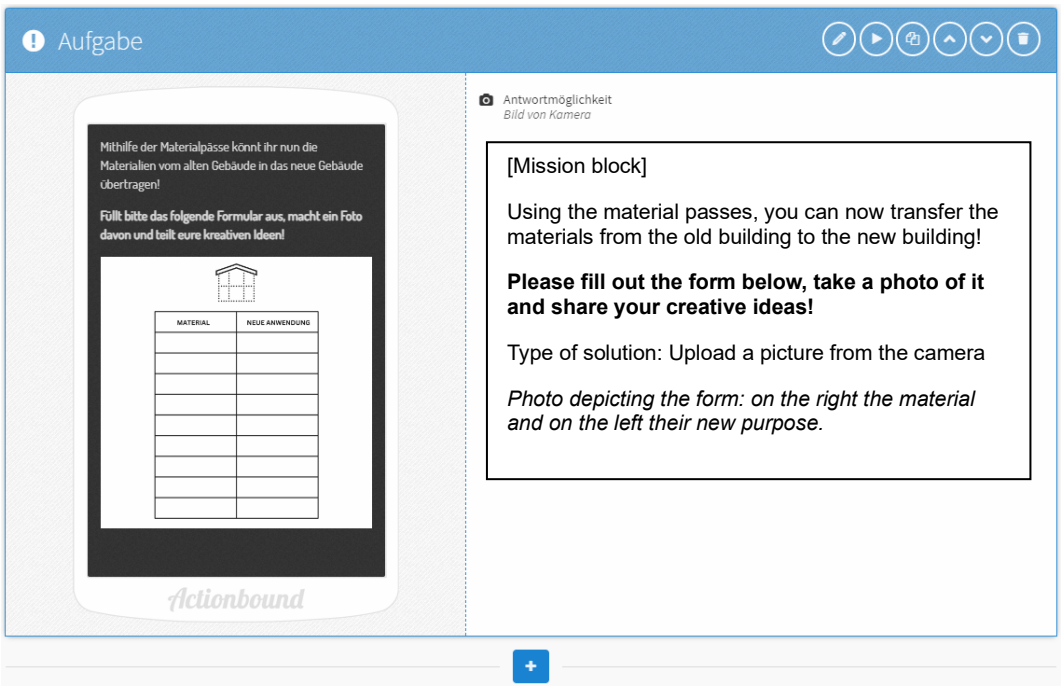
Note: Material pass 1 above, material pass 8 below

Points: 20 / Mode: Sort list

- Parquet
- Support
- Roof tiles
- Facade
- Window
- Staircase
- Carpet
- Solid floor

Attempts: 7 / Penalty for incorrect answer: 2

Photo depicting an example of a Material Passport. For translation, please refer to page X



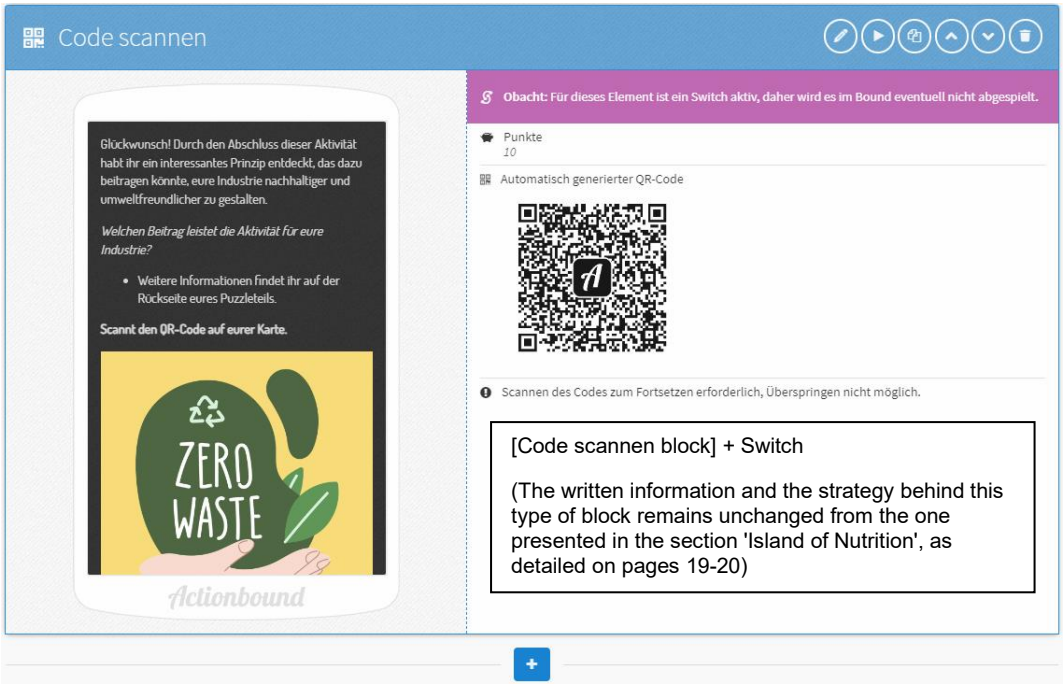
[Mission block]

Using the material passes, you can now transfer the materials from the old building to the new building!

Please fill out the form below, take a photo of it and share your creative ideas!

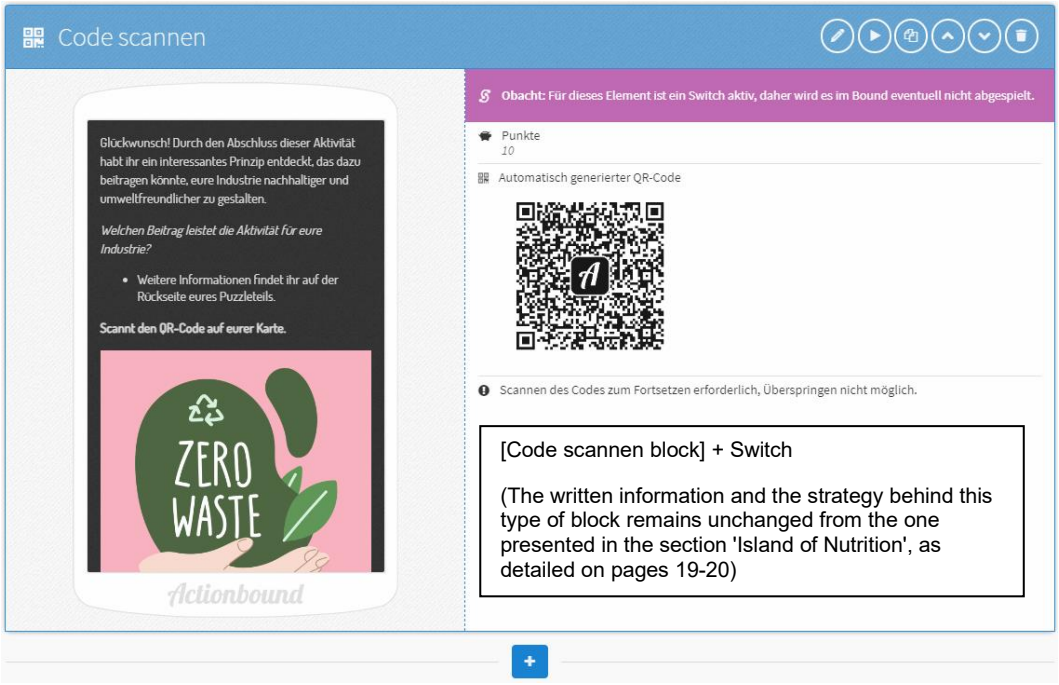
Type of solution: Upload a picture from the camera

Photo depicting the form: on the right the material and on the left their new purpose.



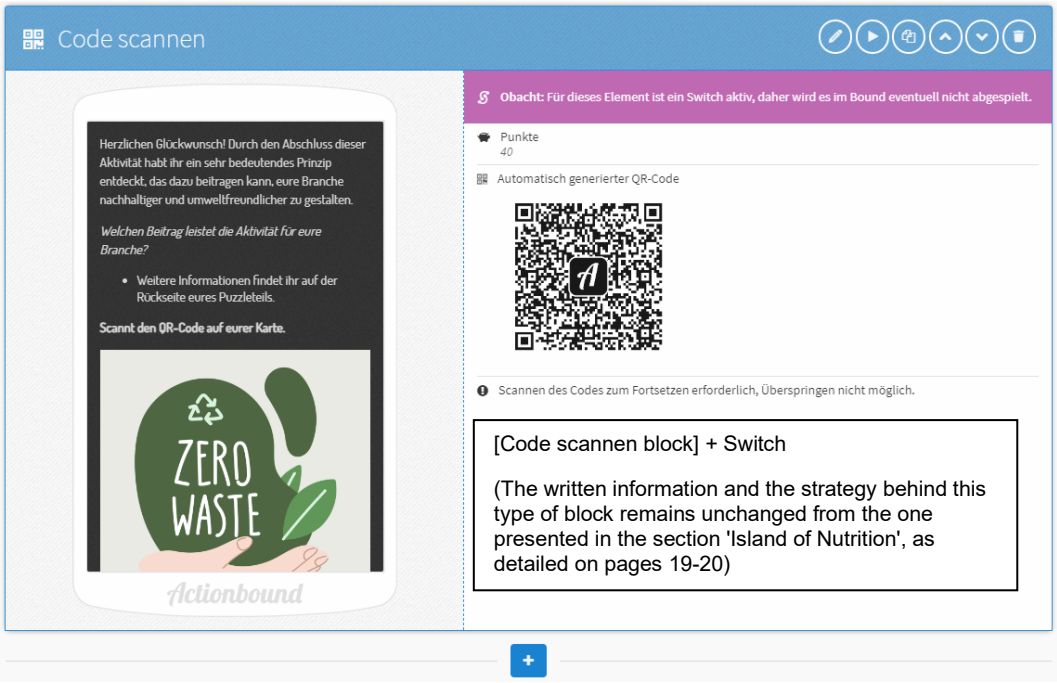
[Code scannen block] + Switch

(The written information and the strategy behind this type of block remains unchanged from the one presented in the section 'Island of Nutrition', as detailed on pages 19-20)



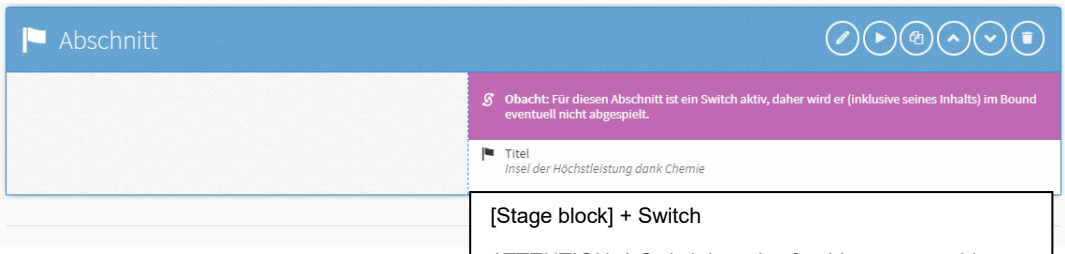
[Code scannen block] + Switch

(The written information and the strategy behind this type of block remains unchanged from the one presented in the section 'Island of Nutrition', as detailed on pages 19-20)



[Code scannen block] + Switch

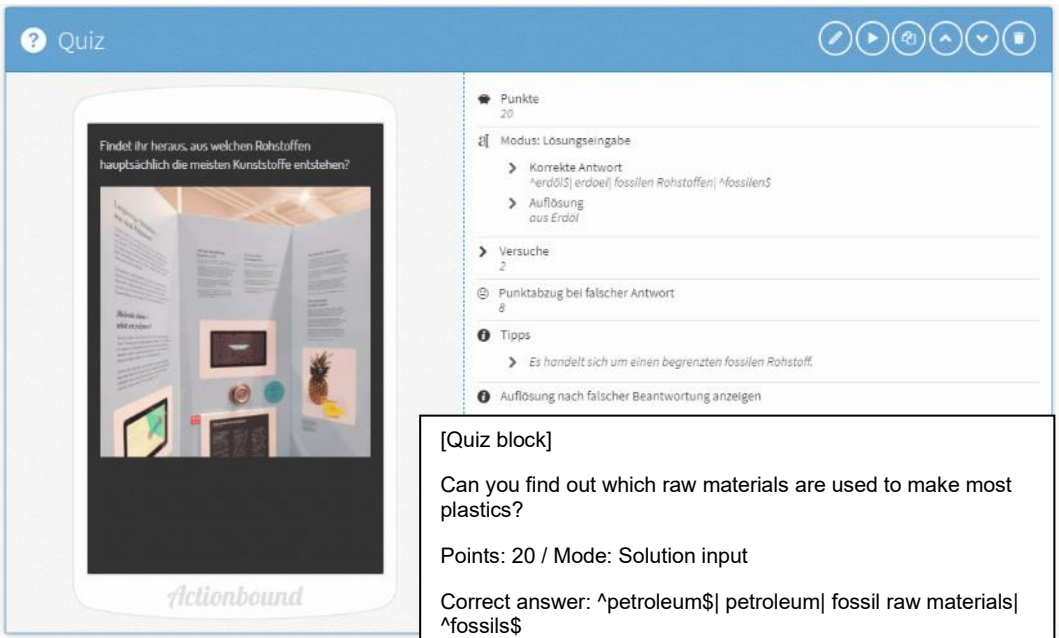
(The written information and the strategy behind this type of block remains unchanged from the one presented in the section 'Island of Nutrition', as detailed on pages 19-20)



[Stage block] + Switch

ATTENTION: A Switch is active for this stage, so this stage including all its elements may not be displayed in the Bound.

Title: Island of High Performance Thanks to Chemistry



[Quiz block]

Can you find out which raw materials are used to make most plastics?

Points: 20 / Mode: Solution input

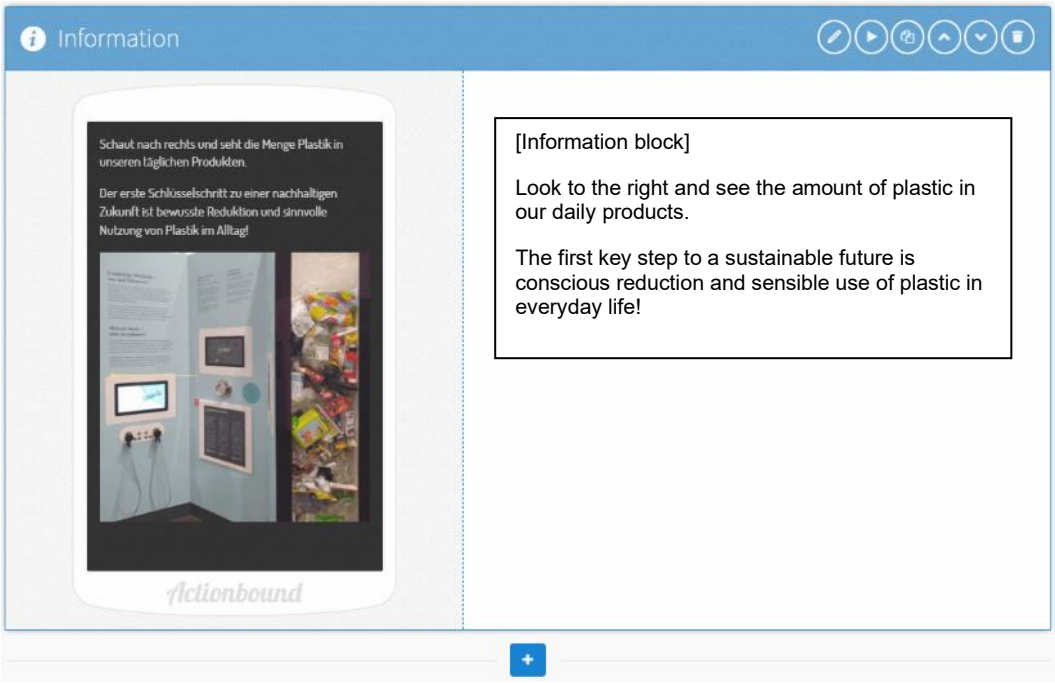
Correct answer: ^petroleum$| petroleum| fossil raw materials| ^fossils$

Solution: from petroleum

Attempts: 2 / Penalty for incorrect answer: 8

Hints: It is a limited fossil raw material.

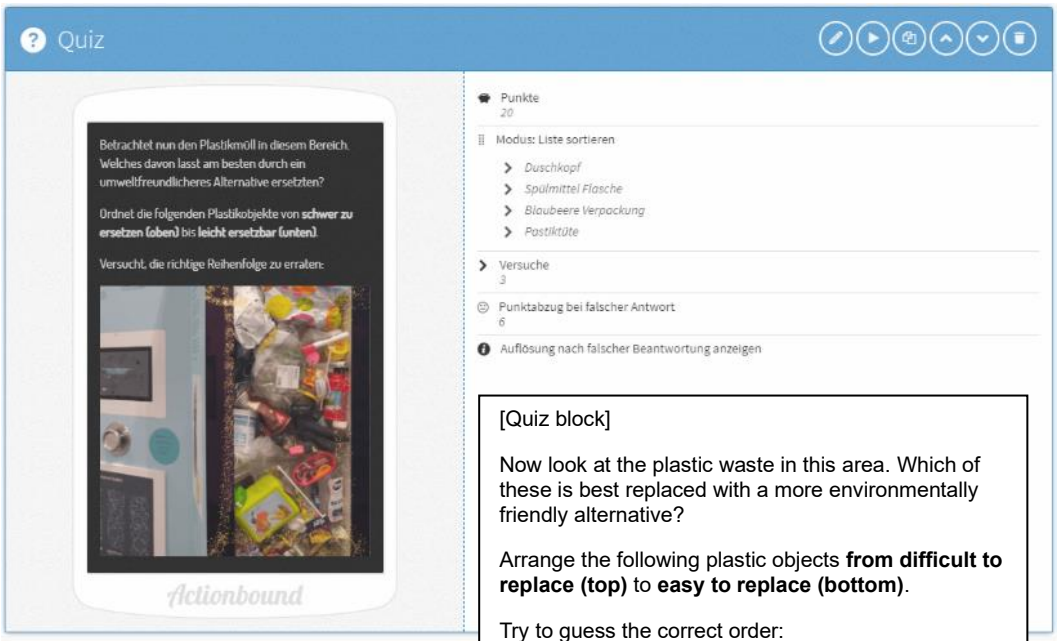
Show solution if answered incorrectly



[Information block]

Look to the right and see the amount of plastic in our daily products.

The first key step to a sustainable future is conscious reduction and sensible use of plastic in everyday life!



[Quiz block]

Now look at the plastic waste in this area. Which of these is best replaced with a more environmentally friendly alternative?

Arrange the following plastic objects **from difficult to replace (top)** to **easy to replace (bottom)**.

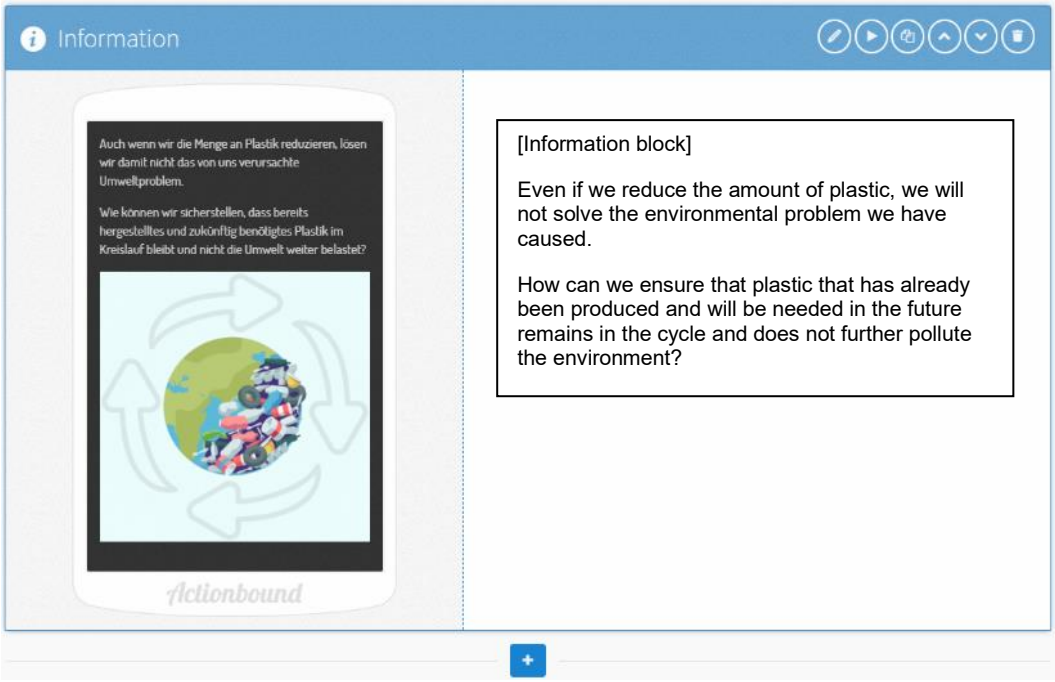
Try to guess the correct order:

Points: 20 / Mode: Sort list

- Shower head
- Dishwashing liquid bottle
- Blueberry packaging
- Plastic bag

Attempts: 3 / Penalty for incorrect answer: 6

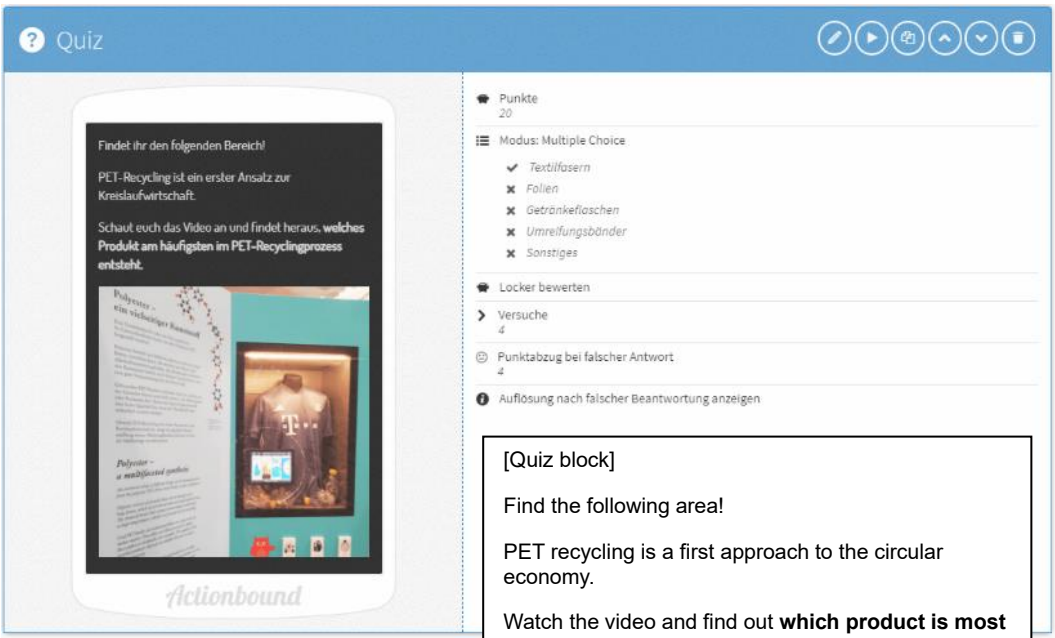
Show solution if answered incorrectly



[Information block]

Even if we reduce the amount of plastic, we will not solve the environmental problem we have caused.

How can we ensure that plastic that has already been produced and will be needed in the future remains in the cycle and does not further pollute the environment?



[Quiz block]

Find the following area!

PET recycling is a first approach to the circular economy.

Watch the video and find out **which product is most often created in the PET recycling process.**

Points: 20 / Mode: Multiple choice

- Textile fibers
- Films
- Drinks bottles
- Strapping bands
- Other

Relaxed scoring

Attempts: 4 / Penalty for incorrect answer: 4

Show solution if answered incorrectly

Aufgabe

Antwortmöglichkeit
Text

[Mission block]

Now, look at the label of your clothing.

It surely contains polyester. But is that the only thing it contains?

Write down here what materials your clothing is made of.

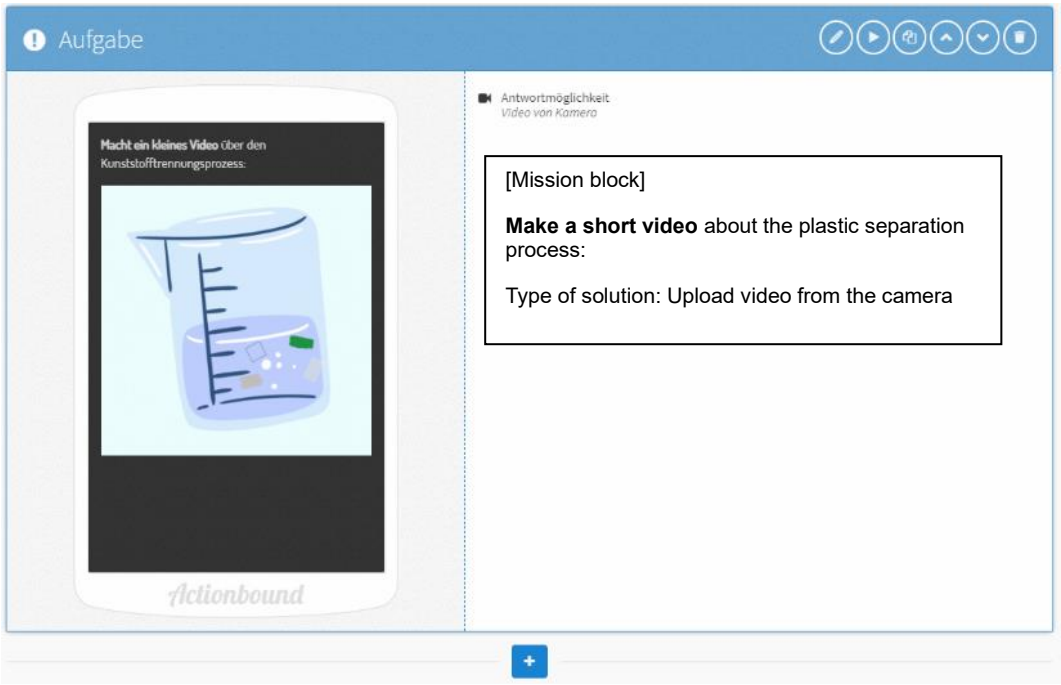
Type of solution: Text

Information

[Information block]

In order to produce high-quality textiles, plastic must be sorted very carefully.

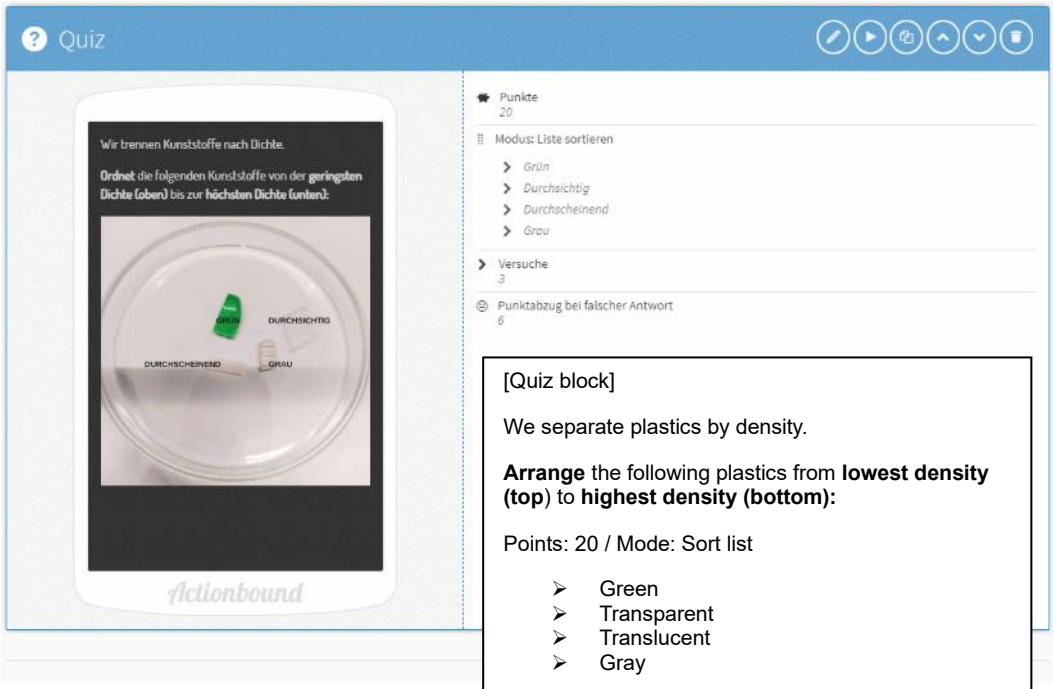
Now, go to the chemistry lab to find out how different plastics can be separated!



[Mission block]

Make a short video about the plastic separation process:

Type of solution: Upload video from the camera



[Quiz block]

We separate plastics by density.

Arrange the following plastics from **lowest density (top**) to **highest density (bottom):**

Points: 20 / Mode: Sort list

- Green
- Transparent
- Translucent
- Gray

Attempts: 3 / Penalty for incorrect answer: 6

Show solution if answered incorrectly

Information

[Information block]

WHAT HAPPENED HERE?

The plastic that is lighter than water floats on top.

- When we add salt, the water becomes denser.
- Then, the plastic with the lowest density compared to the new water mixture suddenly starts floating.
- This allows us to separate it from the heavier plastics.

Text in the photo from right to left:

"Only the density of the green plastic is lower than that of water"

"Now, the density of water is higher than the density of transparent plastic"

Information

[Information block]

Separating plastics is not an easy task!

- However, here in the laboratory, we have selected plastics that can be easily separated from one another due to their densities.

Aufgabe

Antwortmöglichkeit
Text

[Mission block]

Remember your clothes? **Would you use the same method to separate polyester from cotton? Why?**

Share your own thoughts here:

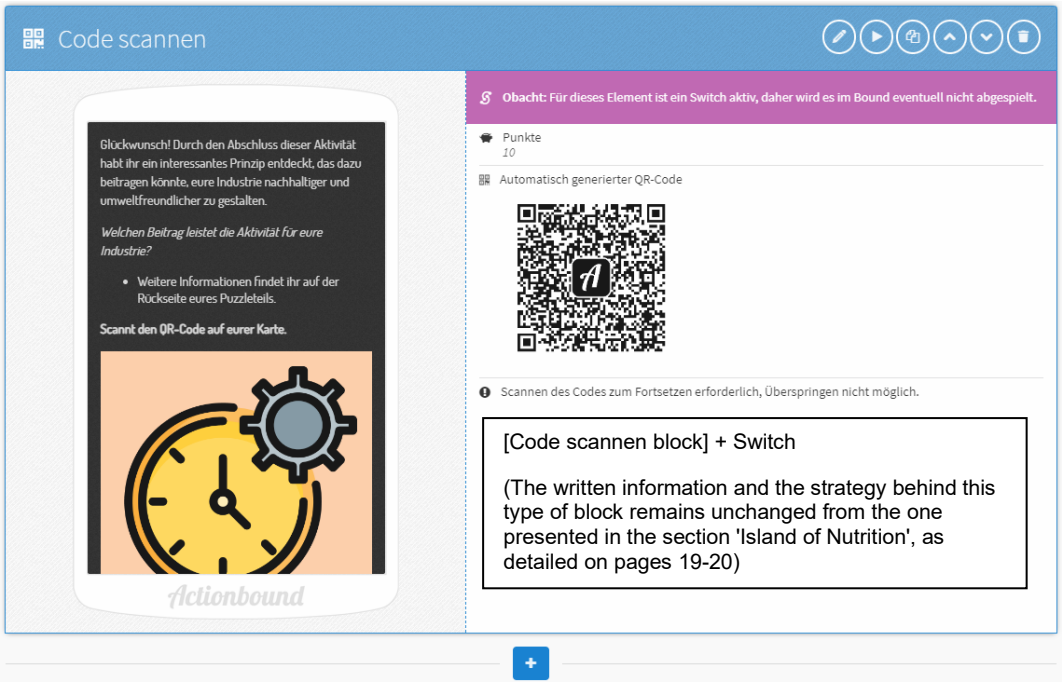
Type of solution: Text

Information

[Information block]

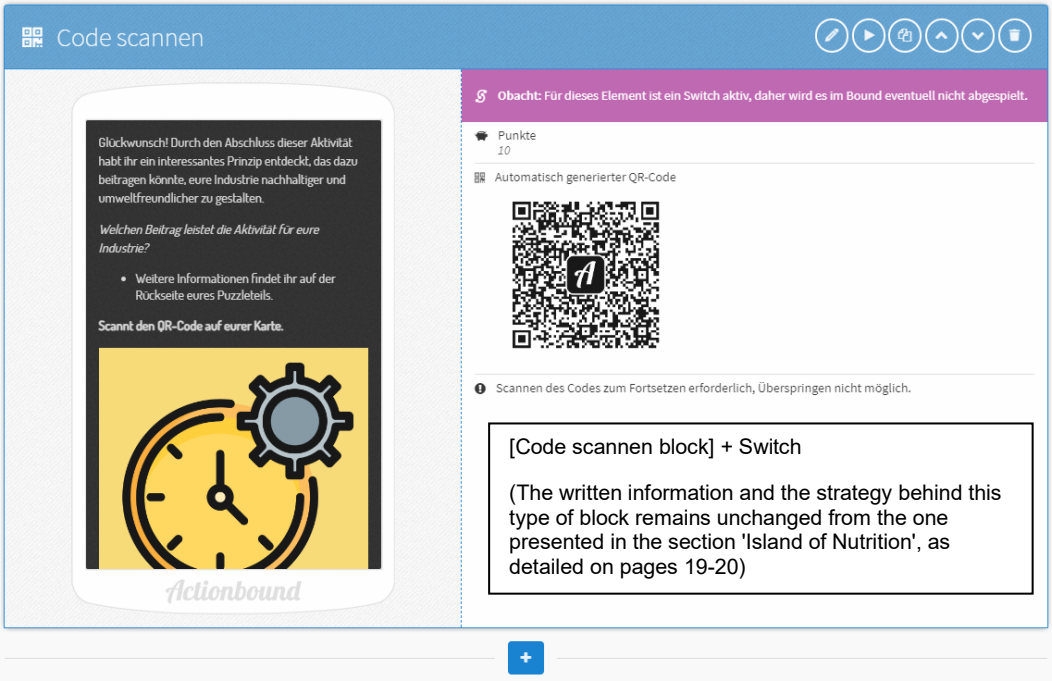
Simply sorting plastic waste properly is not enough.

- When recycled plastics are mixed with different synthetic or natural materials such as cotton, this can sometimes make recycling at the end of their life even more difficult.



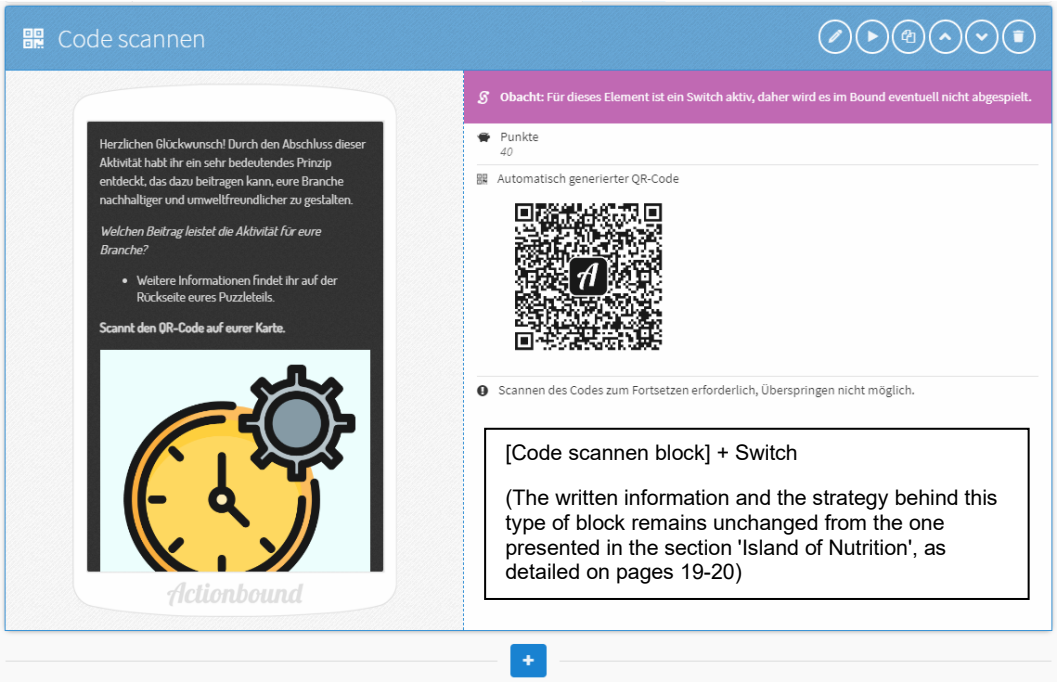
[Code scannen block] + Switch

(The written information and the strategy behind this type of block remains unchanged from the one presented in the section 'Island of Nutrition', as detailed on pages 19-20)



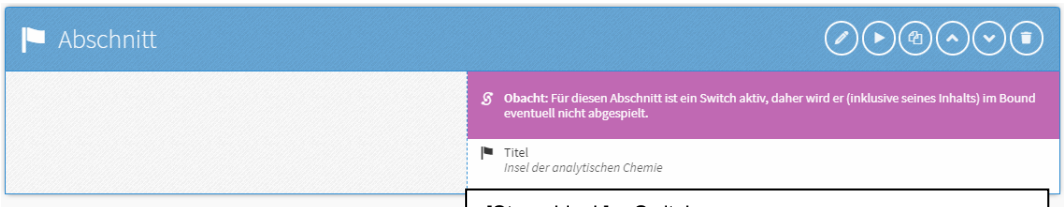
[Code scannen block] + Switch

(The written information and the strategy behind this type of block remains unchanged from the one presented in the section 'Island of Nutrition', as detailed on pages 19-20)



[Code scannen block] + Switch

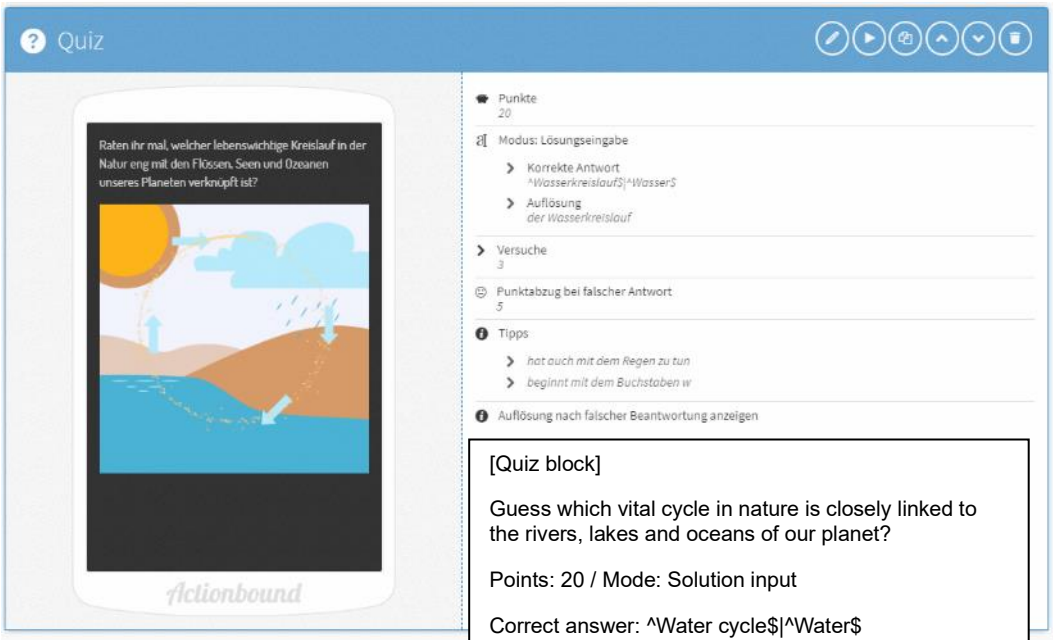
(The written information and the strategy behind this type of block remains unchanged from the one presented in the section 'Island of Nutrition', as detailed on pages 19-20)



[Stage block] + Switch

ATTENTION: A Switch is active for this stage, so this stage, including all its elements, may not be displayed in the Bound.

Title: Island of Analytical Chemistry



[Quiz block]

Guess which vital cycle in nature is closely linked to the rivers, lakes and oceans of our planet?

Points: 20 / Mode: Solution input

Correct answer: ^Water cycle$|^Water$

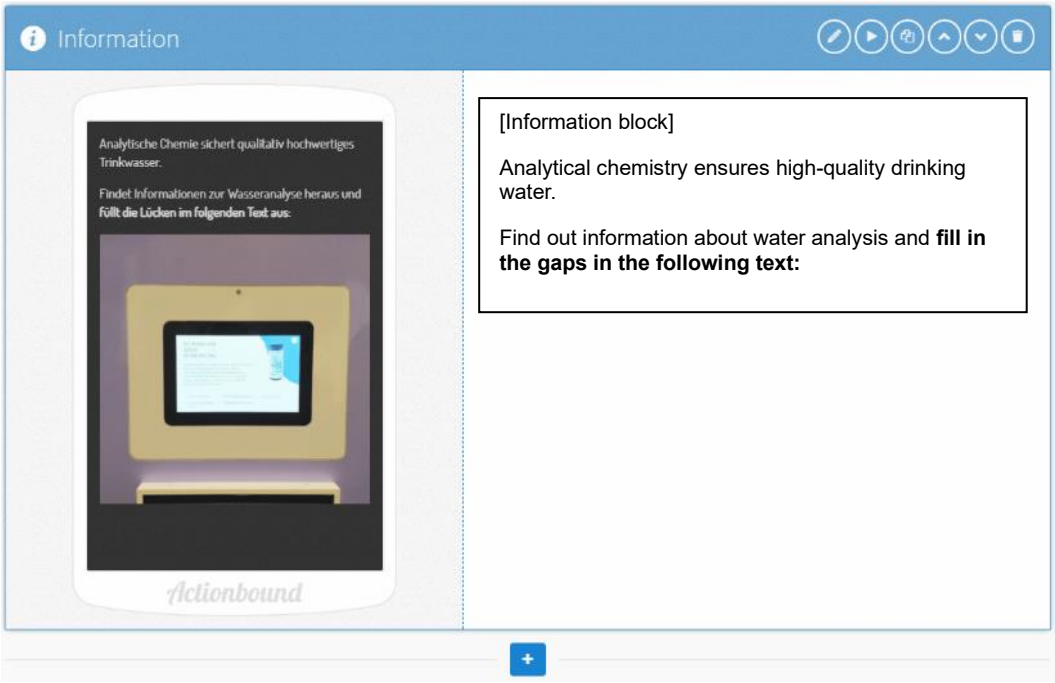
Solution: the water cycle

Attempts: 3 / Penalty for incorrect answer: 5

Hints

- also has to do with rain
- starts with the letter w

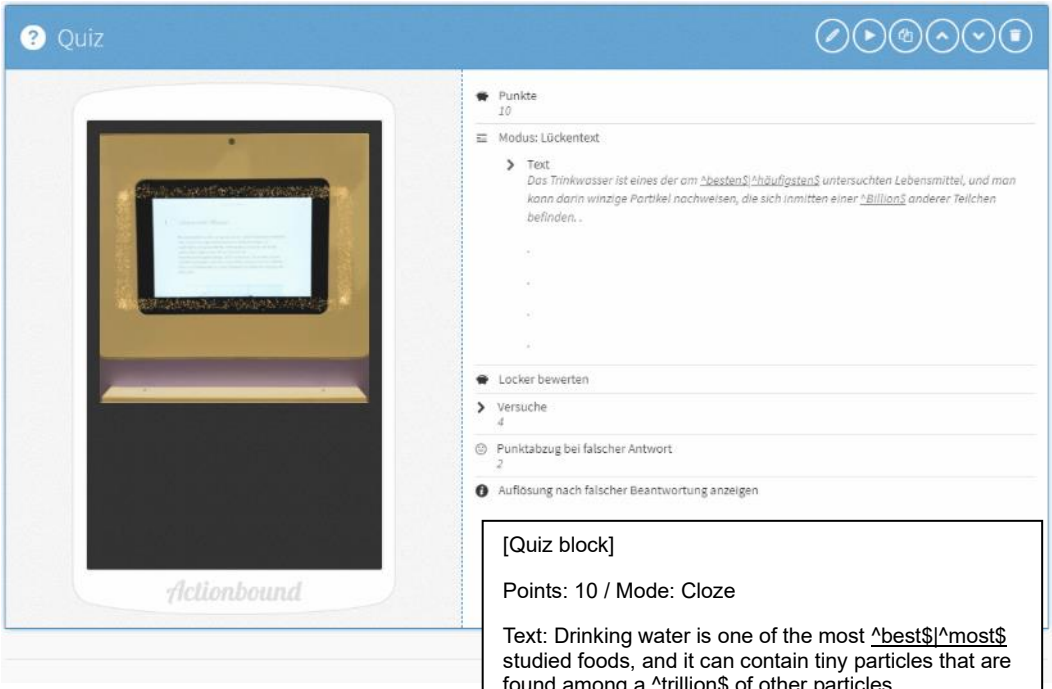
Show solution if answered incorrectly



[Information block]

Analytical chemistry ensures high-quality drinking water.

Find out information about water analysis and **fill in the gaps in the following text:**



[Quiz block]

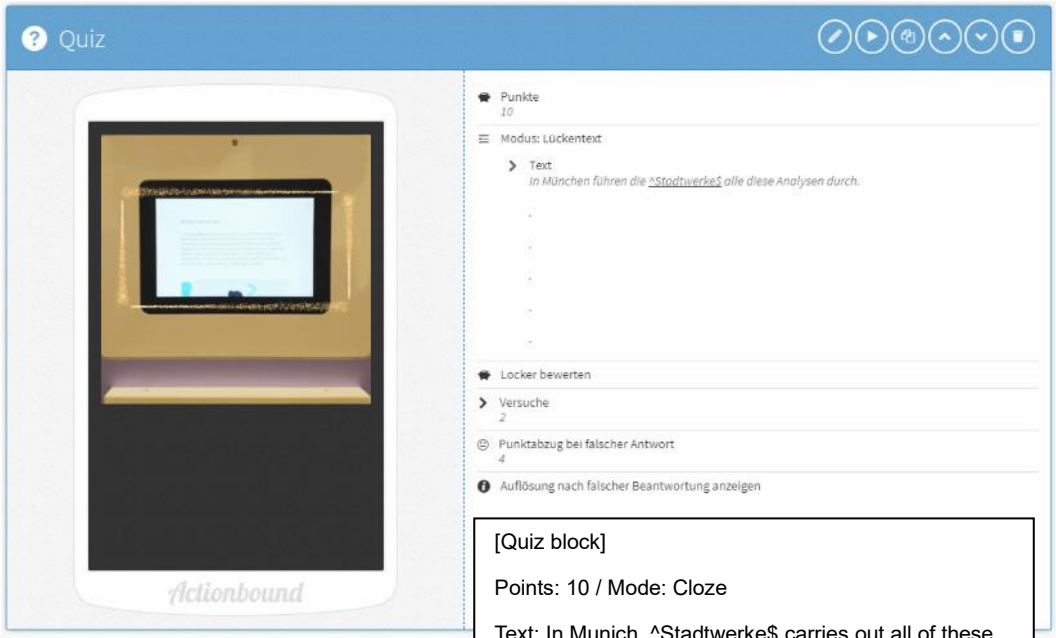
Points: 10 / Mode: Cloze

Text: Drinking water is one of the most ^best$|^most$ studied foods, and it can contain tiny particles that are found among a ^trillion$ of other particles.

Relaxed scoring

Attempts: 4 / Penalty for incorrect answer: 2

Show solution if answered incorrectly



[Quiz block]

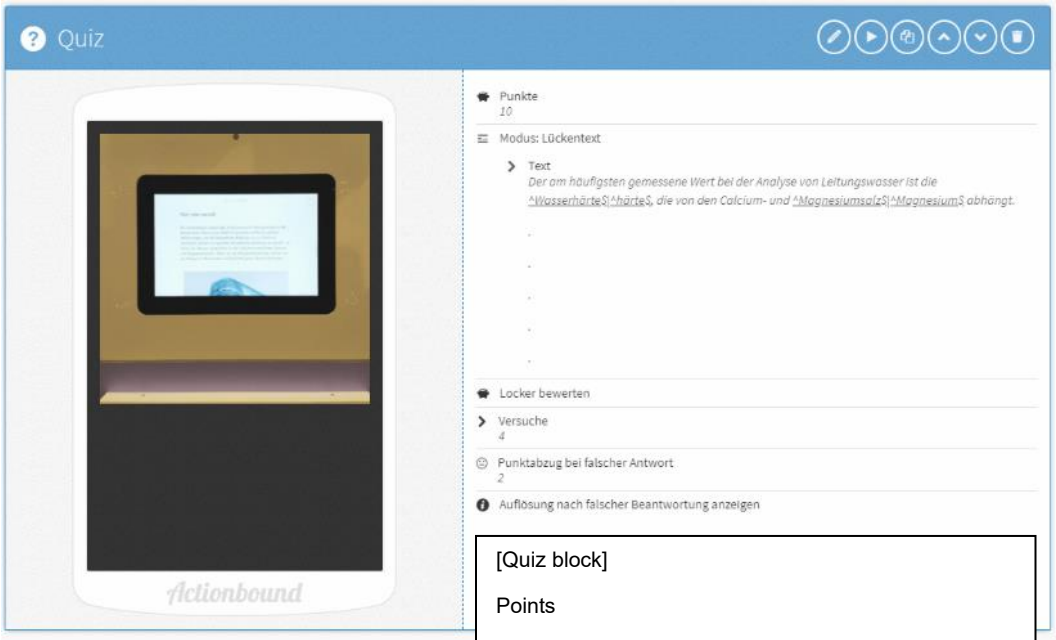
Points: 10 / Mode: Cloze

Text: In Munich, ^Stadtwerke$ carries out all of these analyses.

Relaxed scoring

Attempts: 2 / Penalty for incorrect answer: 4

Show solution if answered incorrectly



[Quiz block]

Points

10

Mode: Cloze

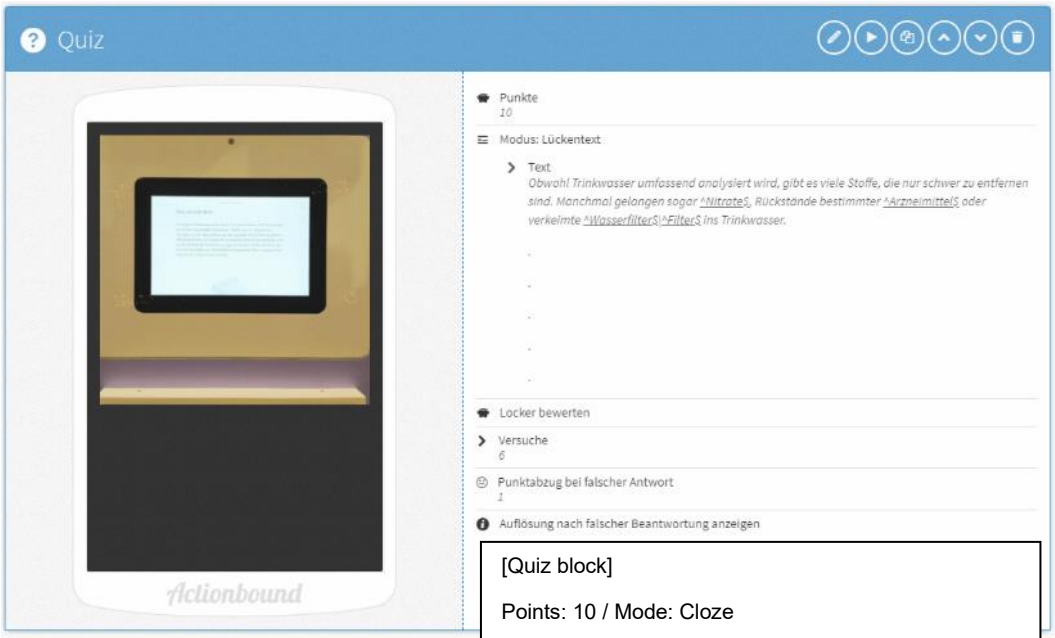
Text

The most commonly measured value when analyzing tap water is the ^water hardness$|^hardness$, which depends on the calcium and ^magnesium salts$|^magnesium

Relaxed scoring

Attempts: 4 / Penalty for incorrect answer: 2

Show solution if answered incorrectly



[Quiz block]

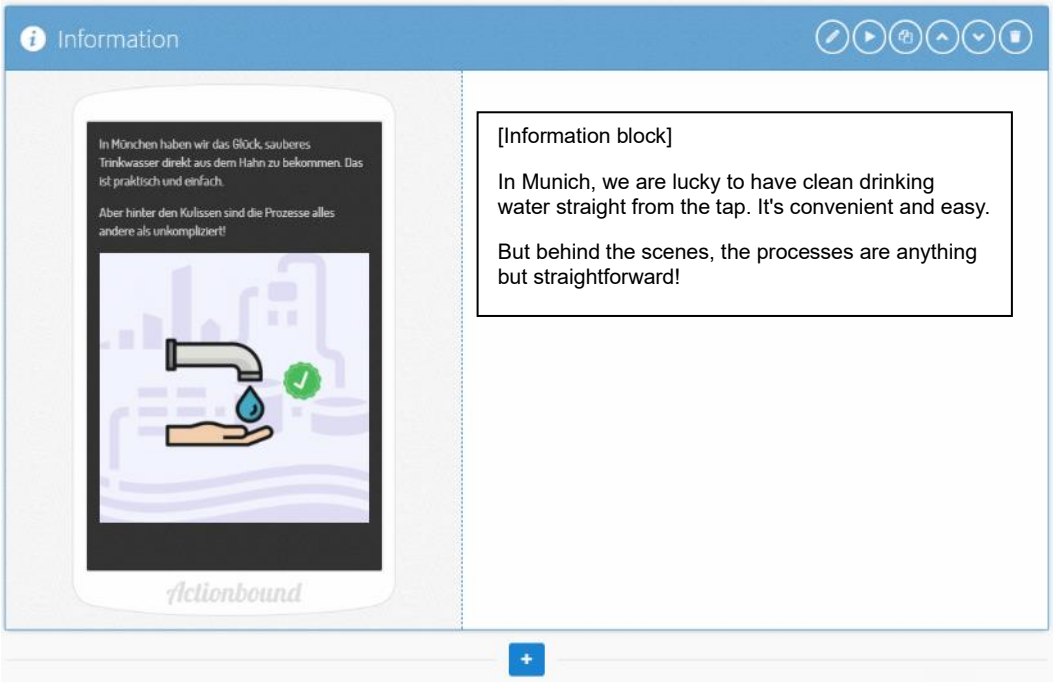
Points: 10 / Mode: Cloze

Text: Although drinking water is analyzed extensively, there are many substances that are difficult to remove. Sometimes even ^nitrates$, residues of certain ^medicines$ or contaminated ^water filters$|^filters$ get into the drinking water.

Relaxed scoring

Attempts: 6 / Penalty for incorrect answer: 1

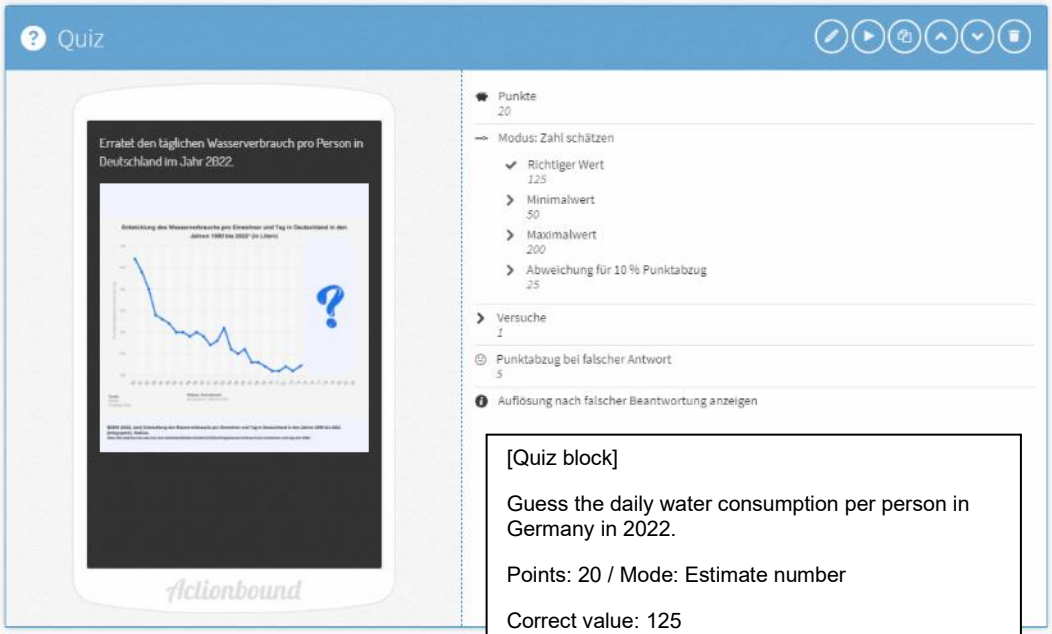
Show solution if answered incorrectly



[Information block]

In Munich, we are lucky to have clean drinking water straight from the tap. It's convenient and easy.

But behind the scenes, the processes are anything but straightforward!



[Quiz block]

Guess the daily water consumption per person in Germany in 2022.

Points: 20 / Mode: Estimate number

Correct value: 125

Minimum value: 50 / Maximum value: 200

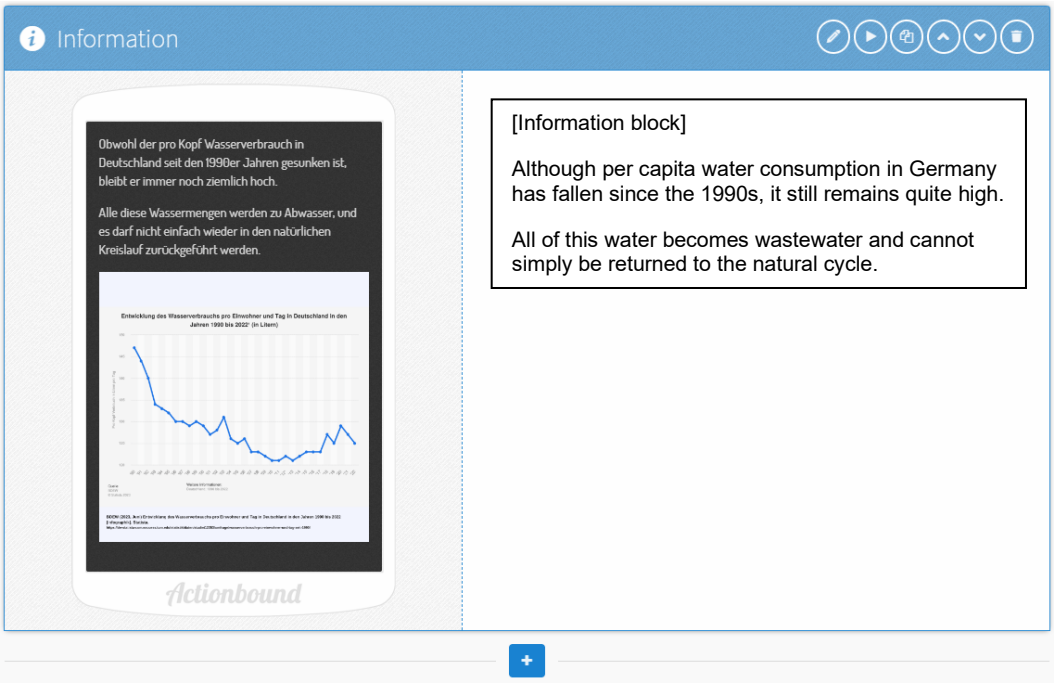
Deviation for 10%-point deduction: 25

Attempts: 1

Penalty for incorrect answer: 5

Show solution if answered incorrectly

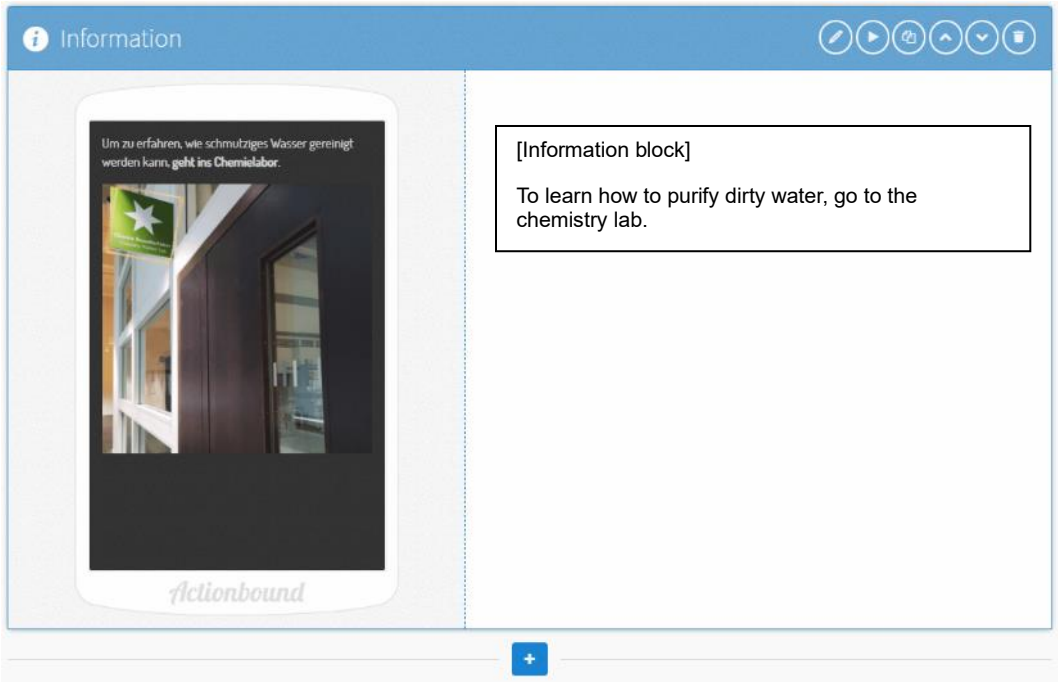
Graphic depicting the development of water consumption per inhabitant and day in Germany from 1990 to 2022 (in litres).

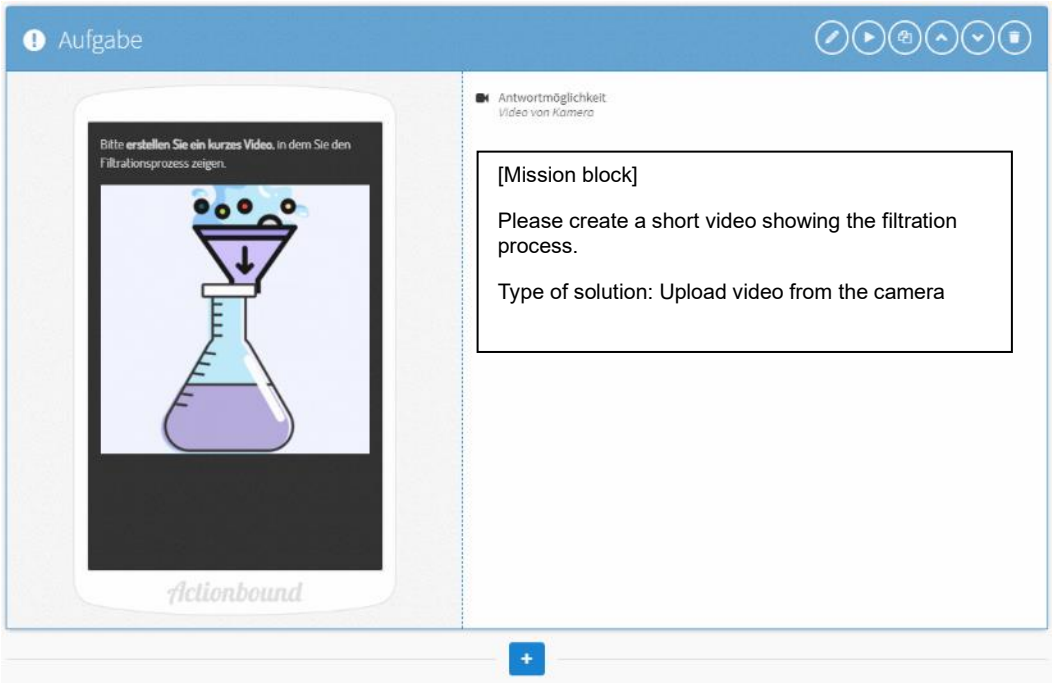


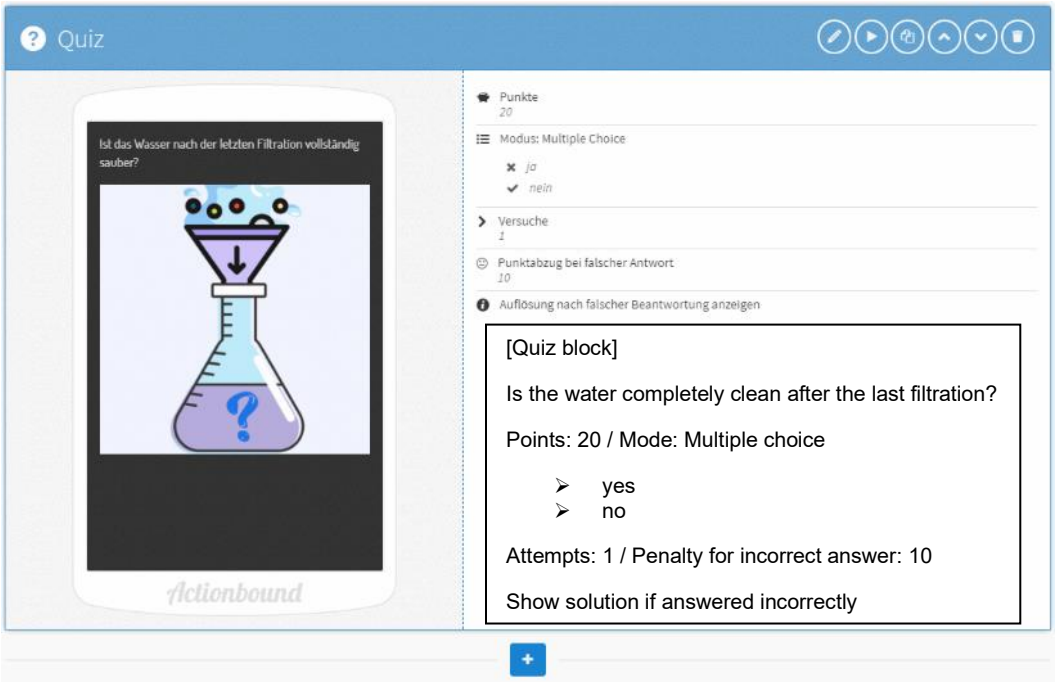
[Information block]

Although per capita water consumption in Germany has fallen since the 1990s, it still remains quite high.

All of this water becomes wastewater and cannot simply be returned to the natural cycle.


Information
Um zu erfahren, wie schmutziges Wasser gereinigt werden kann, geht ins Chemielabor.
Actionbound
[Information block]
To learn how to purify dirty water, go to the chemistry lab.


Aufgabe
Bitte erstellen Sie ein kurzes Video, in dem Sie den Filtrationsprozess zeigen.
Actionbound
Antwortmöglichkeit
Video von Kamera
[Mission block]
Please create a short video showing the filtration process.
Type of solution: Upload video from the camera



[Quiz block]

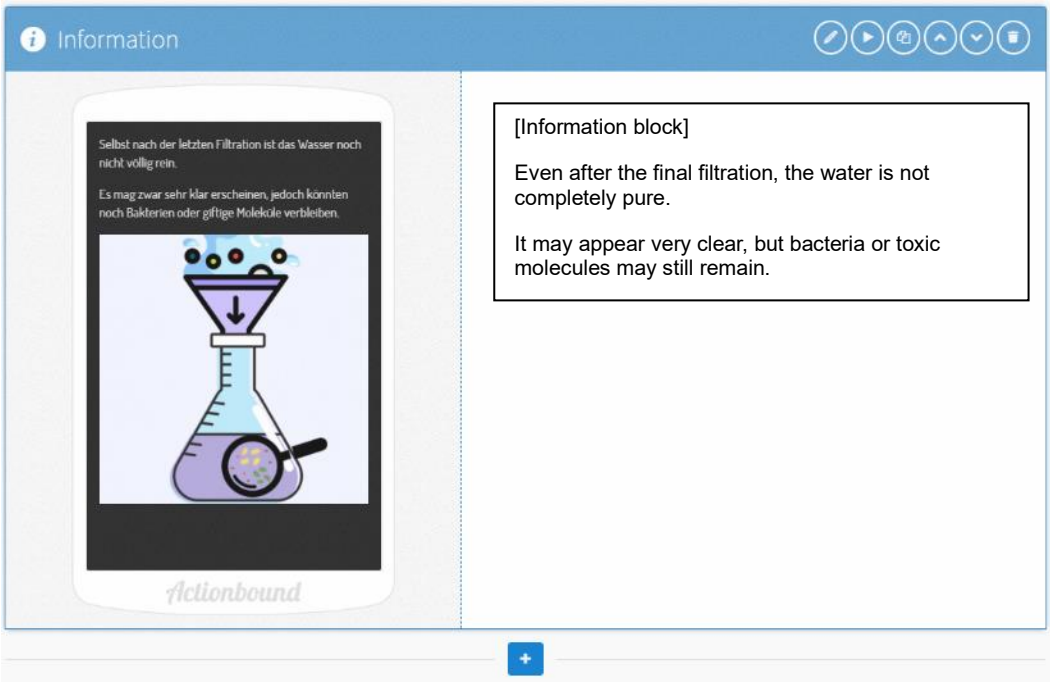
Is the water completely clean after the last filtration?

Points: 20 / Mode: Multiple choice

- yes
- no

Attempts: 1 / Penalty for incorrect answer: 10

Show solution if answered incorrectly



[Information block]

Even after the final filtration, the water is not completely pure.

It may appear very clear, but bacteria or toxic molecules may still remain.

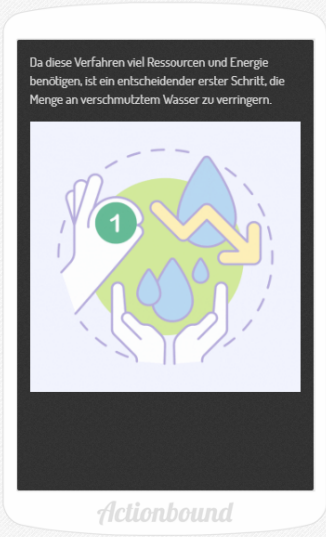
Information

[Information block]

In this experiment, we used a simple filter system based on size.

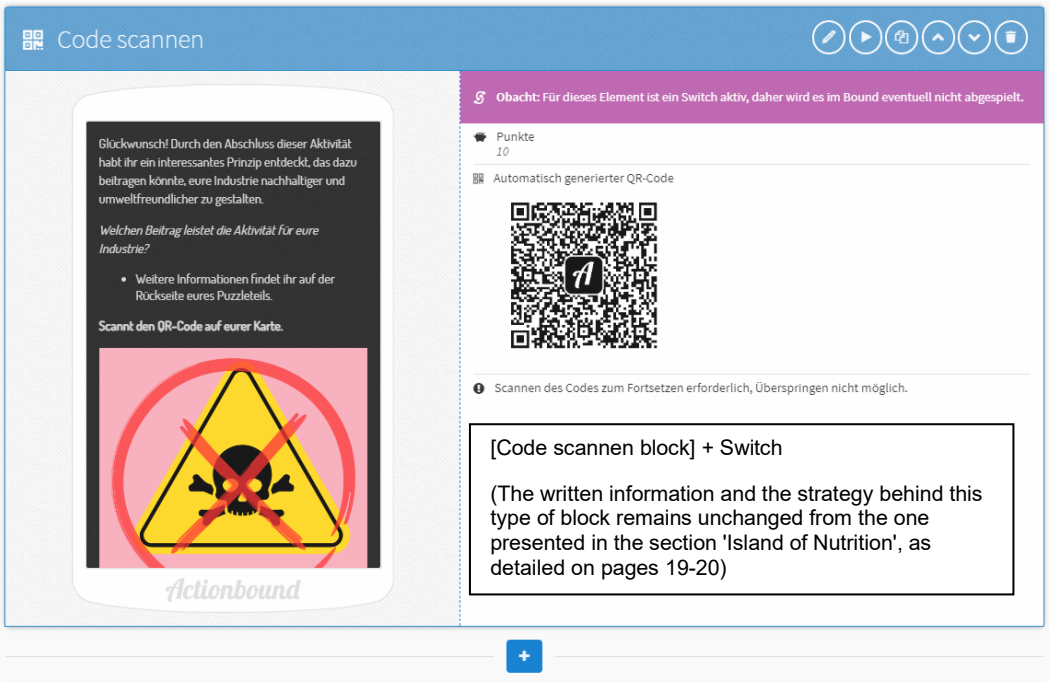
There are many more advanced methods in everyday water treatment that were not used here to ensure that the water is safe to drink.

Information



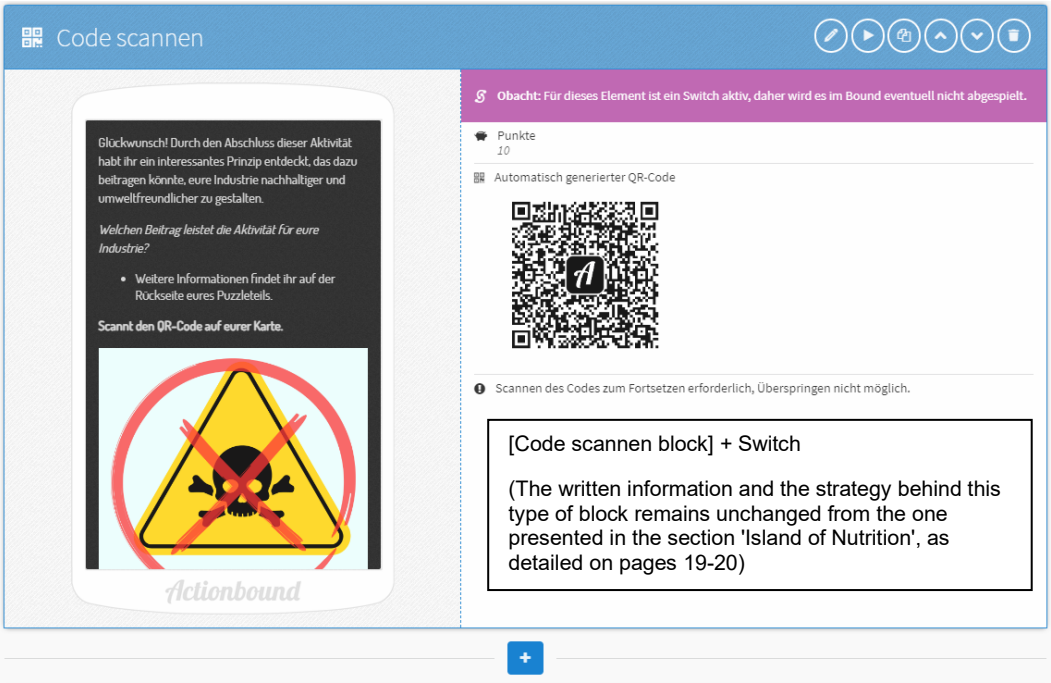
[Information block]

Since these processes require a lot of resources and energy, a crucial first step is to reduce the amount of polluted water.



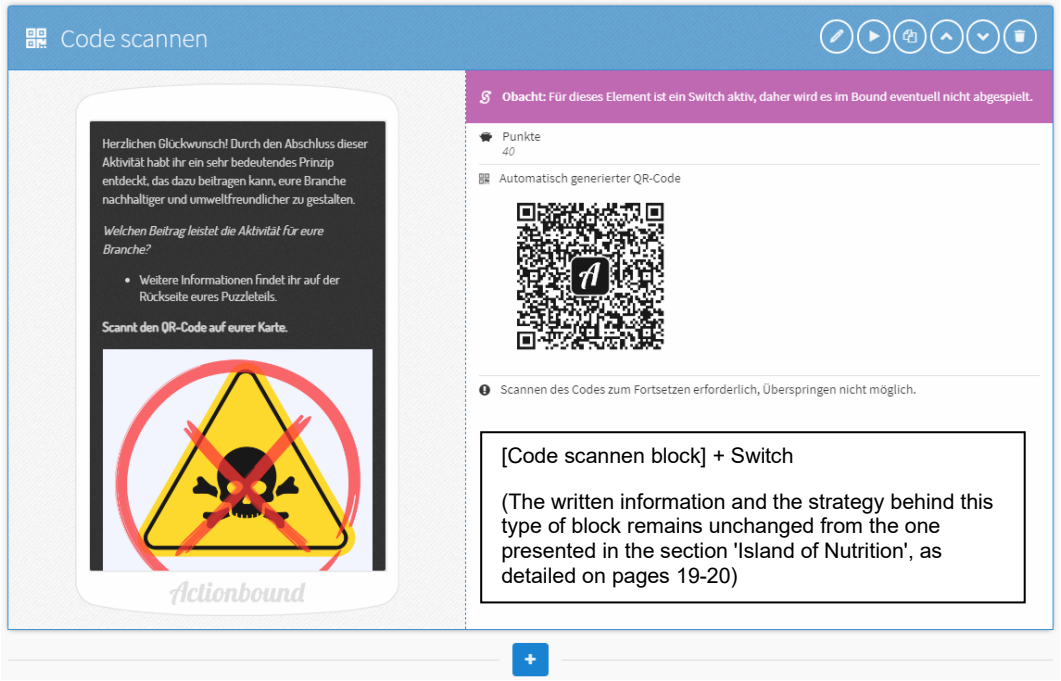
[Code scannen block] + Switch

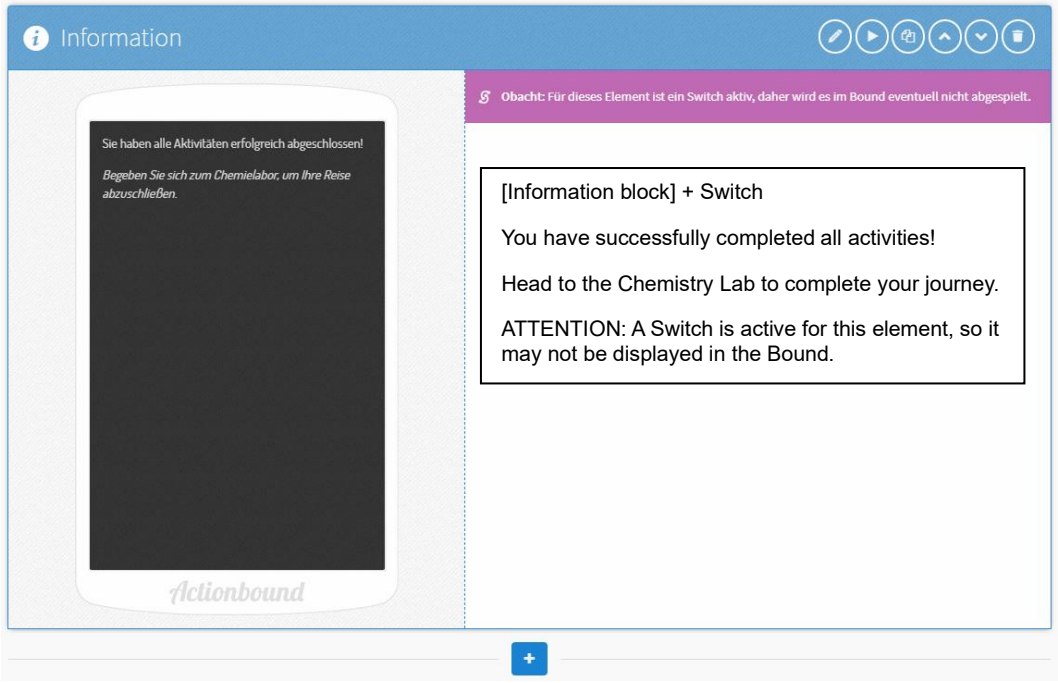
(The written information and the strategy behind this type of block remains unchanged from the one presented in the section 'Island of Nutrition', as detailed on pages 19-20)



[Code scannen block] + Switch

(The written information and the strategy behind this type of block remains unchanged from the one presented in the section 'Island of Nutrition', as detailed on pages 19-20)





Switch[15]

[15] This switch was incorporated to ensure that the information is presented to participants after they complete all the islands. Upon finishing the digital game, participants are directed to the chemical laboratory, which serves as the initial meeting point. Once all groups have gathered, we will proceed together to the starting area of the game for the final activity: The Final Puzzle.

7.2 Chemical Experiments.

7.2.1 Bio-battery.

Biobatterie

Material:

- 4 Bechergläser 250mL
- 4 Krokodilkabel
- Multimeter

Chemikalien:

- Gartenerde
- Kupfer Elektrode (hellbraun gefärbt)
- Zink Elektrode (silber gefärbt)
- Leitungswasser

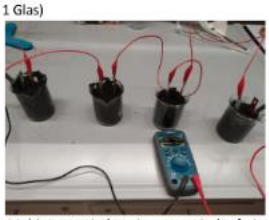
Durchführung:

(Die Bechergläser sind bereits mit Erde gefüllt.)

1. Nimm ein Becherglas und zwei Elektroden (einmal Zink und einmal Kupfer).
2. Stecke beide Elektroden durch den nicht perforierten Teil in der Erde.
3. Schalte das Multimeter ein:

4. Messe die Spannung zwischen den beiden Elektroden (das schwarze Kabel geht zur Zinkelektrode und das rote Kabel zur Kupferelektrode). Wie hoch ist sie?

5. Nimm ein weiteres Becherglas und stecke zwei frische Elektrode (einmal Zink und Einmal Kupfer) in der Erde.
6. Nimm ein Krokodile Kabel und verbinde eine Kupferelektrode einer Batterie mit der Zinkelektrode der anderen Batterie (Wenn du möchtest, kannst du auch mehrere Batterien in Reihe verbinde).
   (1 Batterie = 1 Glas)



7. Verbinde das Multimeter wieder wie zuvor mit der freien Zinkelektrode und der freien Kupferelektrode (diese befinden sich jetzt nicht mehr in ein und demselben Glas). Messe nun die Spannung.
8. Schalte den Multimeter aus, wenn alle Messungen abgeschlossen sind.

Entsorgung

1. Ziehe alle Elektroden heraus und spüle sie mit Wasser ab. Trockne sie anschließend mit einem Papiertuch.

Bio-battery

Material:

- 4 beakers 250mL
- 4 crocodile cables
- Multimeter

Chemicals:

- Garden soil
- Copper electrode (coloured light brown)
- Zinc electrode (colored silver)
- Tap water

Procedure:

(The beakers are already filled with soil.)

1. Take a beaker and two electrodes (one zinc and one copper).
2. Insert both electrodes through the non-perforated part in the soil.
3. Switch on the multimeter:
4. Measure the voltage between the two electrodes (the black cable goes to the zinc electrode, and the red cable goes to the copper electrode). How high is it?
5. Take another beaker and put two fresh electrodes (one zinc and one copper) in the soil.
6. Take a crocodile cable and connect the copper electrode of one battery to the zinc electrode of the other battery (if you want, you can also connect several batteries in series).
   (1 battery = 1 glass)
7. Reconnect the multimeter to the free zinc electrode and the free copper electrode as before (these are no longer in the same glass). Now, measure the voltage.
8. Turn off the multimeter when all measurements are complete.

Disposal:

1. Remove all electrodes and rinse them with water. Then, dry them with a paper towel.

7.2.2 Mini sewage treatment plant.

Mini-Kläranlage

Material:

- 4 Bechergläser 400 mL
- Spatellöffel
- Stativ mit Ring
- Trichter
- Filterpapier
- Spritze
- Membran aus Kunststoff

Chemikalien:

- Flasche mit destilliertem Wasser
- Gartenerde

Durchführung:

1. Fülle ein Becherglas zur Hälfte mit Wasser. Gib einen Löffel Gartenerde in das Glas und rühre um.
2. Lege das Teesieb auf ein leeres Becherglas. Gieße das verschmutze Wasser durch das Sieb. Beobachte: Ist das gesiebte Wasser sauberer?
3. Falte den Rundfilter und stecke ihn in den Trichter. Stelle ein leeres Becherglas unter den Trichter. Nimm das Glas mit dem gesiebten Wasser. Gieße das Wasser durch den Filter. Beobachte wieder: Ist das filtrierte Wasser sauberer?
4. Nimm nun die Spritze und fülle sie mit einem Teil des filtrierten Wassers. Stecke die Kunststoff-Membran mit der weißen Seite fest auf die Spritze. Drücke das Wasser langsam durch die Membran in ein leeres Becherglas. Wie sieht das Wasser nun aus?

Entsorgung:

1. Wirf den Filter in den Abfalleimer.
2. Gieße die Flüssigkeiten in den Abfluss

Mini sewage treatment plant

Material:

- 4 beakers 400 mL
- Spatula spoon
- Tripod with ring
- Funnel
- Filter paper
- Syringe
- Plastic membrane

Chemicals:

- Bottle with distilled water
- Garden soil

Procedure:

1. Fill a beaker halfway with water. Put a spoonful of garden soil in the glass and stir.
2. Place the tea strainer on an empty beaker. Pour the dirty water through the sieve. Observe: Is the sieved water cleaner?
3. Fold the round filter and put it in the funnel. Place an empty beaker under the funnel. Take the glass with the sieved water. Pour the water through the filter. Observe again: Is the filtered water cleaner?
4. Now, take the syringe and fill it with some of the filtered water. Put the plastic membrane with the white side firmly onto the syringe. Slowly press the water through the membrane into an empty beaker. What does the water look like now?

Disposal:

1. Throw the filter in the trash can.
2. Pour the liquids down the drain

7.2.3 Sorting plastics.

Kunststoffe sortieren

Material:

- Erlenmeyer 50mL (Weithals)
- Spatellöffel
- Glasstab
- Pinzette
- Kristallisierschale

Chemikalien:

- Kunststoffproben
- Destilliertes Wasser
- Kochsalz

Durchführung:

1. Fülle etwa 40 mL destilliertes Wasser in den Erlenmeyerkolben. Gib die Kunststoffprobe dazu, schwenke den Kolben und stelle ihn danach ab.
2. Beobachte: Sinken alle Kunststoffe zu Boden? Schwimmen manche?
3. Fische schwimmende Kunststoffe mit der Pinzette aus dem Kolben und lege sie in der Kristallisierschale ab.
4. Gib einen Spatellöffel Kochsalz in den Kolben und schwenke oder rühre mit dem Glasstab, bis sich das Salz aufgelöst hat. Schwimmt jetzt ein weiterer Kunstsoff?
5. Löse so lange Salz im Wasser auf, bis nur noch ein Kunststoff am Boden liegt.

Entsorgung:

1. Schütte das Salzwasser mit der letzten Kunststoffprobe durch den Trichter in das Sammelgefäß.
2. Lege die anderen Kunststoffproben ebenfalls in den Trichter.

Sorting plastics

Material:

- Erlenmeyer flask 50mL (wide neck)
- Spatula spoon
- Glass rod
- Tweezers
- Crystallising dish

Chemicals:

- Plastic samples
- Distilled water
- Table salt

Procedure:

1. Fill about 40 mL of distilled water into the Erlenmeyer flask. Add the plastic sample, swirl the flask and then put it down.
2. Observe: Do all the plastics sink to the bottom? Do some float?
3. Use the tweezers to remove floating plastics from the flask and place them in the crystallising dish.
4. Put a spatula spoon of table salt into the flask and swirl or stir with the glass rod until the salt has dissolved. Is another plastic now floating?
5. Dissolve salt in the water until only one piece of plastic remains at the bottom.

Disposal:

1. Pour the salt water with the last plastic sample through the funnel into the collection container.
2. Place the other plastic samples in the funnel as well.

7.2.4 Soap and water hardness.

Seife und Wasserhärte

Material:

- 4 Erlenmeyerkolben 250 mL
- Pipette
- Pinzette

Chemikalien:

- Destilliertes Wasser
- Isarwasser
- Leitungswasser
- Mineralwasser
- Soda
- Seifenflocken

Durchführung:

1. Gebe den gesamten Inhalt der Wasserflaschen in die entsprechenden Erlenmeyerkolben:
   - Erlenmeyer 1: Destilliertes Wasser
   - Erlenmeyer 2: Isarwasser
   - Erlenmeyer 3: Leitungswasser
   - Erlenmeyer 4: Mineralwasser
2. Füge in jeden Erlenmeyer die gleiche Menge Seife hinzu (ungefähr 2-3 Seifenflocken, nehmen Sie sie mit der Pinzette).
3. Schüttle Sie jeden Erlenmeyerkolben, bis sich Schaum bildet. Wo gibt es mehr Schaum? Wie sieht das Wasser in jedem Erlenmeyer aus?
4. Gebe nun allen Erlenmeyer ohne Schaum etwa 2 ml Soda hinzu. Was ist jetzt passiert?

Entsorgung

1. Gieße das Wasser in den Abfluss.

Soap and water hardness

Material:

- 4 Erlenmeyer flasks 250 mL
- Pipette
- Tweezers

Chemicals:

- Distilled water
- Isar water
- Tap water
- Mineral water
- Soda
- Soap flakes

Procedure:

1. Pour the entire contents of the water bottles into the corresponding Erlenmeyer flasks:
   - Erlenmeyer 1: Distilled water
   - Erlenmeyer 2: Isar water
   - Erlenmeyer 3: Tap water
   - Erlenmeyer 4: Mineral water
2. Add the same amount of soap to each Erlenmeyer (about 2-3 soap flakes, take them with the tweezers).
3. Shake each Erlenmeyer flask until foam forms. Where is there more foam? What does the water in each Erlenmeyer look like?
4. Now add about 2 ml of soda to all Erlenmeyer flasks without foam. What has happened now?

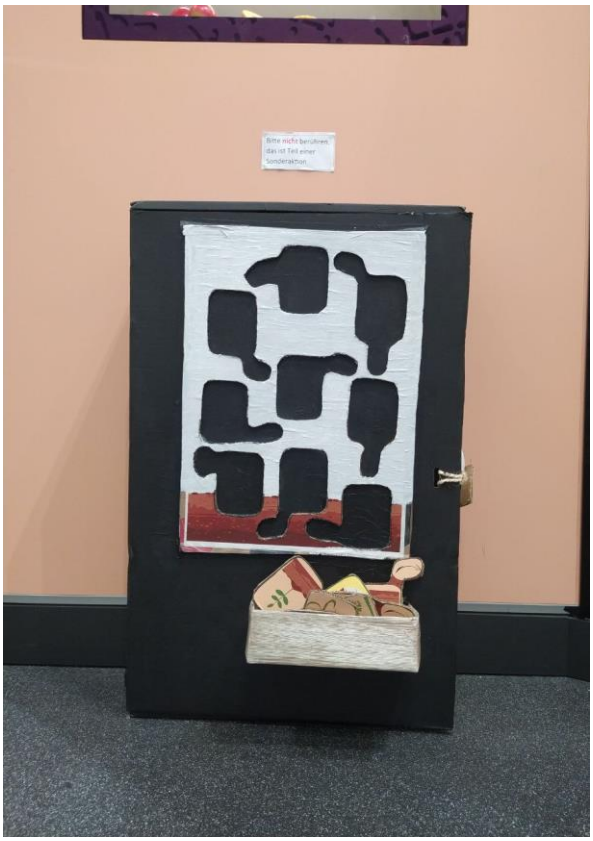
Disposal:

1. Pour the water down the drain.

7.3 Supplementary Material[16]

7.3.1 Additional Materials for the Exhibition Activities.

7.3.1.1 The Island of Nourishment Activity.

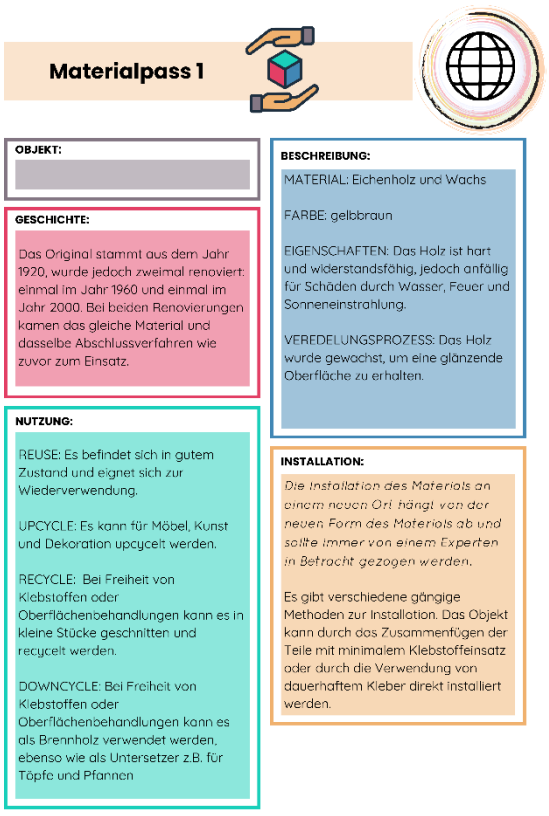


On the right, a picture showing the puzzle design from the Nourishment Island that participants need to assemble in sections to explore various cycles of food waste. On the left, a picture depicting the puzzle as installed in the exhibition, offering insight into how this supplementary material was arranged in the exhibition space.

[16] All the designs were originally created by the author using the online graphic design tool Canva.

7.3.1.2 The Island of Construction Activity.

This image displays the design of an old building slated for demolition. Specific sections of the building are highlighted to represent various materials. Material passports have been created to facilitate the salvage of these materials, although the passports do not name the materials explicitly. Participants must match the highlighted sections to their corresponding material passports.



Material Passport 1

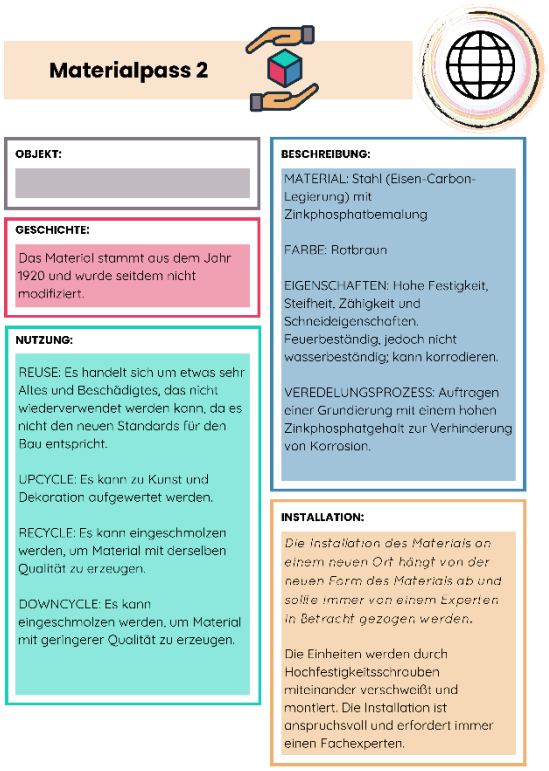
OBJECT

HISTORY: The original dates back to 1920 but has been renovated twice: once in 1960 and once in 2000. Both renovations used the same material and finishing process as before.

DESCRIPTION: MATERIAL: Oak wood and wax COLOUR: yellow-brown PROPERTIES: The wood is hard and resistant but vulnerable to damage from water, fire and sunlight. FINISHING PROCESS: The wood has been waxed to give it a glossy finish.

USE: REUSE: It is in good condition and suitable for reuse. UPCYCLE: It can be upcycled for furniture, art and decoration. RECYCLE: If free from adhesives or surface treatments, it can be cut into small pieces and recycled. DOWNCYCLE: When free from adhesives or surface treatments, it can be used as firewood, as well as a trivet for pots and pans, for example.

INSTALLATION: The installation of the material in a new location depends on the new shape of the material and should always be considered by an expert. There are several common methods of installation. The object can be installed directly by joining the parts together with minimal use of adhesive or by using permanent glue.



Material Passport 2

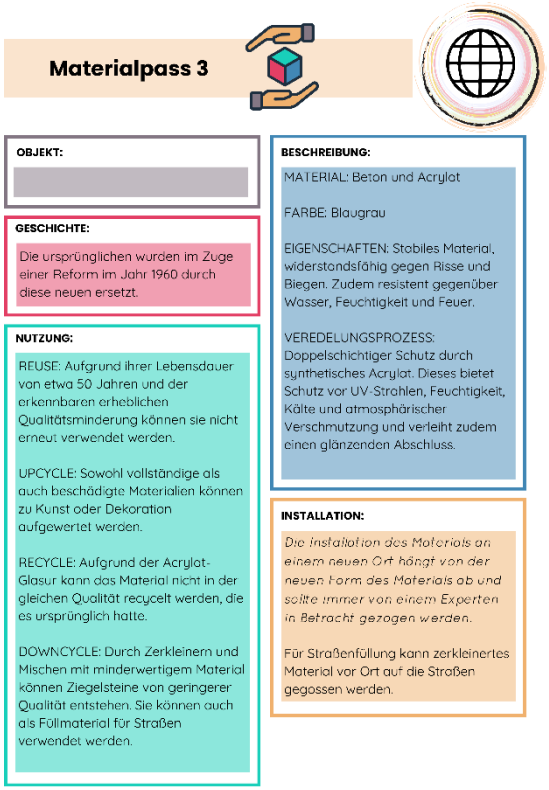
OBJECT

HISTORY: The material dates back to 1920 and has not been modified since then.

DESCRIPTION: MATERIAL: Steel (iron-carbon alloy) with zinc phosphate coating COLOUR: Red-brown PROPERTIES: High strength, stiffness, toughness and cutting properties. Fire resistant but not water resistant; may corrode. FINISHING PROCESS: Applying a primer with a high zinc phosphate content to prevent corrosion.

USE: REUSE: It is something very old and damaged that cannot be reused because it does not meet the new standards for construction. UPCYCLE: It can be upgraded to art and decoration. RECYCLE: It can be melted down to produce material of the same quality. DOWNCYCLE: It can be melted down to produce lower-quality material.

INSTALLATION: Installation of the material in a new location depends on the new shape of the material and should always be considered by an expert. The units are welded and assembled together by high-strength bolts. Installation is challenging and always requires a professional expert.



Material Passport 3

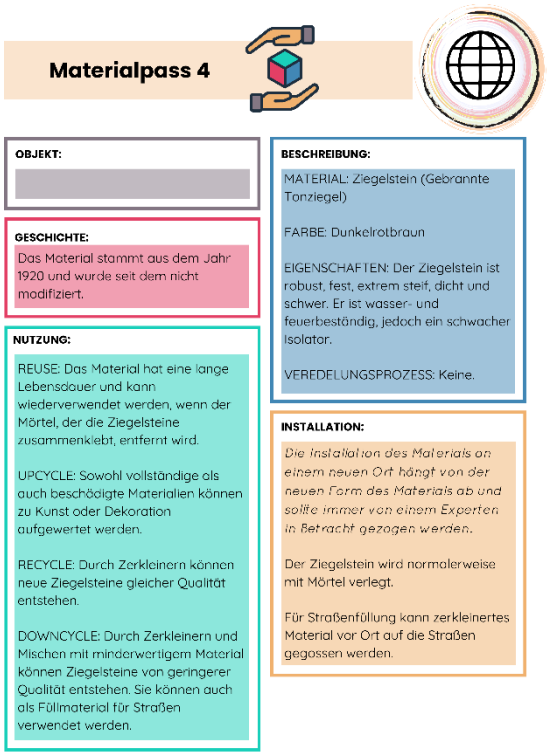
OBJECT

HISTORY: The original ones were replaced by these new ones during a reform in 1960.

DESCRIPTION: MATERIAL: Concrete and acrylate COLOUR: Blue-grey PROPERTIES: Stable material, resistant to cracking and bending. Also resistant to water, moisture and fire. FINISHING PROCESS: Double-layer protection with synthetic acrylate. This offers protection against UV rays, moisture, cold and atmospheric pollution and also gives a glossy finish.

USE: REUSE: Due to their lifespan of around 50 years and the noticeable significant deterioration in quality, they cannot be used again. UPCYCLE: Both complete and damaged materials can be upgraded to become art or decoration. RECYCLE: Due to the acrylic glaze, the material cannot be recycled in the same quality it originally had. DOWNCYCLE: Crushing and mixing with inferior material can result in lower-quality bricks. They can also be used as filler for roads.

INSTALLATION: Installation of the material in a new location depends on the new shape of the material and should always be considered by an expert. The units are welded and assembled together by high-strength bolts. Installation is challenging and always requires a professional expert.



Material Passport 4

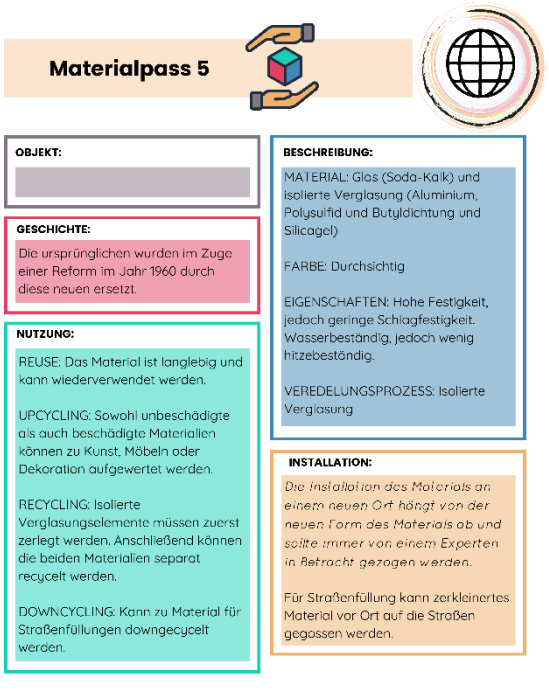
OBJECT

HISTORY: The material dates back to 1920 and has not been modified since then.

DESCRIPTION: MATERIAL: Brick (Burnt clay brick) COLOUR: Dark red-brown PROPERTIES: The brick is robust, strong, extremely rigid, dense and heavy. It is water and fire resistant, but a weak insulator. FINISHING PROCESS: None.

USE: REUSE: The material has a long lifespan and can be reused if the mortar that binds the bricks together is removed. UPCYCLE: Both complete and damaged materials can be upcycled into art or decoration. RECYCLE: Crushing can create new bricks of the same quality. DOWNCYCLE: Crushing and mixing with inferior material can create bricks of lower quality. They can also be used as filler for roads.

INSTALLATION: Installation of the material in a new location depends on the new shape of the material and should always be considered by an expert. The units are welded and assembled together by high-strength bolts. Installation is challenging and always requires a professional expert.



Material Passport 5

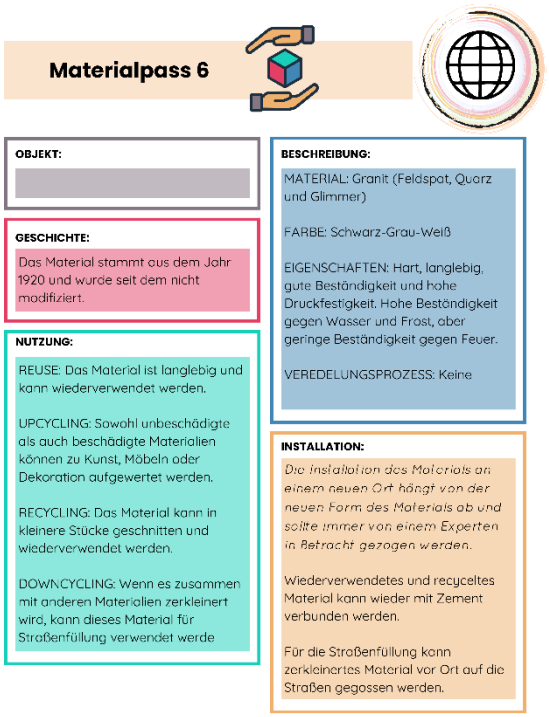
OBJECT

HISTORY: The original ones were replaced by these new ones during a reform in 1960.

DESCRIPTION: MATERIAL: Glass (soda-lime) and insulated glazing (aluminium, polysulphide and butyl sealant and silica gel). COLOUR: Transparent PROPERTIES: High strength but low impact resistance. Water resistant but low heat resistance. FINISHING PROCESS: Insulated glazing.

USE: REUSE: The material is durable and can be reused. UPCYCLING: Both undamaged and damaged materials can be upcycled into art, furniture or decoration. RECYCLING: Insulated glazing elements must first be dismantled. Then, the two materials can be recycled separately. DOWNCYCLING: Can be downcycled into material for road fill.

INSTALLATION: Installation of the material in a new location depends on the new form of the material and should always be considered by an expert. For road filling, crushed material can be poured onto the roads on site.



Material Passport 6

OBJECT

HISTORY: The material dates back to 1920 and has not been modified since then.

DESCRIPTION: Granite (feldspar, quartz and mica) COLOUR: Black-Gray-White PROPERTIES: Hard, durable, good resistance and high compressive strength. High resistance to water and frost but low resistance to fire. FINISHING PROCESS: None

USE: REUSE: The material is durable and can be reused. UPCYCLING: Both undamaged and damaged materials can be upcycled into art, furniture or decoration. RECYCLING: The material can be cut into smaller pieces and recycled. DOWNCYCLING: When shredded together with other materials, this material can be used for road fill.

INSTALLATION: Installation of the material in a new location depends on the new form of the material and should always be considered by an expert. Reused and recycled material can be re-bonded with cement. For road fill, crushed material can be poured on-site onto the roads.

Material Passport 7

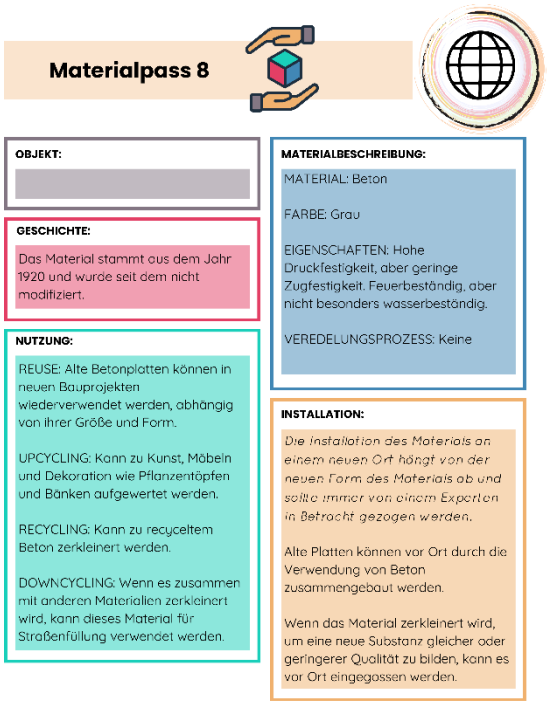
OBJECT

HISTORY: This material was installed in 1990.

DESCRIPTION: MATERIAL: Nylon, dye and adhesive. COLOUR: Red PROPERTIES: Soft, durable and resistant to stains and abrasion. Good resistance to wear, mould, mildew and rot. FINISHING PROCESS: Dyed red

USE: REUSE: Reuse is not possible due to its deterioration. UPCYCLING: The material can be upcycled into art, furniture and decorations, such as small rugs, chair covers, kitchen mats... RECYCLING: If the adhesive is properly removed, the old fibres can be broken down and used to make the same product. DOWNCYCLING: If the adhesive is difficult to remove, the quality of the new product will be compromised, but the material can still be used for lower-quality products.

INSTALLATION: Installation of the material in a new location depends on the new shape of the material and should always be considered by an expert. There are several common methods for installation. The material can be stretched over grippers, attached with double-sided tape or directly attached with permanent adhesive.



Material Passport 8

OBJECT

HISTORY: The material dates back to 1920 and has not been modified since then.

DESCRIPTION: MATERIAL: Concrete COLOUR: Grey PROPERTIES: High compressive strength but low tensile strength. Fire resistant but not particularly water resistant. FINISHING PROCESS: None

USE: REUSE: REUSE: Old concrete slabs can be reused in new construction projects, depending on their size and shape. UPCYCLING: It can be upcycled into art, furniture, and decoration such as plant pots and benches. RECYCLING: It can be crushed into recycled concrete. DOWNCYCLING: When crushed together with other materials, this material can be used for road fill.

INSTALLATION: Installation of the material in a new location depends on the new form of the material and should always be considered by an expert. Old slabs can be assembled on-site using concrete. If the material is crushed to form a new substance of equal or lesser quality, it can be cast on-site.

MATERIAL	NEUE ANWENDUNG

On the right, there is an image of the final form that participants need to complete, specifying the new uses for salvaged materials from the old building in a hypothetical new construction. On the left, there is an image of supplementary materials displayed in the exhibition.

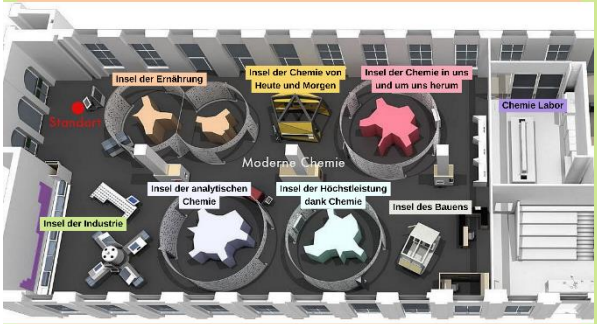
7.3.2 Additional Materials for Participants to Collect.

7.3.2.1 The Industry Cards.

EURE INDUSTRIE:

LEBENSMITTEL *und*
LANDWIRTSCHAFT

EURE KARTE:



EURE ROUTE:

1. Insel der Chemie von Heute und Morgen
2. Insel der Höchstleistung dank Chemie
3. Insel der Ernährung

AKTUELLE PROBLEME DIESER INDUSTRIE IM HINBLICK AUF DIE UMWELT:

Unser heutiges Essen-System hat einige große Probleme, die sowohl der Natur als auch vielen Menschen schaden. Einer der Hauptgründe dafür liegt in der intensiven Monokultur-Landwirtschaft. Auf den Feldern werden allzu oft schädliche Stoffe wie Pestizide und Dünger eingesetzt, die nicht nur die Umwelt verschmutzen, sondern auch zum Aussterben zahlreicher Tier- und Pflanzenarten führen, die für unser Ökosystem von entscheidender Bedeutung sind.

Obwohl moderne Landwirtschaft uns geholfen hat, mehr Essen zu produzieren, wird es oft nicht auf eine umweltfreundliche Weise gemacht. Zusätzlich werfen wir fast ein Drittel der Lebensmittel weg, die wir produzieren. Es ist wichtig zu erkennen, dass trotz der Fortschritte in der Lebensmittelproduktion fast 10% der Menschen weltweit nicht ausreichend zu essen haben. Dies ist eine traurige Realität.

YOUR INDUSTRY:

FOOD & AGRICULTURE

YOUR MAP:

YOUR ROUTE:

1. Island of Chemistry of Today and Tomorrow
2. Island of High-Performance Thanks to Chemistry
3. Island of Nourishment

CURRENT ENVIRONMENTAL PROBLEMS OF THIS INDUSTRY:

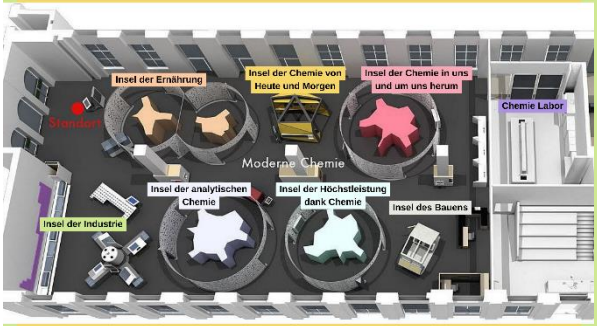
Our current food system has some major problems that are damaging both nature and many people. One of the main reasons for this is intensive monoculture farming. Too often, harmful substances such as pesticides and fertilizers are used in the fields, which not only pollute the environment but also lead to the extinction of numerous animal and plant species that are vital to our ecosystem.

Although modern farming has helped us produce more food, it is often not done in an environmentally friendly way. In addition, we throw away almost a third of the food we produce. It is important to recognise that despite advances in food production, almost 10% of people worldwide do not have enough to eat. This is a sad reality.

EURE INDUSTRIE:

ELEKTRONIK und ENERGIE

EURE KARTE:



EURE ROUTE:

1. Insel der Höchstleistung dank Chemie
2. Insel des Bauens
3. Insel der Chemie von Heute und Morgen

AKTUELLE PROBLEME DIESER INDUSTRIE IM HINBLICK AUF DIE UMWELT:

Unsere heutige Energie- und Elektronikindustrie steht vor großen Problemen. Sowohl bei der Herstellung von Energie als auch bei der Produktion elektronischer Geräte geht es um den Abbau fossiler Brennstoffe und Mineralien. Das verursacht nicht nur Umweltschäden, sondern führt auch zu Konflikten zwischen verschiedenen Gruppen.

Ein weiteres großes Problem ist der Elektroschrott, der am Ende des Lebenszyklus elektronischer Produkte entsteht. Dieser Schrott setzt gefährliche Gase frei, die sowohl Menschen als auch der Umwelt schaden können. Leider landet dieser Müll oft auf riesigen Deponien, meist in ärmeren Ländern.

Besorgniserregend ist zudem, dass viele dieser Produkte bewusst so konzipiert sind, dass sie kürzer halten, als sie könnten. Unsere Industrie fördert unsere Konsumkultur und ermutigt uns dazu, elektronische Geräte wegzuwerfen und neue zu kaufen, anstatt sie zu reparieren oder wiederzuverwenden.

YOUR INDUSTRY:

ELECTRONICS & ENERGY

YOUR MAP:

YOUR ROUTE:

1. Island of High-Performance Thanks to Chemistry
2. Island of Construction
3. Island of Chemistry of Today and Tomorrow

CURRENT ENVIRONMENTAL PROBLEMS OF THIS INDUSTRY:

Our energy and electronics industries today are facing major problems. Both the production of energy and the production of electronic devices involve the mining of fossil fuels and minerals. This not only causes environmental damage but also leads to conflicts between different groups.

Another major problem is the e-waste that is created at the end of the life cycle of electronic products. This waste releases dangerous gases that can harm both people and the environment. Unfortunately, this waste often ends up in huge landfills, mostly in poorer countries.

What is also worrying is that many of these products are deliberately designed to last less time than they could. Our industry promotes our consumer culture and encourages us to throw away electronic devices and buy new ones instead of repairing or reusing them.

EURE INDUSTRIE:

HYGIENE und GESUNDHEIT

EURE KARTE:

EURE ROUTE:

1. Insel des Bauens
2. Insel der analytischen Chemie
3. Insel der Chemie in uns und um uns herum

AKTUELLE PROBLEME DIESER INDUSTRIE IM HINBLICK AUF DIE UMWELT:

Unsere heutige Hygiene- und Gesundheitsindustrie steht vor bedeutenden Herausforderungen, um in eine nachhaltige Zukunft beitragen zu können. Viele ihrer Produkte, wie Seifen und Reinigungsmittel, verschmutzen das Wasser mit schwer abbaubaren Stoffen. Das ist nicht nur schlecht für die Umwelt, sondern kann auch unsere Gesundheit beeinträchtigen.

Ein weiteres Problem ist das lineare Wirtschaftsmodell, das in diesem Sektor fest verankert ist und den Einsatz von Einwegprodukten fördert, obwohl deren hygienische Notwendigkeit nicht immer gegeben ist. Diese Einwegprodukte gelangen oft in unsere Ozeane und tragen erheblich zum Verlust der Artenvielfalt bei. Darüber hinaus ist die Müllproblematik in diesem Sektor besonders kritisch, wenn man bedenkt, dass er nach dem Bau- und der Lebensmittelbranche der größte Verbraucher von Rohstoffen ist.

YOUR INDUSTRY:

HYGIENE & HEALTH

YOUR MAP:

YOUR ROUTE:

1. Island of Construction
2. Island of Analytical Chemistry
3. Island of Chemistry In and Around Us

CURRENT ENVIRONMENTAL PROBLEMS OF THIS INDUSTRY:

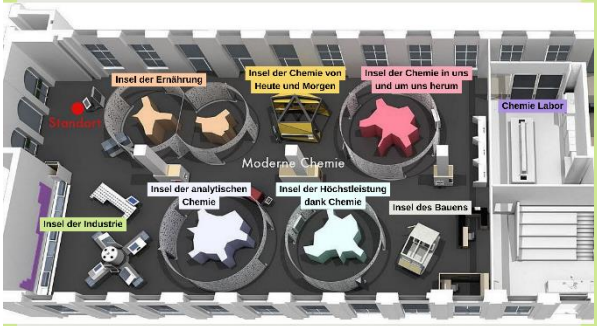
Our current hygiene and health industry faces significant challenges in contributing to a sustainable future. Many of its products, such as soaps and detergents, pollute the water with substances that are difficult to degrade. This is not only bad for the environment but can also affect our health.

Another problem is the linear economic model that is firmly anchored in this sector, which encourages the use of disposable products, even though their hygienic necessity is not always present. These disposable products often end up in our oceans and contribute significantly to the loss of biodiversity. In addition, the waste problem in this sector is particularly critical considering that it is the largest consumer of raw materials after the construction and food sectors.

EURE INDUSTRIE:

BAU und URBANPLANUNG

EURE KARTE:



EURE ROUTE:

1. Insel der Chemie in uns und um uns herum
2. Insel der Chemie von Heute und Morgen
3. Insel des Bauens

AKTUELLE PROBLEME DIESER INDUSTRIE IM HINBLICK AUF DIE UMWELT:

Die Bauindustrie verbraucht enorme Mengen an Rohstoffen und hat bedeutende Auswirkungen auf die Umwelt. Viele Bauprojekte werden oft aus spekulativen Gründen durchgeführt, manchmal sogar ohne wirkliche Nutzung, was zu verlassenen Städten führen kann. Besonders bedauerlich ist, dass gleichzeitig viele Menschen auf der Welt keinen angemessenen Wohnraum finden können.

Noch besorgniserregender ist, dass viele der wertvollen Baumaterialien, die im Bauwesen verwendet werden, nicht richtig recycelt werden, da Gebäude am Ende ihrer Lebensdauer oft abgerissen werden. Gebäude bestehen aus verschiedenen Materialien wie Beton, Holz, Glas, Kunststoff und Metall. Die Zerstörung und Entsorgung dieser Materialien trägt erheblich zur Umweltverschmutzung und Ressourcenknappheit bei, was sowohl Umwelt- als auch soziale Probleme verschärft.

YOUR INDUSTRY:

CONSTRUCTION & URBAN PLANNING

YOUR MAP:

YOUR ROUTE:

1. Island of Chemistry In and Around Us
2. Island of Chemistry of Today and Tomorrow
3. Island of Construction

CURRENT ENVIRONMENTAL PROBLEMS OF THIS INDUSTRY:

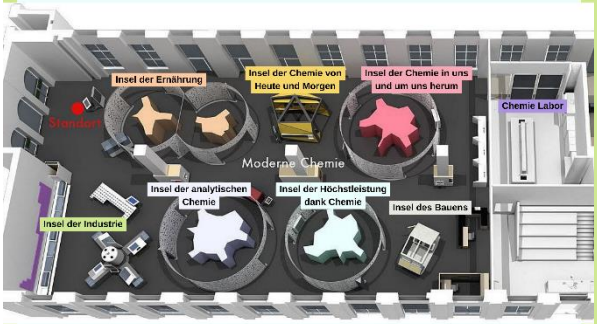
The construction industry consumes enormous amounts of raw materials and has a significant impact on the environment. Many construction projects are often undertaken for speculative reasons, sometimes even without any real use, which can lead to abandoned cities. What is particularly unfortunate is that, at the same time, many people in the world cannot find adequate housing.

Even more worrying is that many of the valuable building materials used in construction are not properly recycled, as buildings are often demolished at the end of their life. Buildings are made of various materials, such as concrete, wood, glass, plastic and metal. The destruction and disposal of these materials contribute significantly to pollution and resource scarcity, exacerbating both environmental and social problems.

EURE INDUSTRIE:

POLYMEREN und KUNSTSTOFFE

EURE KARTE:



EURE ROUTE:

1. Insel der analytischen Chemie
2. Insel der Ernährung
3. Insel der Höchstleistung dank Chemie

AKTUELLE PROBLEME DIESER INDUSTRIE IM HINBLICK AUF DIE UMWELT:

Die Polymer- und Kunststoffherstellungsindustrie ist eine der bedeutendsten in unserer modernen Gesellschaft. Von Verpackungen für Essen und Shampoo bis hin zu Computern, Handys und sogar Autos, Flugzeugen und Satelliten – Plastik ist überall. Diese Produkte sind äußerst vielseitig, kostengünstig und einfach herzustellen, weshalb sie von unschätzbarem Wert sind. Gleichzeitig stellen sie jedoch eine ernsthafte Bedrohung für unseren Planeten dar.

Einerseits werden die meisten dieser Produkte aus nicht erneuerbaren fossilen Rohstoffen hergestellt, was nicht nur die Umwelt verschmutzt, sondern auch soziale Konflikte verursacht. Anderseits werden diese Materialien aufgrund ihrer niedrigen Kosten nicht ausreichend recycelt, und viele von ihnen landen auf Deponien oder in den Ozeanen, was zu Verschmutzung von Boden und Wasser führt.

YOUR INDUSTRY:

POLYMERS & PLASTICS

YOUR MAP:

YOUR ROUTE:

1. Island of Analytical Chemistry
2. Island of Nourishment
3. Island of High-Performance Thanks to Chemistry

CURRENT ENVIRONMENTAL PROBLEMS OF THIS INDUSTRY:

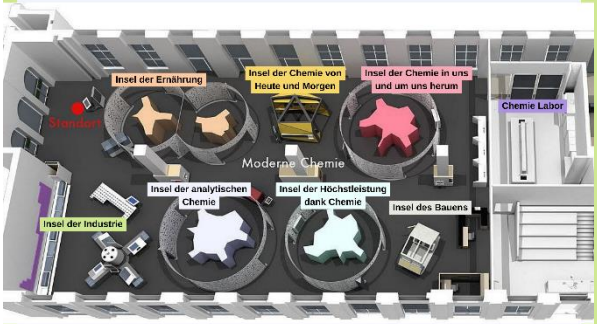
The polymer and plastic manufacturing industry is one of the most important in our modern society. From food and shampoo packaging to computers, cell phones and even cars, airplanes and satellites, plastic is everywhere. These products are extremely versatile, inexpensive and easy to manufacture, which makes them invaluable. At the same time, however, they pose a serious threat to our planet.

On the one hand, most of these products are made from non-renewable fossil raw materials, which not only pollutes the environment but also causes social conflict. On the other hand, due to their low cost, these materials are not sufficiently recycled and many of them end up in landfills or in the oceans, causing soil and water pollution.

EURE INDUSTRIE:

WASSER BEHANDLUNG

EURE KARTE:



EURE ROUTE:

1. Insel der Ernährung
2. Insel der Chemie in uns und um uns herum
3. Insel der analytischen Chemie

AKTUELLE PROBLEME DIESER INDUSTRIE IM HINBLICK AUF DIE UMWELT:

Die Wasseraufbereitungsindustrie ist für unser modernes Leben von grundlegender Bedeutung, und sauberes Wasser ist ein universelles Menschenrecht. Leider haben viele Menschen keinen Zugang, während andere es verschwenden. Diese Verschwendung ist nicht nur die Schuld des Verbrauchers. Viele Wasserversorgungssysteme, auf die die Städte unseres Planeten angewiesen sind, sind nicht kreislauforientiert.

In vielen Fällen wird Trinkwasser für unnötige Zwecke verwendet. Verunreinigtes Wasser wird nicht ordnungsgemäß behandelt und in Flüsse und Meere abgeleitet, was ein Risiko für die Umwelt darstellt. Dieses Wasser wird auch nicht wiederverwendet oder recycelt, obwohl es bei richtiger Aufbereitung und Trennung eine wertvolle Nährstoffquelle für viele Unternehmungen sein könnte.

YOUR INDUSTRY:

WATER TREATMENT

YOUR MAP:

YOUR ROUTE:

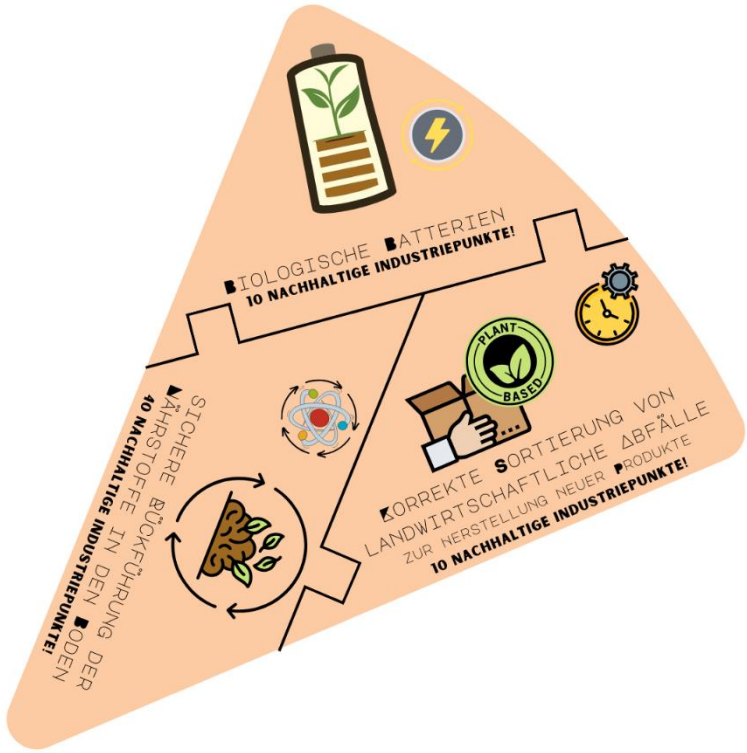
1. Island of Nourishment
2. Island of Chemistry In and Around Us
3. Island of Analytical Chemistry

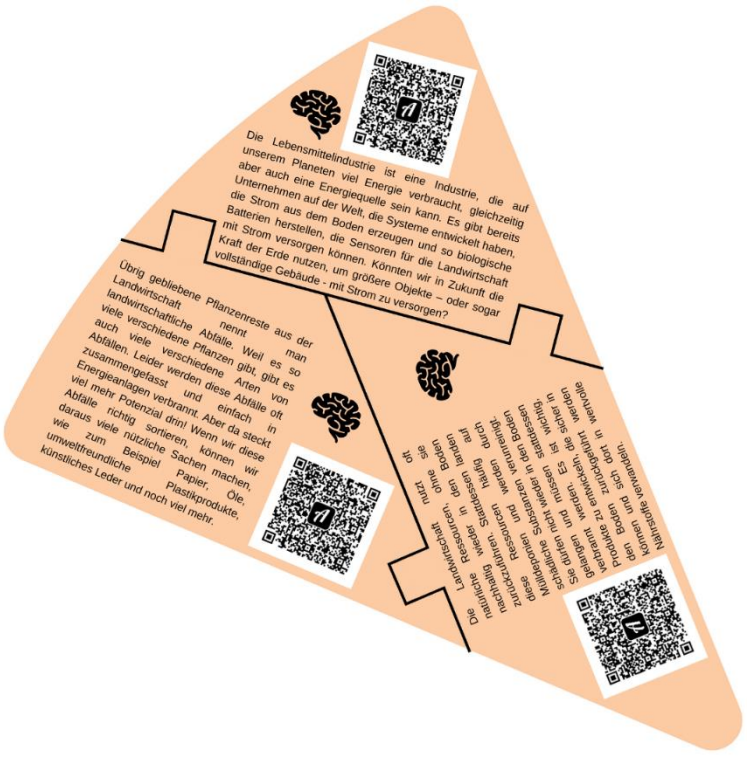
CURRENT ENVIRONMENTAL PROBLEMS OF THIS INDUSTRY:

The water treatment industry is fundamental to our modern lives, and clean water is a universal human right. Unfortunately, many people do not have access, while others waste it. This waste is not just the fault of the consumer. Many water supply systems that our planet's cities rely on are not circular.

In many cases, drinking water is used for unnecessary purposes. Contaminated water is not properly treated and discharged into rivers and seas, posing a risk to the environment. This water is also not reused or recycled, even though if properly treated and separated, it could be a valuable source of nutrients for many ventures.

7.2.3. Industry Point Cards[17].





FOOD & AGRICULTURE

BIOLOGICAL BATTERIES

10 Sustainable Industry Points

The food industry is an industry that uses a lot of energy on our planet, but at the same time it can be a source of energy. There are already companies in the world that have developed systems that generate electricity from the ground, creating biological batteries that can power sensors for agriculture. In the future, could we use the power of the earth to power larger objects - or even entire buildings?

SAFE RETURN OF NUTRIENTS TO THE SOIL

40 Sustainable Industry Points

Agriculture often uses natural resources without returning them to the soil in a sustainable way. Instead, these resources often end up in landfills and become contaminated with harmful substances. They must not be returned to the soil and must instead be burned. It is important to develop products that can be safely returned to the soil and transformed into valuable nutrients.

CORRECT SORTING OF AGRICULTURAL WASTE FOR THE PRODUCTION OF NEW PRODUCTS

10 Sustainable Industry Points

Leftover plant residues from agriculture are called agricultural waste. Because there are so many different plants, there are also many different types of waste. Unfortunately, this waste is often grouped together and simply burned in energy plants. But there is much more potential in it! If we sort this waste properly, we can make many useful things out of it, such as paper, oils, environmentally friendly plastic products, artificial leather and much more.

[17] The following cards are presented in their assembled digital design. These cards function like puzzle pieces, each contributing to a larger puzzle. Each card is placed at the location where participants complete their final island activity and contain sustainable solutions relevant to the specific industry unlocked on each island. Additionally, each card features a QR code for extra points. Note the colour of the cards, as each corresponds to its respective industry: orange for Food & Agriculture, yellow for Electronics & Energy, and so on. To simplify translation and enhance readability, the explanation included on the back side of the card is directly written beneath the specific sustainable solution presented on the front.

ELECTRONICS & ENERGY

NO ELECTRONIC WASTE

10 Sustainable Industry Points

E-waste is a serious problem in our society, so it is important to set up practical systems such as technology product collection networks, repair and reuse. Saving products from landfills is especially crucial to salvage the value of materials from improper disposal and incineration. Chemical knowledge can help us create new uses for all this garbage. Could material passports facilitate this process?

SUSTAINABLE ENERGY PRODUCTION

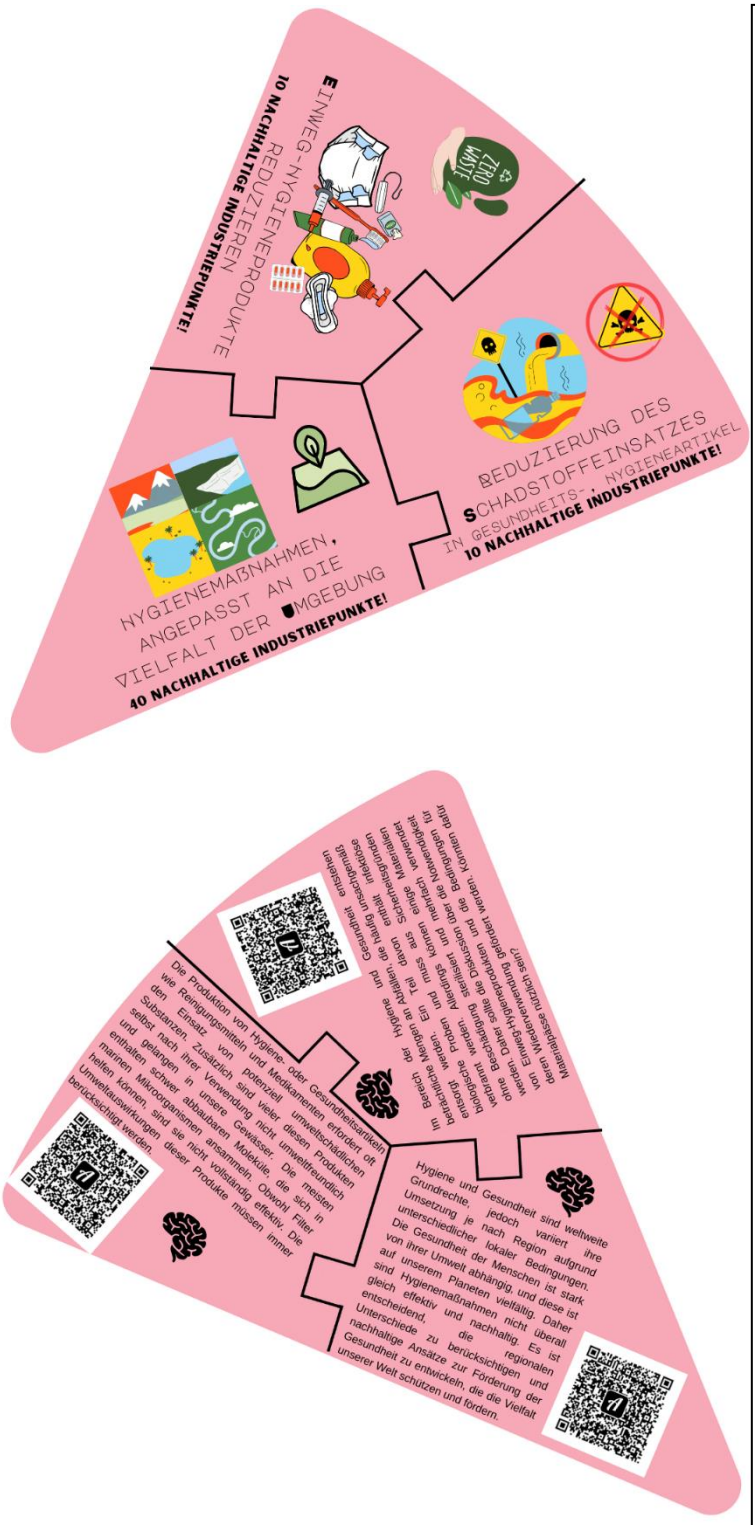
40 Sustainable Industry Points

Energy is everywhere in the world, in varying amounts. We often hear that a sustainable future requires the use of digital technologies. However, this requires the production of many electronic and energy products. If these products and the energy they require are not environmentally friendly, the digital future will not be sustainable. To generate large amounts of green energy, we need to be creative and explore new ways.

MODULAR DESIGN (ELECTRICALLY DEMOUNTABLE AND REPAIRABLE PRODUCTS)

10 Sustainable Industry Points

The electronics industry is known for producing express products with programmed obsolescence to encourage consumerism. Unfortunately, these products are not designed to last long or be easily repaired. A modular design consisting of replaceable parts or components offers the opportunity to simplify repairs and improve recycling when repair is no longer possible.



HYGIENE & HEALTH

REDUCE DISPOSABLE HYGIENE PRODUCTS

10 Sustainable Industry Points

The hygiene and health sector generates significant amounts of waste, which is often disposed of improperly. Some of it contains infectious biological samples and must be incinerated for safety reasons. However, some materials can be sterilised and used multiple times without damage. Therefore, the discussion on the need for single-use hygiene products and the conditions for their reuse should be encouraged. Could material passports be useful for this?

HYGIENE MEASURES ADAPTED TO THE DIVERSITY OF THE ENVIRONMENT

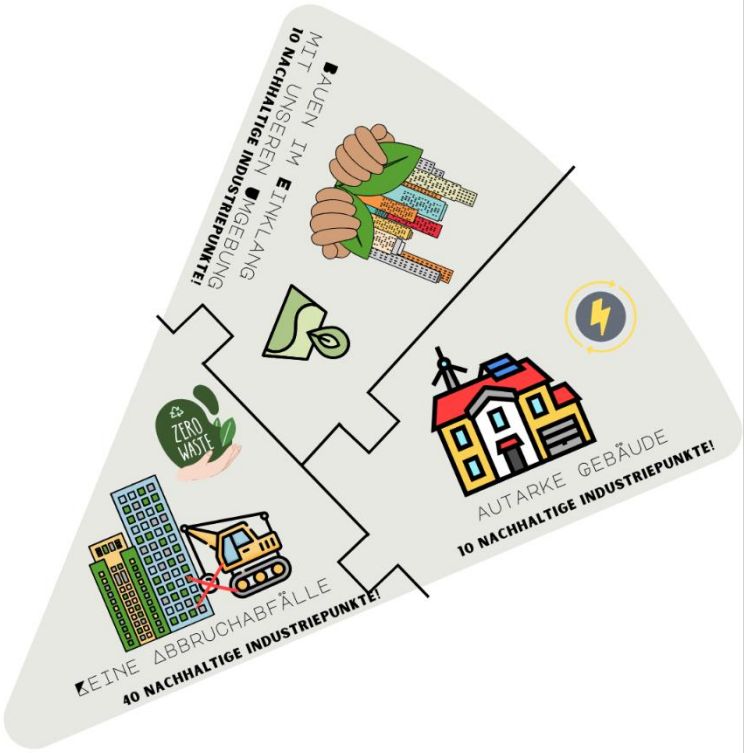
40 Sustainable Industry Points

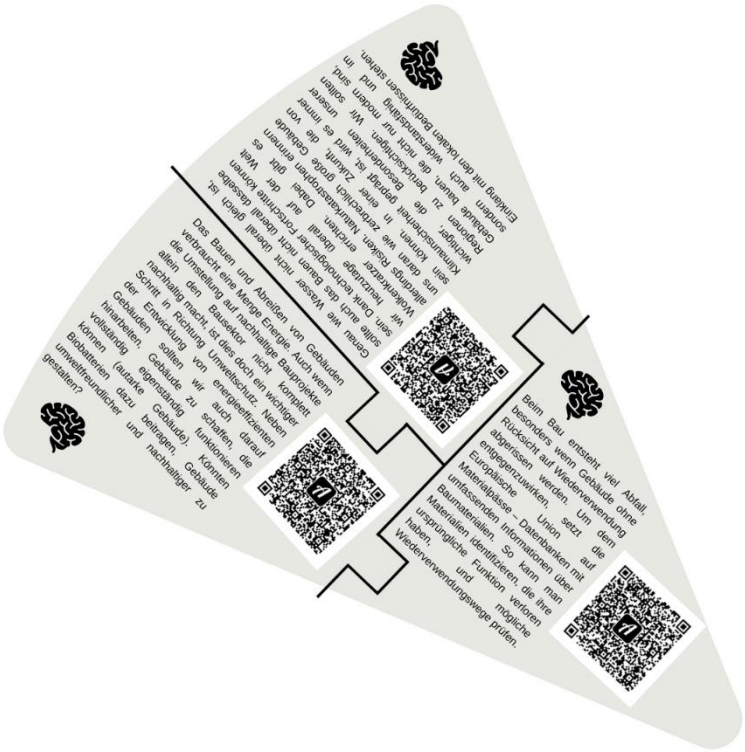
Hygiene and health are fundamental rights worldwide, but their implementation varies across regions due to different local conditions. People's health is highly dependent on their environment, and this is diverse across our planet. Therefore, hygiene measures are not equally effective and sustainable everywhere. It is crucial to take regional differences into account and develop sustainable approaches to promoting health that protect and promote the diversity of our world.

REDUCTION OF THE USE OF HARMFUL SUBSTANCES IN HEALTH AND HYGIENE PRODUCTS

10 Sustainable Industry Points

The production of hygiene or health products, such as cleaning products and medicines, often requires the use of substances that are potentially harmful to the environment. In addition, many of these products are not environmentally friendly even after use and end up in our waterways. Most contain molecules that are difficult to break down and accumulate in marine microorganisms. Although filters can help, they are not completely effective. The environmental impact of these products must always be considered.





CONSTRUCTION & URBAN PLANNING

BUILDING IN HARMONY WITH OUR ENVIRONMENT

10 Sustainable Industry Points

Just as water is not the same everywhere, construction should not be the same everywhere. Thanks to technological advances, we can now build skyscrapers anywhere in the world. But there are risks involved. Natural disasters remind us how fragile large buildings can be. In a future marked by climate uncertainty, it is increasingly important to take into account the specificities of our regions. We should build buildings that are not only modern but also resilient and in tune with local needs.

NO DEMOLITION WASTE

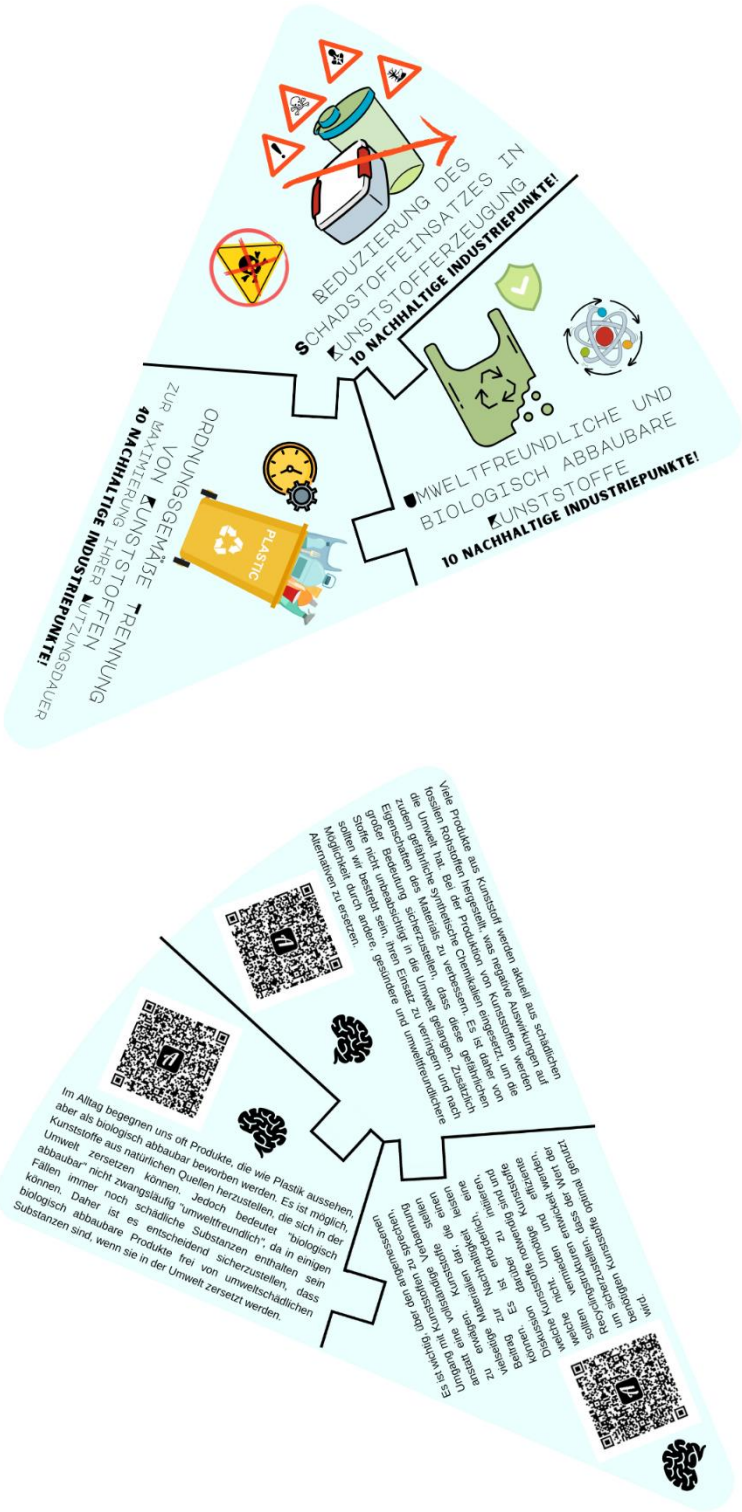
40 Sustainable Industry Points

A lot of waste is generated during construction, especially when buildings are demolished without consideration for reuse. To counteract this, the European Union is relying on material passports - databases with comprehensive information on building materials. This makes it possible to identify materials that have lost their original function and to examine possible ways of reusing them.

SELF-SUFFICIENT BUILDINGS

10 Sustainable Industry Points

Building and demolishing buildings consumes a lot of energy. Even though switching to sustainable construction projects alone will not make the construction sector completely sustainable, it is an important step towards protecting the environment. In addition to developing energy-efficient buildings, we should also work towards creating buildings that can function completely independently (self-sufficient buildings). Could biobatteries help make buildings more environmentally friendly and sustainable?



POLYMERS & PLASTICS

REDUCING THE USE OF POLLUTANTS IN PLASTICS PRODUCTION

10 Sustainable Industry Points

Many plastic products are currently made from harmful fossil raw materials, which has a negative impact on the environment. In addition, dangerous synthetic chemicals are used in the production of plastics to improve the properties of the material. It is therefore of great importance to ensure that these dangerous substances do not inadvertently enter the environment. In addition, we should strive to reduce their use and, where possible, replace them with other, healthier and more environmentally friendly alternatives.

PROPER SEPARATION OF PLASTICS TO MAXIMIZE THEIR USEFUL LIFE

40 Sustainable Industry Points

It is important to talk about the appropriate use of plastics rather than considering a complete ban. Plastics are versatile materials that can contribute to sustainability. It is necessary to initiate a discussion about which plastics are necessary and which are not. Unnecessary plastics should be avoided and efficient recycling structures should be developed to ensure that the value of the plastics needed is optimally used.

ENVIRONMENTALLY FRIENDLY AND BIODEGRADABLE PLASTICS

10 Sustainable Industry Points

In everyday life, we often come across products that look like plastic but are advertised as biodegradable. It is possible to produce plastics from natural sources that can decompose in the environment. However, "biodegradable" does not necessarily mean "environmentally friendly", as in some cases, harmful substances may still be present. Therefore, it is crucial to ensure that biodegradable products are free of environmentally harmful substances when they decompose in the environment.

FOOD & AGRICULTURE

USE WASTEWATER

10 Sustainable Industry Points

Wastewater is more than just dirty water - it is a valuable source of things that are important to all of us. For example, wastewater can be used to extract not only nutrients but also biosolids, fertilisers and other molecules of industrial interest, such as sulfides, ferrites and even rare earths. These treasures are used in various fields, with agriculture being a particular beneficiary.

PROPER WASTEWATER TREATMENT

40 Sustainable Industry Points

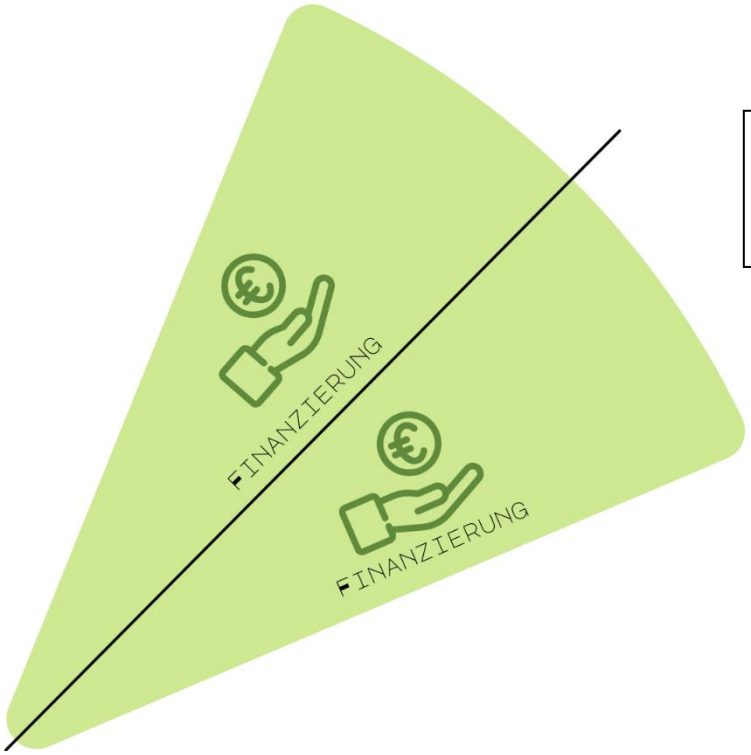
Every year, huge amounts of wastewater are generated around the world. This amount is constantly increasing due to population growth. Unfortunately, 80% of this wastewater is released into the environment without adequate treatment, which is dangerous for both human health and our planet. That is why it is especially important to ensure that wastewater is always treated properly and does not contain toxic substances before it enters the environment.

DECENTRALISED AND LOCAL WASTEWATER SYSTEMS

10 Sustainable Industry Points

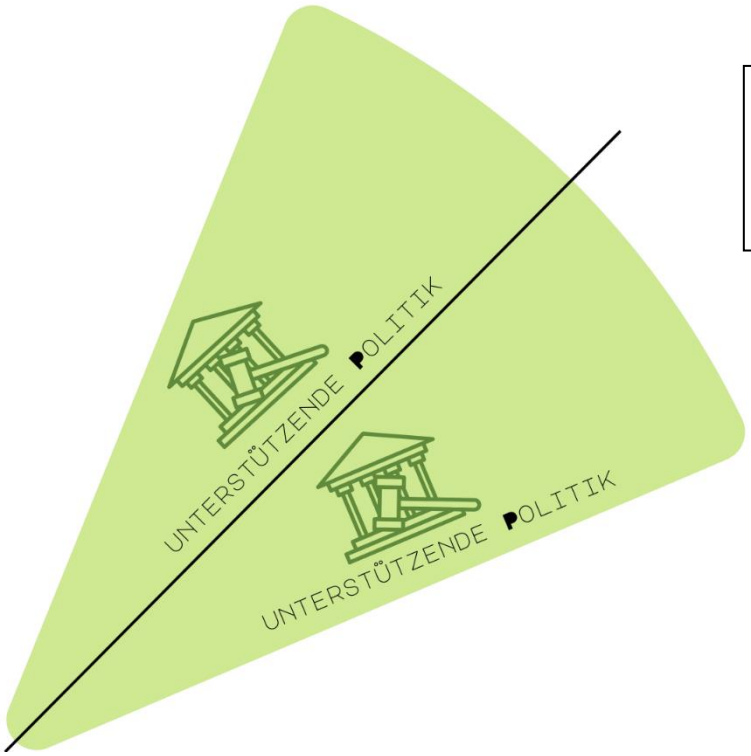
Currently, centralised wastewater systems exist across the country, which, while providing health benefits, waste a lot of water, nutrients and energy. A shift to decentralised wastewater treatment structures could be more environmentally friendly and health-promoting. Decentralised systems are small, local systems that allow for separate collection of wastewater. This not only saves and reuses water but also increases the resilience of the system as a whole.

7.2.4 Additional Material to Foster Discussion: The Final Puzzle Complementary Cards[18].



FINANCING

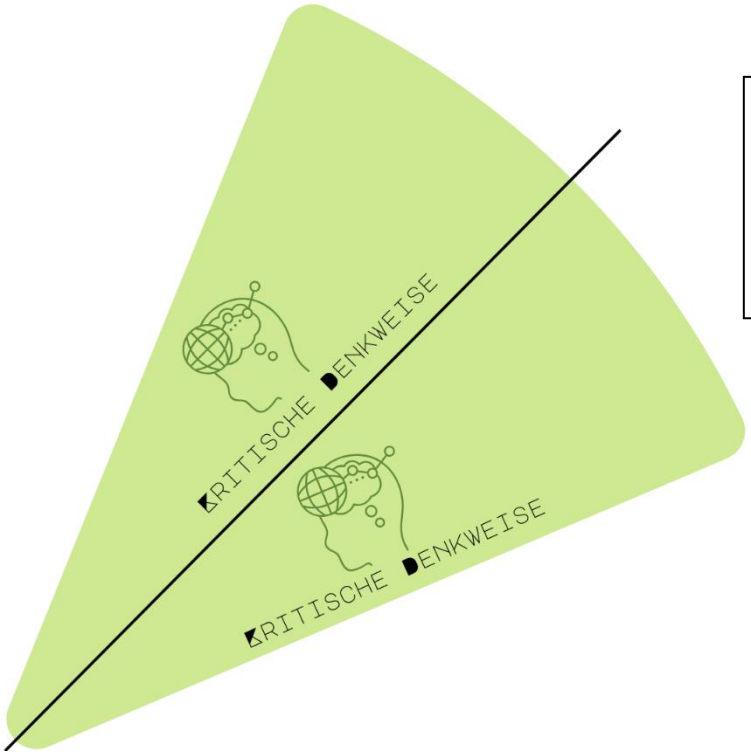
This card highlights the crucial role of financial support in promoting sustainability.



SUPPORTIVE POLICY

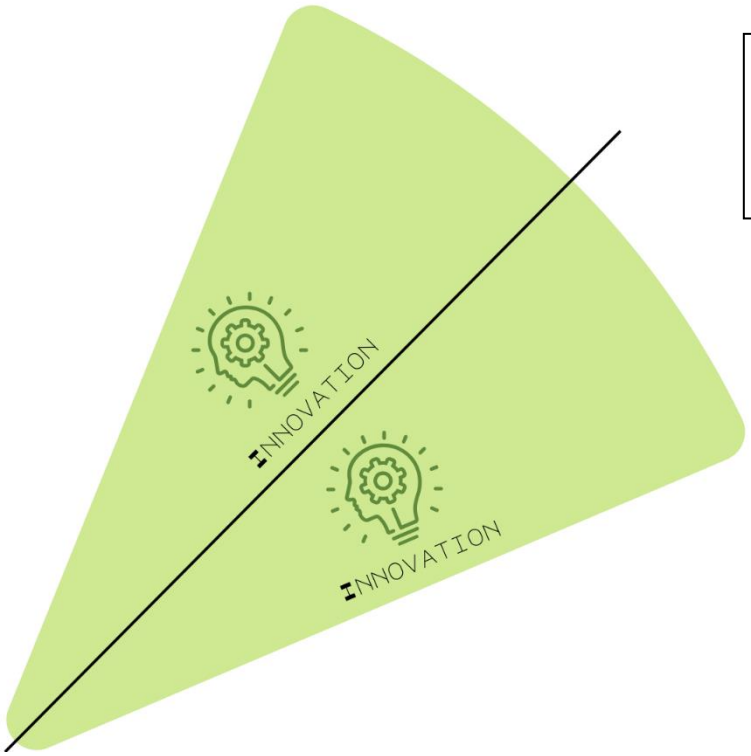
This card emphasises the essential need for a supportive policy to achieve sustainable change.

[18] The Final Puzzle Complementary Cards are designed to facilitate the concluding discussion of the game. The game culminates in an activity where participants present the challenges facing their industries and share their game findings on enhancing sustainability. Using the Industry Point Cards accumulated throughout the game, participants collectively assemble a final puzzle, only to discover that it is incomplete. This prompts them to reflect on what might be missing. The Final Puzzle Complementary Cards were created to address the most commonly mentioned gaps during these discussions. These cards are not initially shown to participants to avoid influencing their responses. If participants identify issues related to these cards, they are added to the puzzle to complete it.



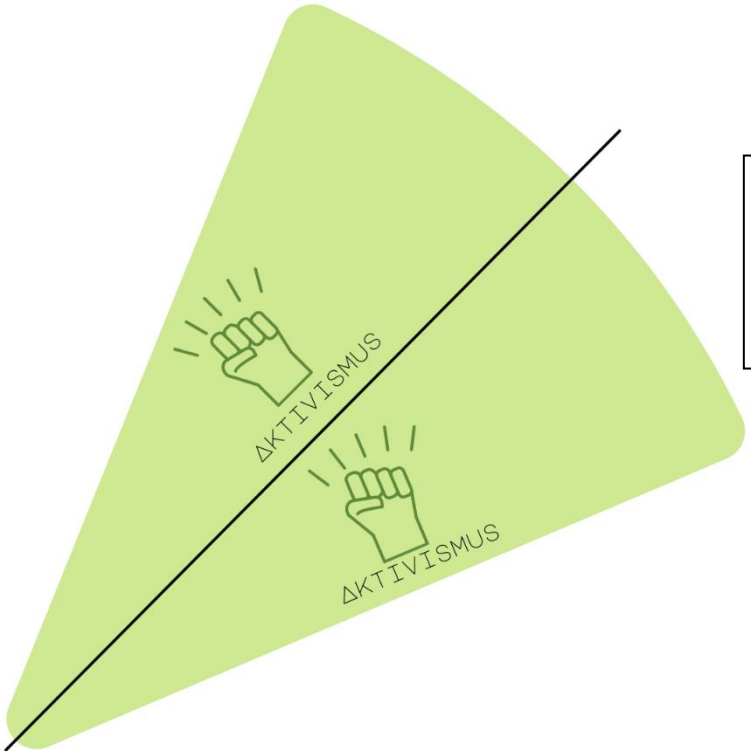
CRITICAL THINKING

This card underscores the need for critical thinking to recognise the shortcomings of our existing unsustainable systems and to rigorously assess the viability of sustainable alternatives.



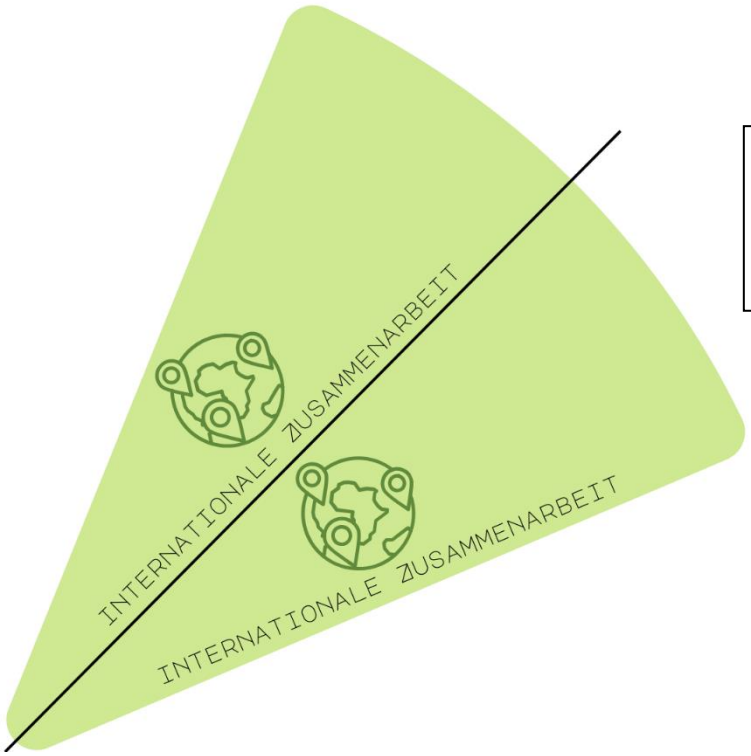
INNOVATION

This card acknowledges the pivotal role of innovation in discovering sustainable solutions.



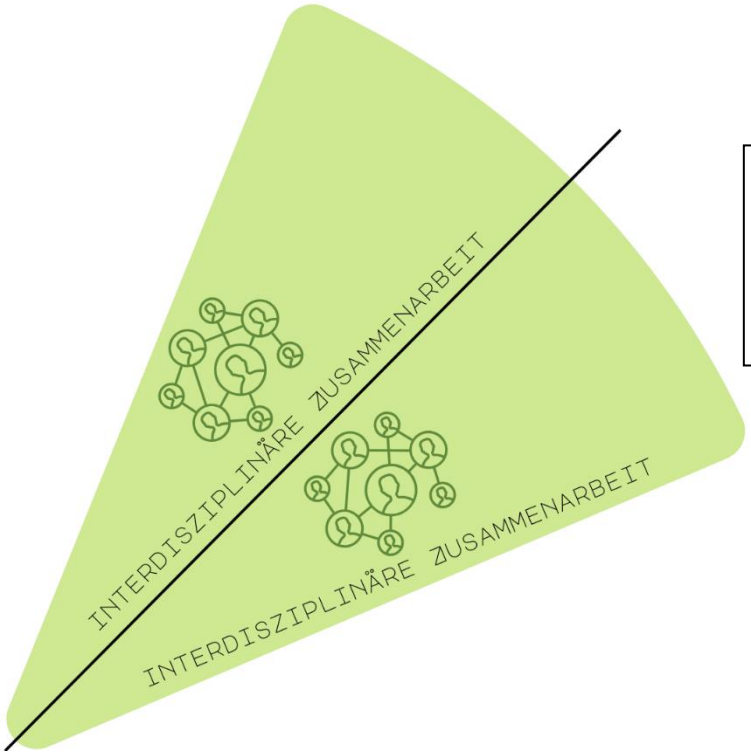
ACTIVISM

This card calls attention to the critical role of activism in challenging present unsustainable systems and fostering sustainable change.



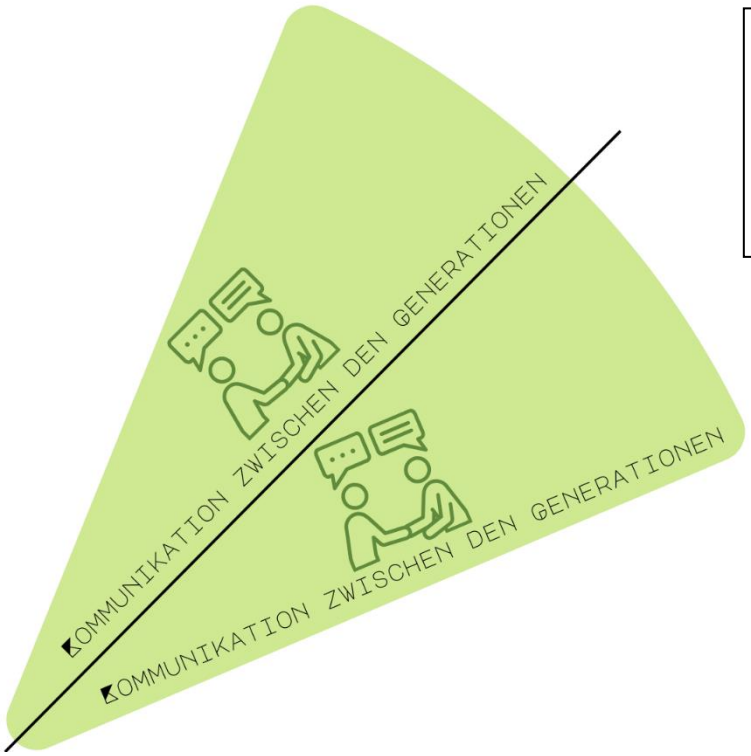
INTERNATIONAL COOPERATION

This card recognises the crucial importance of global collaboration in the quest for sustainability.



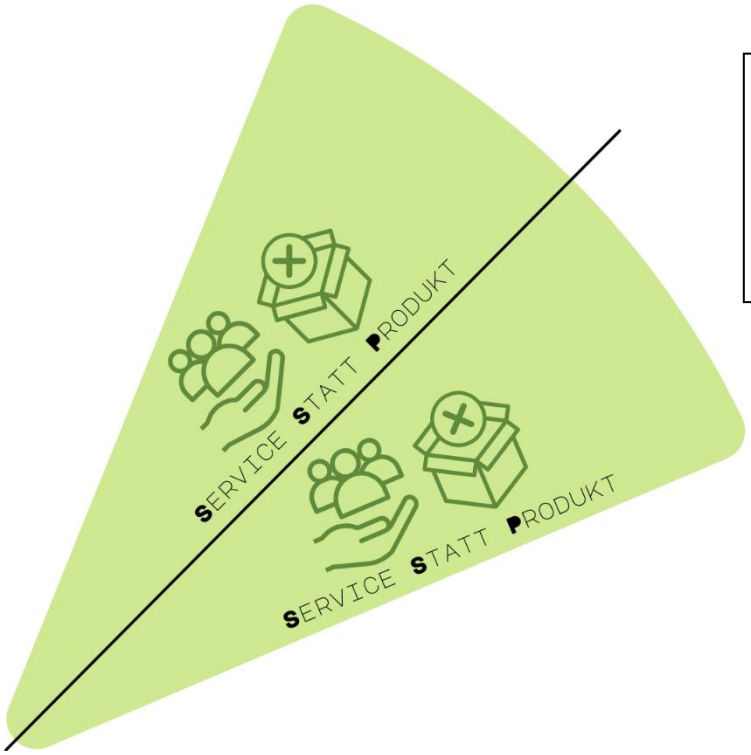
INTERDISCIPLINARY COLLABORATION

This card underscores the value of cross-disciplinary approaches in achieving true sustainability.



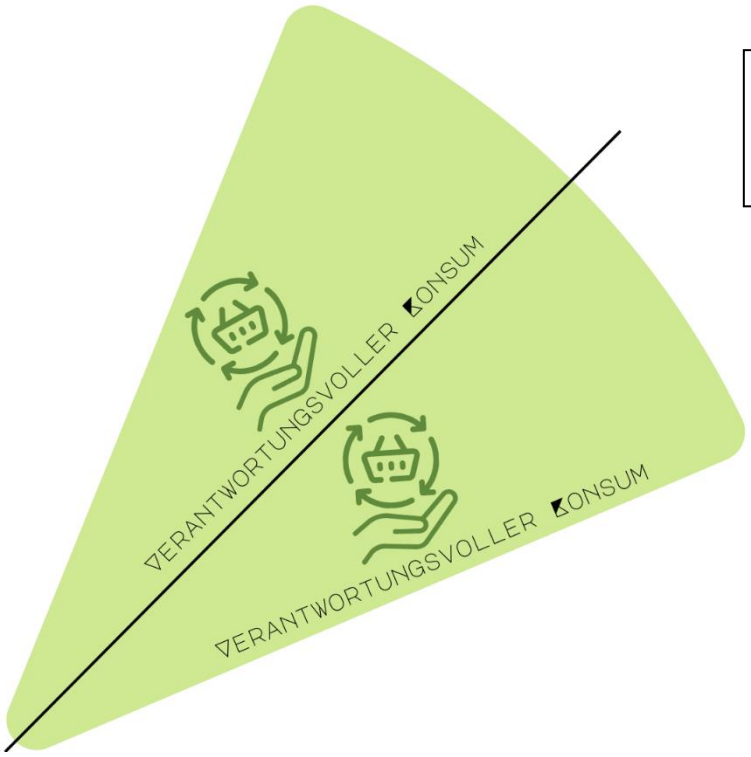
COMMUNICATION BETWEEN GENERATIONS

This card emphasises the role of communication in ensuring that the needs of different generations are met for truly sustainable change.



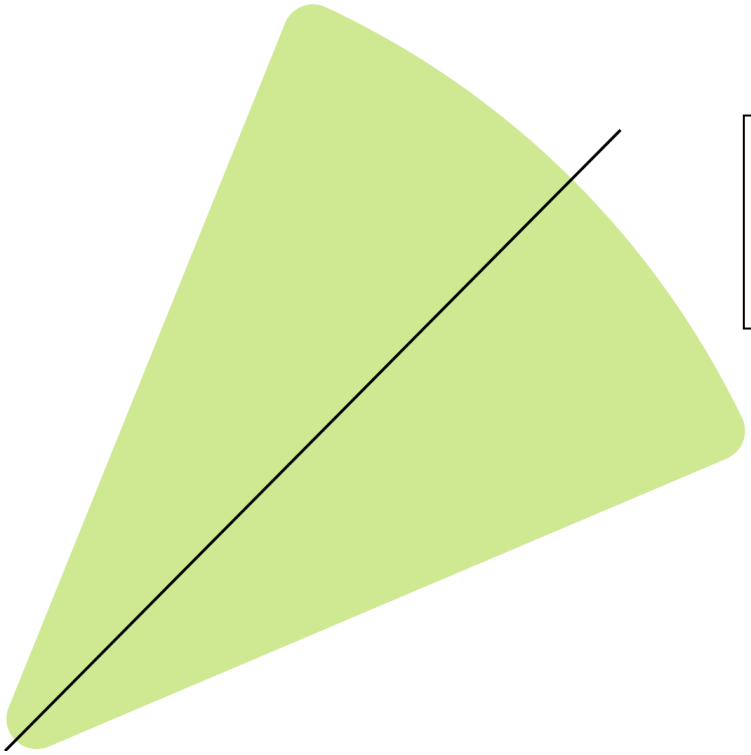
SERVICE INSTEAD OF PRODUCT

This card illustrates a circular strategy: selling services rather than products, aiming to reduce excess production and minimise waste.



RESPONSIBLE CONSUMPTION

This card stresses the need for responsible consumption practices.



EMPTY CARD

Additional blank cards are provided for participants to suggest other sustainable solutions not included in the pre-existing options.