

1 **Ocean literacy and how serious games can play a part: the case of the jellyfish and the**
2 **microplastics governance game MoreGoJelly!**

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15 **Abstract**

16 Serious Games is a method that can be used to reach the public on complex topics related to the ocean.
17 Though games used for learning generally, and ocean literacy specifically, have developed gradually
18 since the 70s, it was not until the popularization of digital games, around the turn of the millennium,
19 that serious games rose to prominence in academia. Since then, vast amounts of serious games-research
20 have been published each year – chiefly on digital games, but also increasingly on hybrid and analogue
21 games. In this article, we present results from a series of serious games that were played in three
22 geographical regions in Norway with future generation stakeholders, and tie this to Ocean Literacy. We
23 report on the potential benefits of serious games for learning and motivation based on these results. The
24 games were played within the context of the United Nations Decade of Ocean Science, the sustainable
25 development goals and multilevel governance, with a special focus on microplastic pollution and
26 jellyfish blooms. We argue that using serious games can be beneficial not just for outreach, but also as
27 a tool for unintrusive collection of qualitative data in the form of narratives from transcriptions post
28 gaming session, and contribute to ocean literacy.

29 **Impact Statement**

30 The article discusses the effectiveness of serious games in enhancing ocean literacy, using a specific
31 example of the dual challenges of jellyfish blooms and microplastic pollution. Researchers engaged
32 high school students in three different – but coastal - geographical locations in Norway in gameplay
33 that simulates environmental scenarios, to foster a deeper understanding of marine ecosystems and the
34 impact of human activities on ocean health. The article assesses that serious games can be an effective
35 tool for environmental education, offering an immersive and interactive experience that traditional
36 teaching methods may lack, which can lead to not only increased awareness among students about
37 marine issues but also motivate them to learn more and take action.

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38 **Keywords: Educational games; Game-based learning; Ocean Literacy; Serious**
39 **Games; Sustainable Development Goals**

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42 Introduction

43 Ocean literacy is defined as "...an understanding of the ocean's influence on you and your influence on
44 the ocean." and an ocean-literate person embodies three qualities: They 1) understand fundamental
45 concepts around how the ocean functions; 2) communicate meaningfully about the ocean; and 3) can
46 make decisions that are both informed and responsible with regards to the ocean and the resources
47 therein (Cava et al., 2005). This was after a group of scientists brought to the surface their concern of
48 that the general public had a lack of understanding about the importance of the ocean which could
49 hinder the uptake of knowledge around its importance (Costa and Caldeira, 2018; McCauley et al.,
50 2019). This is further contextualized by Oceanographer Robert Ballard who said in a TED talk that "we
51 went to the moon, played golf up there, before we went to the largest feature on our own planet" (*Robert*
52 *Ballard*, 2008), referring to the underwater mountain range the Great Rift Valley in the Southern
53 Hemisphere, which covers 23% of the Earth's surface. Research has demonstrated that the ocean is
54 fundamental for life on Earth and human prosperity, and learning and sharing knowledge to sometimes
55 shift community perceptions through education or capacity building around ocean literacy is critical,
56 though it should be noted that it arguably also can be considered controversial, depending on the
57 approach or positionality of the ocean literacy educator. The ocean has often been thought of as
58 immortal, and so large and robust that it would be impossible to ruin (Mead, 2021). However, we now
59 know that its health is under systemic threat (Cowan and Tiller, 2021, 2021; Cullum et al., 2016; De
60 Santo et al., 2019; Laffoley et al., 2020; Levin and Le Bris, 2015; Tiller et al., 2019b). In light of this,
61 in recent years, there has been a surge in scientific and popular literature on this topic leading to
62 extensive research and discussion in the field of political science regarding multilevel and comparative
63 governance approaches to tackle the growing environmental crisis of plastic pollution (Barrowclough
64 and Birkbeck, 2020; Bergmann et al., 2022; Brandon et al., 2023; Cowan et al., 2024, 2023; Gago et
65 al., 2022; Maes et al., 2023; March et al., 2022; Raubenheimer et al., 2018; Tessnow-von Wysocki and
66 Le Billon, 2019; Tiller et al., 2022).

67

68 One of these threats come from plastic pollution, and a significant stride to ameliorate this was taken
69 on March 2nd, 2022, in Nairobi, Kenya during the fifth session of the United Nations Environment
70 Assembly (UNEA-5). This day, heads of state, environmental ministers and representatives from 175
71 nations united to endorse a historic resolution to end plastic pollution and forge an international legally
72 binding agreement by 2024 (UNEP, 2022). Following the resolution's adoption, four sessions of inter-
73 governmental negotiations occurred, including the most recent one in April 2024. However, the
74 foundation of forming a plastic treaty was not a sudden development – it was the culmination of decades
75 of research and implementation of numerous national and regional level regulations that came before it
76 (Dauvergne, 2018; Diana et al., 2022; Harris et al., 2023). The goal of the agreement is to address the
77 full lifecycle of plastics, including its production, design and disposal, to stop it from, among others,
78 leaking into the ocean and harmfully affect marine biodiversity with unknown effects on humans and
79 nature alike. During the second session of negotiations a 'potential options' paper was created along
80 with the input of the United Nations (UN) member states. The paper, which included elements that the
81 treaty may have, had one possible core obligation on strengthening waste management which included
82 commitments to develop new technologies for collecting and disposing of plastic pollution (UNEP,
83 2023), which was later brought forth in the revised draft treaty text that was circulated prior to the fourth
84 and second to last negotiation session for a plastic treaty in Ottawa, Canada in April 2024 (UNEP,
85 2024).

86 Though a multilateral treaty is critical to achieve a joint effort to curb plastic pollution in the ocean, it
87 should be acknowledged that it alone cannot address all technical and social challenges with plastic.
88 Therefore, solutions must be fostered and developed from the ground level including citizens, industry,
89 local governments, and researchers. One technological solution for waste management that has shown
90 potential is based on another environmental challenge to human prosperity in coastal communities,
91 namely jellyfish blooms. In a laboratory setting, (Patwa et al., 2015) found that there were inherent
92 properties in jellyfish mucus that allowed it to rapidly capture micro and nano-particles, and thereby
93 ensuring that they could be removed from the water, and in turn further reduce the quantities of plastic
94 particles released to the environment when used during the last stages in waste water management
95 facilities (Freeman et al., 2020).

96 This is just one example of solutions that are sought to ensure a clean ocean. However, when stepping
97 outside the realm of ocean research, we are faced with the fact that the public often have lower literacy
98 in these matters of the ocean. In a study by the Ocean Conservation Trust in the United Kingdom, for
99 example, they found that – as recent as in 2022 – still only 29% of the respondents said they had very
100 good or good awareness of global challenges, and only 29% of respondents found the principle “The
101 Earth has one big ocean with many features” to be completely true – with in fact 15% finding this
102 principle to not be at all true (Ansell, 2022). To ensure that a future plastic treaty is efficient, it will
103 need public support and a common understanding that this is a matter of utmost importance to
104 themselves also (Tiller et al., 2022). Are there tools that can be used to ensure that the public becomes
105 further knowledgeable about the ocean, and the functioning thereof, to collectively take action to
106 preserve it?

107 We argue that serious games can contribute towards sharing knowledge of the ocean with the public,
108 knowledge that is necessary for positive change. This article will set out by examining ocean literacy
109 and serious games as an innovative methodology towards increasing ocean literacy. We first discuss
110 the concept of Ocean Literacy, followed by a focus on the pedagogy of gaming. After this we present
111 the game itself, and report on results from three gaming sessions with high school students in three
112 different regions of Norway, and the narratives from these to exemplify the efficacy of using Serious
113 games for Ocean Literacy. We conclude by considering the applicability of using this game as an
114 educational tool for Ocean Literacy in the majority world as well, and with participants that are not part
115 of the formal educational system.

116 Ocean Literacy

117 We have now entered the UN Decade of Ocean Science, where we will work for global mobilization of
118 the ocean community towards "The ocean we need for the future we want" (United Nations, 2021).
119 Efforts are made to directly contribute to the implementation of the Sustainable Development Goals
120 (SDGs), even beyond SDG 14 – Life Below Water, by working to ensure that the public understands
121 the ocean's importance within the context of the SDGs as well demands for innovation in
122 communication. In the beginning of the 21st century, the concept of ocean literacy was rarely taught in
123 formal science education (Hoffman and Barstow, 2007). The absence triggered an ocean literacy
124 movement in the United States (US), with both top-down and bottom-up reactions. Two US national
125 commissions – the Pew Ocean Commission and the United States Commission on Ocean policy – both
126 called for more ocean literacy and noted the importance of inspiring the next generation to understand
127 and appreciate oceans (Fauville, 2019). The year 2002 marked the start of the grassroot movement to
128 promote ocean science education (Panto, 2019) and there were debates on what citizens should know
129 in order to be considered ocean literate (Schoedinger et al., 2010). These discussions resulted in a list
130 of seven principles of ocean literacy. While acknowledging that these principles are critiqued for not
131 encompassing among others the contributions that Indigenous perspectives and worldviews (MacNeil
132 et al., 2021), for the purposes of this study we will frame our study around how:

133 *1) the Earth has one big ocean with many features; 2) the ocean and life in*
 134 *the ocean shape the futures of the Earth; 3) the ocean is a major influence on*
 135 *weather and climate; 4) the ocean makes Earth habitable; 5) the ocean*
 136 *supports a great diversity of life and ecosystems; 6) the ocean and humans are*
 137 *inextricable interconnected and finally; 7) the ocean is largely unexplored*
 138 *(National Oceanic and Atmospheric Administration (NOAA), 2013).*

139 While 2002 marked the start for the grassroots ocean literacy movement, it was not until 10 years later
 140 that it gained significant European attention. In 2013, the European Marine Board highlighted, in its
 141 position paper on seas and ocean research in Europe, the need for a European agreement on how to
 142 improve ocean literacy (European Marine Board, 2013). As a consequence of the growing European
 143 ocean literacy movement, other national and regional marine science education associations were
 144 established (Francesca et al., 2017), for example, the Canadian Network for Ocean Education (CaNOE)
 145 and the Asian Marine Educators Association (AMEA). While these national and regional institutions
 146 were important, the need for international collaboration on ocean literacy led to the engagement of the
 147 United Nations Educational, Scientific and Cultural Organization (UNESCO). Another example of
 148 ocean literacy being recognized on the international scene is the Galway Statement on Atlantic Ocean
 149 Cooperation, a research alliance between the EU, Canada and the US, which states that:

150 *We further intend to promote our citizens' understanding of the value of the Atlantic by*
 151 *promoting oceans literacy. We intend to show how results of ocean science and observation*
 152 *address pressing issues facing our citizens, the environment and the world and to foster public*
 153 *understanding of the value of the Atlantic Ocean (Geoghegan-Quinn et al., 2013).*

154 These initiatives, among others, have subsequently led to several different tools being applied to educate
 155 the general public about the ocean. For example, the ResponSEAbLe project was funded under Horizon
 156 2020 to identify knowledge gaps in the European population in relation to oceans and to design and
 157 implement various tools. Some of the ocean literacy tools they implemented were films, cartoons, social
 158 media, table games and applied games (Panto, 2019).

159 Serious Games

160 Serious games are increasingly used to communicate the importance of environmental sustainability
 161 and natural resource management, including oceans to the public (Edwards et al., 2019; Katsaliaki and
 162 Mustafee, 2012; Madani et al., 2017; Panto, 2019). Although the term serious game dates back only
 163 half a century (Abt, 1987), its use can be traced further back (Djaouti et al., 2011), notably to military
 164 strategy simulations, which has been used for centuries (Caffrey, 2019). Games and serious games are,
 165 however, difficult to define (Crookall, 2011; Stenros, 2016) – there is no one agreed upon definition of
 166 serious games to this day, and different definitions were developed because of different perspectives
 167 and for different purposes (Susi et al., 2015). However, the most common understanding is that serious
 168 games are games that have a purpose beyond pure entertainment and enjoyment (Laamarti et al., 2014;
 169 Michael and Chen, 2005), and that though they can be fun, it is not their sole purpose (Madani et al.,
 170 2017) – learning and enjoyment are both necessary and are considered complimentary processes (Abdul
 171 and Felicia, 2015; Gee, 2003). Some have also argued that it is possible for entertainment games to
 172 become serious games if an educational or training purpose is inserted (Susi et al., 2015), though others
 173 believe a purpose must be present during the development of the game (Girard et al., 2013; Madani et
 174 al., 2017).

175 Although serious games has been used for a long time, it was not until the popularization of digital
 176 games, around the turn of the millennium, that serious games rose to prominence in academia (Gee,
 177 2003; Maier and Größler, 2000). During the last two decades, vast amounts of serious games-research

178 has been published each year (Zhonggen, 2019) – chiefly on digital games. Following this, some
 179 scholars have equated the term ‘serious game’ with ‘digital serious game’ (Djaouti et al., 2011; Michael
 180 and Chen, 2005; Rooney, 2012), yet analogue and hybrid serious games also remain prevalent (Lamb
 181 et al., 2018; Wouters and Oostendorp, 2017). Games that offer significant interaction between players
 182 to enable collaborative learning are especially fruitful in this context (Almås et al., 2021; Chen et al.,
 183 2015; Den Haan and Van der Voort, 2018). These strengths are not inherent to games but should rather
 184 be interpreted as possibilities that can be leveraged through consciously designing for enjoyment and
 185 engagement, and learning, whilst accounting for individual differences (Almås et al., 2023; Klabbers,
 186 2018). To further elucidate the role of engagement and learning, and the rationale for using serious
 187 games, learning and engagement in games are presented briefly in the next sections to better
 188 conceptualize the game played for ocean literacy.

189 Learning and Knowledge

190 There are three forms of learning that become especially relevant when using serious games to develop
 191 knowledge, as these differentiate the learning that occurs in games from most other forms of learning
 192 activity. These three interconnected forms or concepts are *sociality*, *situatedness* and *experientiality*,
 193 and the results of the gaming session presented for the purposes of this study will reflect upon these.

194 1) Sociality denotes the idea that more or better learning occurs when the learning situation includes
 195 collaborative social interaction and is likely the least utilized of the three concepts in serious game
 196 research, as many games are solitary endeavors. For instance, in a recent meta-analytic study of
 197 instructional techniques in serious games, only 12% of included comparisons employed collaboration
 198 (Wouters and Oostendorp, 2017). However, social interaction as an approach to learning more generally
 199 is well founded in research from several divergent traditions (eg Bandura, 1986; Bruner, 2019; Lave
 200 and Wenger, 1991; Vauras and Volet, 2013; Wells, 1999). Serious games can create a space in which
 201 social interaction is encouraged and directed towards learning objectives, incorporating dialogue both
 202 amongst peers and with content experts.

203 2) Situatedness, or simply ‘situated’, has been used as a prefix for other concepts, most notably learning
 204 and cognition. The common idea of these concepts is that the situation in which knowledge develops is
 205 inseparable from the knowledge itself. Situations produce knowledge through action (Brown et al.,
 206 1989). Understanding learning like this is at odds with the persistent view that knowledge is to be
 207 mechanistically acquired, simply receiving facts (Freire, 1970; Lave and Wenger, 1991). Serious games
 208 can create situations where players are required to actively engage, and the situation can be closer to
 209 reality than that created through passive forms of learning (Greco et al., 2013).

210 Lastly, 3) experientiality denotes the understanding of learning as being intrinsically linked with
 211 experience. Just like situatedness, experientiality builds on the idea of active learning or learning by
 212 doing (Dewey, 1938), and in one conception of experiential learning, “Experiential Learning Theory”,
 213 learning is seen as movement between the dialectically opposed processes of action/reflection and
 214 experience/abstraction (Kolb, 2015). Simply put, it involves having an experience, reflecting on,
 215 thinking about, and analyzing it, and (actively) experimenting with it – in a recurring spiral. Serious
 216 games as such can incorporate this form of learning rather explicitly by moving the player between
 217 getting information and acting on that information – requiring some degree of interim reflection and
 218 analysis.

219 Engagement and Enjoyment

220 Even if the content and the pedagogical underpinnings of a serious game are sound, there is no guarantee
 221 that the play experience will be both engaging and enjoyable. However, these factors can (and often do)

222 go hand in hand, but that does not happen automatically. To leverage the opportunities of enjoyment
223 and an engaging experience the concepts of self-determination and flow are useful – both in the design
224 and the use of serious games. The first, self-determination, is linked to self-determination theory (Ryan
225 and Deci, 2018). This is a theory of intrinsic motivation in which competence, relatedness and autonomy
226 are understood as base needs for self-motivation and healthy psychological development. Competence
227 need can be also be understood as the innate desire to expand abilities and master challenges, whereas
228 relatedness represents the need for meaningful connection (Rigby and Ryan, 2011). Finally, the need
229 for autonomy is constituted by the desire to act volitionally. The need for competence coincides with
230 the objective of serious games learning as well. To fulfill this need, games must be appropriately
231 difficult whilst providing the right kind and amount of feedback to players. The need for autonomy can
232 also be satisfied by games, insofar as the game provides choices and opportunities for decision-making
233 through volitional action, more so than mere freedom to do anything. Lastly, the need for relatedness
234 can be strongly supported in serious games, not only by playing together, but more profoundly through
235 the feeling of mattering to others when cooperating. This can lead to pleasure and connectedness when
236 sharing experiences if the individual is being acknowledged and supported whilst having an impact.

237 The second concept to consider, flow, can be understood as a mental state related to motivation –
238 specifically the sensation experienced from acting with total involvement (Csikszentmihalyi, 1990).
239 This creates a total immersion in which the individual “blocks out” everything outside of the action in
240 question. Play activities are a common way of experiencing flow. For flow to occur, the play experience
241 must not only be engaging and enjoyable, but also strike a balance between boredom and anxiety, i.e.,
242 between being too easy and too hard, simply put (Kiili et al., 2012). How to achieve this is rarely an
243 easy question to answer, but having goals, challenges, feedback, and (some) control helps (note
244 similarities to self-determination theory, especially the need for competence, here). Reaching this state
245 of involvement is a lot to ask of a serious game, of course, but there are some ways in which theorizing
246 around flow can explain the engagement that accompanies a good game. First, there is a discussion
247 around microflow as a counterpart to “proper”, deep flow and how the feelings associated with flow
248 can exist on a continuum, in which microflow denotes the low-challenge, weakly structured end
249 (Csikszentmihalyi, 1975). This non-fixed view of flow can legitimize looking at the antecedents of flow
250 without expectation of necessarily fully reaching flow (Sweetser and Wyeth, 2005), and in combination,
251 these present a framework for understanding the role of the building blocks of flow in the experience
252 of play. These theoretical developments explicate the link between flow and serious games,
253 emphasizing the importance of enjoyment and motivation.

254 Consciously designing for each of these concepts, as we did for the purposes of the current game, can
255 help leverage the potential benefits of serious games. However, it is the interaction between them that
256 creates a lasting experience for players. For instance, social interaction is a crucial aspect of situated
257 learning (Lave and Wenger, 1991), especially for tacit knowledge (van Haften et al., 2020), connected
258 to the base need of relatedness (Rigby and Ryan, 2011). Furthermore, it has a potential strength when
259 employing experiential learning drawing on sharing of and learning from varied experiences (Kolb,
260 2002). Experiential learning can also be further strengthened when mapped to the antecedents of flow
261 (Kiili, 2006), both of which can be seen as related to the self-determination theory needed for
262 competence (Rigby and Ryan, 2011). Furthermore, despite the perceived importance of these concepts,
263 there are several other potential benefits a game can have over traditional learning, such as
264 multimodality, self-explanation (Mayer, 2019), personalization and adaptivity (Wouters and
265 Oostendorp, 2017), to name a few. These, however, are not as widely applicable as the grand concepts
266 within learning and enjoyment focused on here, which largely substantiates two profound concepts that
267 learning efforts commonly lack – action and interaction (Freire, 1970).

268 Despite these perceived benefits, recent meta-analytic studies (Mayer, 2019; Wouters and Oostendorp,
269 2017) are partially inconclusive (Loh et al., 2015). One potential reason for this is a one-sided focus on
270 learning outcomes rather than the whole picture of learning, enjoyment, context, and game design
271 (Abdul and Felicia, 2015). Applying a more holistic approach in design, reporting, and study of serious
272 games might, therefore, improve future knowledge (Nadolny et al., 2020). In the same vein, it could be
273 argued that the meta-analysis, de-emphasizing the quality of serious games, is an inherently flawed
274 approach in the case of evaluating serious games (Almås et al., 2023).

275 Methodology

276 Building on this, we consciously designed a serious game on the topic of marine plastic pollution and
277 jellyfish blooms for both enjoyment and learning, with the added element of harvesting data from the
278 players (**Error! Reference source not found.-Error! Reference source not found.**). We then, from
279 2020-2021, invited high school students from three different cities in Norway (**Error! Reference source
280 not found.**) to participate in a total of six serious game sets (two in each city). The students were
281 recruited using the snowball method (Biernacki and Waldorf, 1981), a convenience sampling method
282 used when samples of participants with the target characteristics are not easily accessible to the
283 research group, and existing subjects recruit further subjects to the study among their acquaintances
284 until data saturation has been reached (Naderifar et al., 2017). The quality of the results sampled from
285 this group far outweighs the relatively small number, as is often the case in qualitative research studies
286 where large samples can be ineffective and do not provide the detailed and contextual information
287 wanted by the researcher. In total six players attended in Trondheim, eight in Tromsø, and eight in
288 Bergen. We chose to focus on high school student because of their category of “future generations”,
289 notifying that they too are stakeholders within the context of pollution and solutions thereto. This is
290 also clearly stated by Heads of State and Government and high level representatives that met at the
291 United Nations Conference on Sustainable Development in Rio de Janeiro from 20 to 22 June 2012 *and
292 renewed their commitment to sustainable development not only for the present but also for future
293 generations* (United Nations, 2012). In addition, one of the drivers of the movement towards more
294 ocean literacy was the lack of ocean topics on core curricula in the formal K-12 education system (Cava
295 et al., 2005). The placement of these schools in coastal cities in Norway was a sample of convenience,
296 with the main research partners located in these three cities that are relatively large in population size
297 in Norway (2nd, 4th and 16th largest)¹.

298 The game was developed through a collaboration with game developer House of Knowledge and the
299 research institute SINTEF Ocean, both located in Norway. Given that the background for the game was
300 a research project, the topic of the game was to illustrate the twin ocean challenges of both plastic
301 pollution and jellyfish blooms. The development started with a brainstorming session on what the game
302 logic should be and what the setup should be, in terms of physical or digital. The session ended with a
303 decision that the game was to be played live, with a map of Norway as the backdrop and with a story
304 of plastic pollution and jellyfish blooms building up to proposals for technological solutions. It was
305 decided that it would be a physical game boards for the participants, but shortly thereafter, Covid-19
306 made this more difficult, and it was decided that we would develop a digital version to play with the
307 participants from Bergen, because the school the students represented were under lockdown. In Tromsø
308 and Trondheim, the game was played physically under periods of lower restrictions. The digital version
309 was developed to simulate the board game pieces and game setting as close as possible (**Error!
310 Reference source not found.**).

311

¹ Population statistics Norway 2023: <https://www.ssb.no/statbank/table/05277/tableViewLayout1/>

312 The logic of the game was centred on an assessment of the serious game as a communication tool for
313 ocean literacy, with an emphasis on assessing similarities and differences between groups of future
314 generation representatives from three different geographical regions in Norway (western-, mid- and
315 northern- Norway) and diverse backgrounds. The game was to be played as a multi-player game with
316 no more than four players, to ensure that all players were given ample time to discuss and participate in
317 the game. The players first had to fill in a personal questionnaire to ensure General Data Protection
318 Regulation compliance and then, as a group, they were presented with four sustainable development
319 goals: SDGs 3 – *good health and well-being*, 8 – *decent work and economic growth*, 12 – *responsible*
320 *consumption and production* and 14 – *life below water* (**Error! Reference source not found.**). The
321 logic behind the choice of these four SDGs were based on the expertise of the research team at the game
322 conceptualization stage. They were selected through a process of coding all the SDGs and their targets
323 in terms of their relevance and efficacy either for regulating the harvesting of jellyfish or the prevention
324 of plastic pollution and chose for inclusion the SDGs that had elements of both pollution and sustainable
325 use of marine resources included. At the target level of detail, the cards chosen were not difficult to
326 choose qualitatively. The relevant targets were also specified on the back side of the cards so that the
327 participants could read and understand this choice.

328 The game started with each participant filling out a questionnaire focusing primarily on demographics,
329 but also four questions on their background knowledge and experience with both jellyfish and pollution.
330 The survey was taken on their phones prior to the game starting and there was not post survey to assess
331 learning, which we acknowledge would have greatly enhanced this study. After this survey, the
332 participants were provided with contextual cards and an emphasis on these SDGs. We wanted to bring
333 more awareness and contextualization to the concept of SDGs and as such, we gave background
334 information about the case of microplastics rising in the ocean and jellyfish blooms happening in
335 selected areas of the world, including in Norway. The latter was done for the participants to gain
336 knowledge and have a background in a real environmental problem, to which the SDGs can be related
337 specifically.

338 In the Serious game, the students had to select the three most important goals from their perspectives
339 and rank them in terms of importance in the context of assessing microplastic pollution and jellyfish
340 blooms and their effects on coastal communities in Norway. This was a choice made based on the three
341 interconnected forms or concepts of learning relevant when using serious games to develop knowledge
342 that frame this development, namely sociality, situatedness and experientiality, with a special focus on
343 the two latter – namely situatedness - where situations produce knowledge through action and players
344 have to actively engage with a situation that can be considered closer to reality than that created through
345 passive forms of learning; and experientiality – or learning by having an experience, and having a
346 requirement of reflecting on and analysing this experience. In this case, they were in an experimental
347 decision-making situation of the game and asked to make rational choices based on the knowledge at
348 hand.

349
350 Discarding an SDG meant that one of the SDGs would have to be discarded from the top ranking. We
351 did this to give a better understanding to the participants of the real-life challenges that policy makers
352 are faced with when having to make decisions where there is no one agreed-upon solution or that a good
353 solution is discarded because others are perceivably better. By both forcing the groups to actively
354 remove one of the SDGs, and subsequently rank them in terms of their perceived importance, our aim
355 was to demonstrate the difficulties in making choices like these but also for them to reflect on their
356 values vis-a-vis the results at the end of theme – i.e., did they proceed to follow their values throughout
357 the game or were political realities and choices during the game in contradiction with their original

358 values. They were allowed to change the order and inclusion of SDGs two more times during the game,
359 each time after having received more information that could influence this choice.

360

361 Because of the contextual setting, the game was set up around a map of Norway, and the players
362 received game cards that gave background information on the marine environmental challenges in
363 question, preparing the students to play. Next, players received game cards that outlined a hypothetical
364 event that happens in a community somewhere in Norway. They had to assess how this event would
365 affect the social, economic, and environmental sustainability of the region from -3 (very negative) to
366 +3 (very positive).

367

368 The participants were then presented with three governance options for this given event, and they were
369 asked to decide which governance choice they would choose, followed by a discussion on how this
370 governance choice in turn would affect the three sustainability pillars. They were presented with nine
371 events and nine governance cards (a total of 27 governance options) during the game (see *Error! Reference*
372 *source not found.* and *Error! Reference source not found.*).

373

374 Results:

375 The pre-game survey showed that only 20% of the players had had no experience at all with jellyfish,
376 and almost 70% considered them a natural part of the ocean environment though 25% considered them
377 dangerous. In terms of plastic pollution, all players were either moderately worried (18%), very worried
378 (41%) or extremely worried (41%). In terms of changing their lifestyle to reduce how much they
379 affected the environment negatively, only 25% were extremely willing, 47% were very willing and 27%
380 were a little willing. When challenged with the SDGs, the groups from the three high schools in Norway
381 all found connections between the four SDGs, and three out of six groups chose to change which goals
382 they wanted to rank as more important than others throughout the game (Table 1). At the beginning of
383 the game sessions, for example, one of the groups from Tromsø and both groups from Trondheim
384 ranked SDG 12 – *responsible production and consumption* as the most important among the goals. SDG
385 12 was discussed as being generally among the most important goals, comprehensive, and beneficial
386 for the other SDGs. One of the groups from Bergen discussed how the goal could be perceived as both
387 most *and* least important among the four SDGs, depending on the context. The other group from Bergen
388 as well as the groups from Tromsø pointed out that SDG 12 could be specifically beneficial for the
389 ocean and life below water. Participants from the group from Bergen also said that working towards
390 SDG 12 may positively affect human and animal health and could contribute to reaching SDG 14 if use
391 and production were to be carried out more responsibly, especially in terms of plastics.

392

393 The other group from Tromsø and both groups from Bergen ranked SDG 3 – *good health and well-*
394 *being* as the most important among the four SDGs, although it was seen as very important by all the
395 participating groups in different ways. Good health and well-being were seen as fundamental and vital
396 for the human population and necessary for the other SDGs to be achieved. The participants in one of
397 the groups from Tromsø agreed on that “If you don’t feel good, you won’t bother to do anything at all”.
398 Additionally, the participants in one of the groups from Trondheim raised the question “If we don’t
399 have this one [SDG 3] with us, how are the rest of them [SDGs 8, 12 and 14] going to be solved?”. This
400 indicates awareness of how the SDGs can depend on each other and affect the achievement of each
401 other.

402

403 SDG 8 - *decent work and economic growth* was not ranked among the most important SDGs for any of
404 the groups but was discussed both positively and negatively in various ways by the students across and

405 within the groups. The groups from Tromsø and Bergen experienced difficulties fully understanding
406 the goal. One of the participants from one of the groups from Bergen said that “I don’t understand how
407 SDG 8 can have anything to do with this, plastic in the ocean, and so on”. Whereas a participant from
408 the other group said, “I didn’t quite understand the thing about the economy”. In Tromsø, one of the
409 groups said that it was more important to care for the environment than jobs and decent work, even
410 though jobs too were important. For example, one of the students from Tromsø stated that "this one
411 [SDG 8] is important to make people follow [sustainability measures]”. However, during discussion
412 about how decent work and economic growth were perceived as necessities for sustainable
413 development, one of the other students from Tromsø stated that:

414

415 *I believe that this one [SDG 8] is the least important one. Or “decent work” is important to*
416 *maintain a certain [living] standard, but I don’t know if economic growth is as important when*
417 *it comes to sustainable development.*

418

419 The students in the other group from Tromsø said that it was more important with economic growth
420 than protecting the ocean since economic growth facilitate development and reduce poverty. Both
421 groups from Bergen emphasized the importance of development when they discussed SDG 8. One of
422 the groups specifically pointed out the importance of being employed for peoples’ well-being (SDG 3).
423 The other group from Bergen focused more on investments having a key role in solving environmental
424 issues. In Trondheim, one of the groups downplayed the importance of SDG 8 by saying that the "the
425 economy always makes it". This group perceived economic growth as something that may be achieved
426 through the other goals, and that this goal was therefore not as important but rather redundant. The other
427 group was split, and although they ranked SDG 8 the lowest, it was still considered as important. They
428 mentioned that solutions to address sustainability challenges, such as marine plastic pollution, needs to
429 be both attractive and profitable to be actively used or implemented as well as that overall economic
430 growth is important.

431

432 High importance of SDG 14 – *Life below water* was only perceived and pointed out explicitly by the
433 groups from Tromsø and Bergen. It was seen as important for marine ecosystems, peoples’ health, and
434 for other SDGs to be facilitated or have any effect, including SDGs 3 and 8. Although the students first
435 discussed how, for example, SDG 3 was necessary to work with SDG 14, this showed that the students
436 also reflected on relationships between the goals the other way around. Furthermore, one of the groups
437 from Bergen and one of the groups from Trondheim were of the opinion though that SDG 14 focused
438 more on marine life, marine (especially plastic) pollution, and life below water – not above water,
439 disregarding or choosing not to focus on connectivity between marine and terrestrial systems. Still, the
440 group from Bergen pointed out that it was important to focus on life below water through SDG 14 and
441 that this was more important than economic growth. The group from Trondheim, on the other hand,
442 believed that the intentions of SDG 14 may be excessive and that they could be achieved through work
443 to achieve the other SDGs.

444

445 The first time prioritizing or ranking the SDGs, all groups with high school students in the three cities
446 placed SDG 3 as either number one or number two out of the four goals. Furthermore, all but one of the
447 groups from Bergen positioned SDG 12 as either number one or two. The one group that stood out from
448 Bergen chose SDG 14 as goals number two instead SDG 3 or 12. This showed that, with one exception,
449 all groups initially prioritized good health and wellbeing and responsible production and consumption
450 above life below water and decent work and economic growth.

451

452 After receiving a few cards with background information, the students had the opportunity to rank the
453 goals once more. Only one of the groups (from Trondheim) chose to do so. They kept SDGs 3 and 12
454 as the two highest ranked goals but chose to change from SDG 14 to SDG 8 for their third place as they
455 recognized higher value relating to decent work and economic growth after looking at the SDG cards
456 one more time. After going through all the informative cards and events and measures throughout the
457 game, the students had the opportunity to re-rank the SDGs again. At this point in time the students had
458 carried out many discussions and been introduced to the topic of marine plastic pollution and jellyfish
459 blooms more in-depth. Three out of the six groups (one from each city) chose to re-position their goals.
460 The group from Trondheim changed position of one goal, the group from Tromsø changed the position
461 of two goals, and the group from Bergen repositioned all the goals.

462

463 The highest and second highest ranked goals remained in the same position for all but one of the groups
464 from Bergen and one of the groups from Tromsø. The group from Bergen switched out their highest
465 ranked goal SDG 3 with SDG 14, and the group from Tromsø changed their second ranked goal from
466 SDG 3 to SDG 14. That is, both groups chose to move SDG 14 – *Life below water* above SDG 3 –
467 *Good health and well-being* when given the opportunity to re-position the order of the goals. The group
468 from Bergen said that their choice to prioritize SDG 14 was “*based on what we have been through*
469 *now*”, demonstrating that they had gained more knowledge and arguably increased their ocean literacy
470 in the process of playing the game and ranking the SDGs accordingly with the knowledge they gained
471 through the gaming session. The group from Tromsø discussed their re-ranking where one student said
472 that “*I believe that responsible production is also about decent work because it concerns a safe and*
473 *responsible workplace that produces righteously*”, indicating that parts of the achievements from
474 working with SDG 8 may be reached by working with SDG 12. Another student from the same group
475 added that:

476

477 *The reason for why we placed SDG 12 at the top was to have less plastics in the ocean because*
478 *[this leads to] less waste, and [SDG] number 3 was so that people wouldn't throw things in the*
479 *ocean so that we would be okay.*

480

481 This latter also shows that the students had gained information about how the ocean is affected and that
482 they also saw this in connection with land-based actions, which is critical for ocean literacy and the
483 sixth principle on how “...the ocean and humans are inextricable interconnected...” (Panto, 2019). All
484 the groups ended with SDG 12 on either first or second place, except for one of the groups from Bergen.
485 All but one of the groups from Tromsø ended with SDG 3 in either first or second place. The group
486 from Tromsø chose the SDGs 14 and 12 as the two highest ranked goals instead of the SDGs 3 and 12
487 which the other groups prioritized. SDG 8 was positioned last by four out of six groups, and in third
488 place by the two groups choosing to have SDG 8 as one of their three prioritized ones.

489

490 The results from start to finish in terms of prioritized order of the SDGs were relatively consistent,
491 where SDG 3 – *Good health and well-being* and SDG 12 – *Responsible consumption and production*
492 were overall perceived as highly important for the case, also after receiving information and discussing
493 the topic at hand. However, the arguments for why they chose to prioritize the way they did changed as
494 they at the third re-ranking referred to the discussions, events and alternative measures they were
495 exposed to during the game when prioritizing goals.

496

497
498
499

Table 1: SDG goal rankings from each area

SDG goals	Trondheim		Bergen		Tromsø	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
Initial ranking	12	12	3	3	12	3
	3	3	12	14	3	12
	14	14	14	12	14	8
Second ranking	12	12	3	3	12	3
	3	3	12	14	3	12
	8	14	14	12	14	8
Final ranking	12	12	3	14	12	3
	3	3	12	3	14	12
	14	14	14	8	3	8

500

501 Since there was no post-game survey, the results only showed the baseline data for these groups.
 502 However the, qualitative data reflects their learning and at the end of the session, the students were
 503 asked to give oral feedback on the experience to work with marine plastic pollution and jellyfish blooms
 504 in a Serious games format to gain some understanding on whether or not they had gained an increase in
 505 ocean literacy as expressed by the seven principles (National Oceanic and Atmospheric Administration
 506 (NOAA), 2013; Panto, 2019). Each group discussed, and mentioned that, for example, “*I knew nothing*
 507 *about jellyfish [before playing the game]*”. The students said that they did not know that jellyfish could
 508 be used to capture microplastics, that it could be eaten, or that it could even be a problem. Relating to
 509 the measures and governance actions against plastic pollution, the students reflected and discussed. One
 510 of the students emphasized that “*There are many things here that we do not know how it will affect*
 511 *other animals, or like the food chain or something, so if we only knew exactly how [actions affect] ...*”.
 512 This indicated a reflection around how knowledge gaps on the relationship between actions and
 513 consequences in ecosystems can challenge governance, and how they had gained knowledge around the
 514 principles on ocean literacy, especially “...5) the ocean supports a great diversity of life and ecosystems;
 515 6) the ocean and humans are inextricable interconnected...”.

516

517 Discussion & Conclusion:

518 The issue of environmental degradation of the ocean from climatic and non-climatic stressors, whether
 519 it is ocean acidification or plastics, has gained increased saliency over the years in the research
 520 community and in some select industries particularly affected (Galdies et al., 2020; Jewett et al., 2017;
 521 Mangi et al., 2018; Tiller et al., 2019a; Tiller and Richards, 2018). The year 2004, however, marked the
 522 start of the grassroot on ocean literacy movement to ensure that the public would become more
 523 knowledgeable about the importance of the Ocean. Throughout the years, there have been both top-
 524 down and bottom-up initiatives. These initiatives have subsequently led to several different tools being
 525 applied to educate the public about the ocean and its importance, and various tools to bridge the gap in
 526 knowledge have been tested and developed during these years. For the purposes of this study, we chose
 527 to use Serious games as a tool for communicating knowledge about importance ocean issues. In this
 528 case, the high school students who played the game took on the role as decision makers to manage
 529 specific ocean issues they were presented to. While, as this article shows, there is not one agreed-upon

530 definition of serious games, it is evident that they may promote awareness about environmental and
531 sustainability issues.

532

533 Serious games, according to the literature, need to incorporate social interaction, create a situation in
534 which knowledge develops, and facilitate experiential learning. These three concepts were incorporated
535 into the serious game in this study. Consciously designing for each of these concepts around SDGs for
536 ocean literacy can help leverage the potential benefits of serious games where the interaction between
537 them can create a lasting experience for players while making it more likely that the participants gain
538 knowledge about the topic at hand. Keeping in mind the three forms of learning that the literature
539 considers relevant when using serious games to develop knowledge, namely *sociality* – where more or
540 better learning occurs when the learning situation includes collaborative social interaction including
541 both dialogue with peers and content experts; *situatedness* - where situations produce knowledge
542 through action and players have to actively engage with a situation that can be considered closer to
543 reality than that created through passive forms of learning; and *experientiality* – or learning by having
544 an experience, and having a requirement of reflecting on and analyzing this experience. For the
545 purposes of this study, we wanted to bring more awareness and contextualization to the concept of
546 SDGs and as such, we gave background information about the case of microplastics rising in the ocean
547 and jellyfish blooms happening in selected areas of the world, including in Norway. The latter was done
548 for the participants to gain knowledge and have a background in a real environmental problem, to which
549 the SDGs can be related specifically, linked to both situatedness and experientiality, mixed with
550 sociality.

551 First, the game in this study created a space in which social interaction was encouraged - *sociality*. That
552 is, the students worked together to make choices, including to rank the SDGs. The importance of social
553 interaction as an approach to learning is well founded (Bandura, 1986; Bruner, 2019; Lave and Wenger,
554 1991; Vauras and Volet, 2013; Wells, 1999), and is key to the serious game in this study. Second, the
555 game created a situation in which knowledge would expectedly be developed - *situatedness*. That is,
556 the students could gain knowledge of ocean literacy through discussing and ranking the SDGs, through
557 reading the cards on marine environmental challenges, by assessing how the hypothetical events given
558 to them affect the social, economic, and environmental sustainability of the region, and through ranking
559 the governance choices they made. Finally, the game is expected to have facilitated experiential
560 learning, *experientiality* - which is defined as having an experience, reflecting on it, thinking/analyzing
561 about it, and (actively) experimenting with it – in a recurring spiral (Kolb, 2015). In the game, students
562 were moved between getting information and acting on that information. They were also required to do
563 some degree of interim reflection and analysis. Provided that a serious game designed to incorporate
564 social interaction, create a situation in which knowledge develops, and facilitate experiential learning
565 results in that participants' knowledge of the topics presented during the game would increase (Kolb,
566 2015), the serious game played by students in this study would expectedly have contributed to
567 increasing the participants' ocean literacy.

568

569 Serious games, as argued for, can increase players' ocean literacy through presenting them with an
570 ocean-related case, which in this case were the examples of marine plastic pollution and jellyfish blooms
571 as a potential solution to the former, and encourage them to look at the case as part of a larger system
572 through the ranking of the global SDGs. That is, at the beginning of the serious game in this study,
573 students were instructed to rank the importance of game specific SDGs, and, in the middle and at the
574 end of the game, students were then instructed to think about their ranking and were given the
575 opportunity to re-rank their choices should they deem it necessary. Some of the students did re-rank the
576 SDGs when given the opportunity, and this re-ranking indicate that the game had impacted the way that

577 the students thought about the SDGs in relation to the case at hand: regulation of the harvesting of
578 jellyfish and marine plastic pollution and the discussions that were made throughout the game.

579

580 Furthermore, the results demonstrate that students playing the game thought about all the SDGs and the
581 relationships between them rather than latching on to perhaps the most obviously relevant SDG. Indeed,
582 the results show that the students, in large part, saw the goals as interconnected, with many of the groups
583 prioritizing SDG 3 - *good health and wellbeing* and SDG 12 - *responsible consumption and production*,
584 seeing them as foundational and comprehensive in content, and affecting all other SDGs. In the context
585 of ocean literacy, serious games have been applied to promote awareness about environmental and
586 sustainability issues. Recent reviews of serious games within this context have found that games can
587 improve engagement and motivation, strengthen problem-solving, and establish positive affect between
588 players. However, a lack of longitudinal studies and measure of opinion changes may limit the
589 applicability of the findings (Baird et al., 2014; Edwards et al., 2019; Madani et al., 2017). Pre- and
590 post-testing quantitatively and in a structured manner was not specifically focused on in this study,
591 however, which may be addressed in future research during the gaming session. Future studies should
592 also focus on unanswered questions about the scaling of the approach, how Serious Games such as these
593 might work outside the formal education sector, or how it might work in countries of the global majority.

594

595 Still, in our case, with students sampled from three coastal cities in Norway, the students emphasized
596 increased ocean literacy themselves during the game and in the wrap up session at the end of the gaming
597 session. Reflection after a session is important when playing a learning game. This way, feedback can
598 be given on learning experiences, if any. For example, one of the players said that they knew nothing
599 about the topic [jellyfish and plastics] before the gaming session. Another student said that even though
600 they knew a little about jellyfish and plastics beforehand, what they learned, however, was that when
601 playing the game, and thus making governance choices, they did indeed value environmental choices
602 more than economic ones. Another student said that when they were ranking events and governance
603 strategies, they felt that they were the prime minister, and that had been fun. One student also said that
604 they were surprised about the complexity around the task of solving environmental challenges and that
605 there was so much more to it than they had ever imagined.

606

607 This type of thinking is important as we are in the UN Decade of Ocean Science, where we need to
608 mobilize the ocean community towards thinking about "the ocean we need for the future we want"
609 (United Nations, 2022) and directly contributing to the implementation of the SDGs – even beyond
610 number 14 – *Life Below Water*. In general, the results demonstrate that serious games can increase
611 students' knowledge of aspect of the ocean – ocean literacy – and stimulate critical thinking about
612 interconnected SDGs, important to the future of our ocean, as they said themselves as well. As such,
613 Serious games can be a good way of promoting and raising awareness of environmental and
614 sustainability issues, and, as this study shows, they are a way to educate future generations about the
615 ocean and thus increase ocean literacy.

616

617 While an increasing number of organizations are seeking to educate the public about the ocean, the
618 public still knows far too little about the ocean. By using tools like serious games, we can work to
619 educate the public about the ocean in a fun and engaging way. For, as the UN Secretary-
620 General António Guterres said, the Intergovernmental Panel on Climate Change (IPCC) report was
621 "code red for humanity" (United Nations, 2021), and, "Caring for, and using, our oceans in sustainable
622 ways is critical to achieve ecological and economic goals for communities everywhere" (United
623 Nations, 2022). The implementation of the SDGs, which are key to the survival of our planet, will take
624 moving beyond traditional methods and including future generations in the discussions. Part of that

625 move includes ocean literacy – ensuring "the understanding of the ocean's influence on humans and of
626 our influence on the ocean" (Costa and Caldeira, 2018) – and that this understanding is reached at a
627 younger age so that the future decision makers already have a thorough understanding of the importance
628 of the ocean. We are now fast approaching the dusk of the allotted time for the *Intergovernmental*
629 *Negotiating Committee to Develop an International Legally Binding Instrument on Plastic Pollution,*
630 *Including in the Marine Environment (INC)*, scheduled to be completed in 2024 in Busan, Republic of
631 Korea. This global agreement on curbing plastic pollution may have started with lofty ambitions, but
632 now have to streamline and come to an agreement on a legally binding language to steer policy makers
633 in individual states to make changes necessary to stop plastic pollution. Using Serious Games in
634 grassroot movements for increasing ocean literacy may be one tool for gaining ground in local
635 communities to assert pressure on local policy makers.

636

637 Conflict of interest

638 No potential competing interest was reported by the authors.

639

640 Human participants

641 The authors declare that the project obtained ethical approval it must have for all protocols from the
642 national review board NSD (Norwegian Centre for Research Data) and the study meets national
643 guidelines for research on humans.

644

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648

649 Data availability statement

650 The data that support the findings of this study are available from the corresponding author, [IHA],
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920 **Figure 1: Map of Norway and case area locations (Tromsø, Trondheim, and Bergen).**



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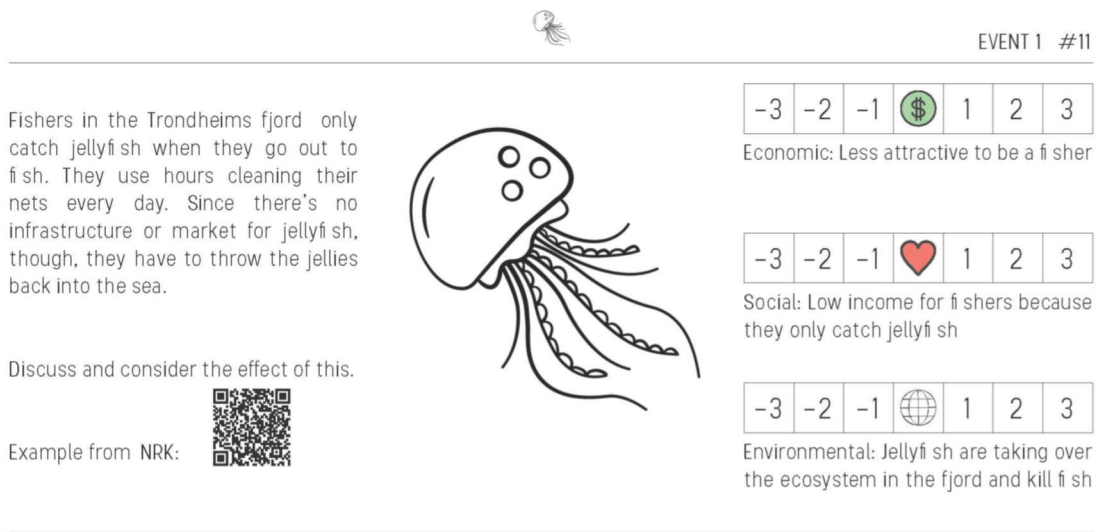
923 **Figure 2: The four SDGs presented to the players at the beginning of the game. The description of the**
924 **relevant indicators and targets were given on the back of the cards to give full context to the players.**



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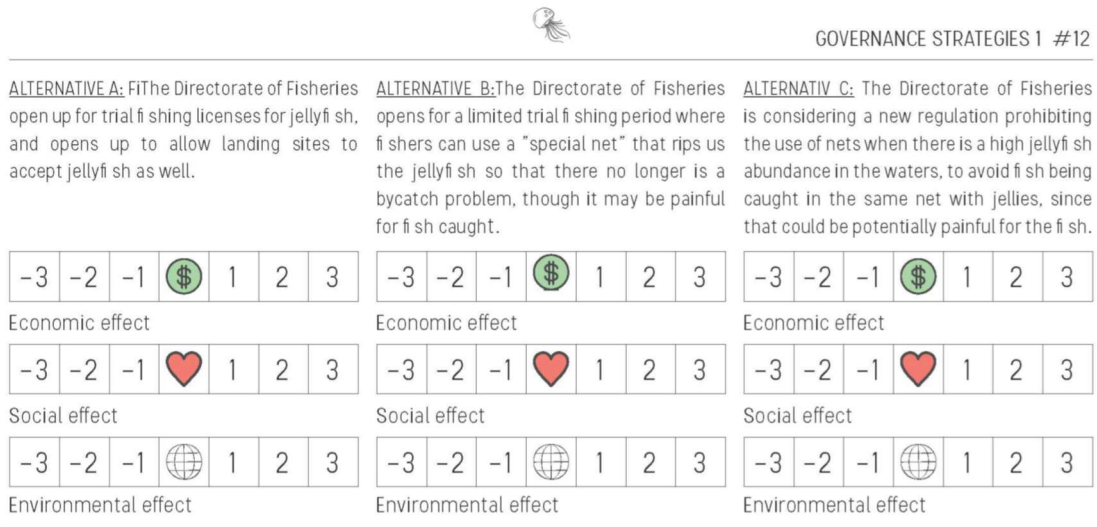
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927 **Figure 3: Event card with three sustainability pillars to be evaluated.**



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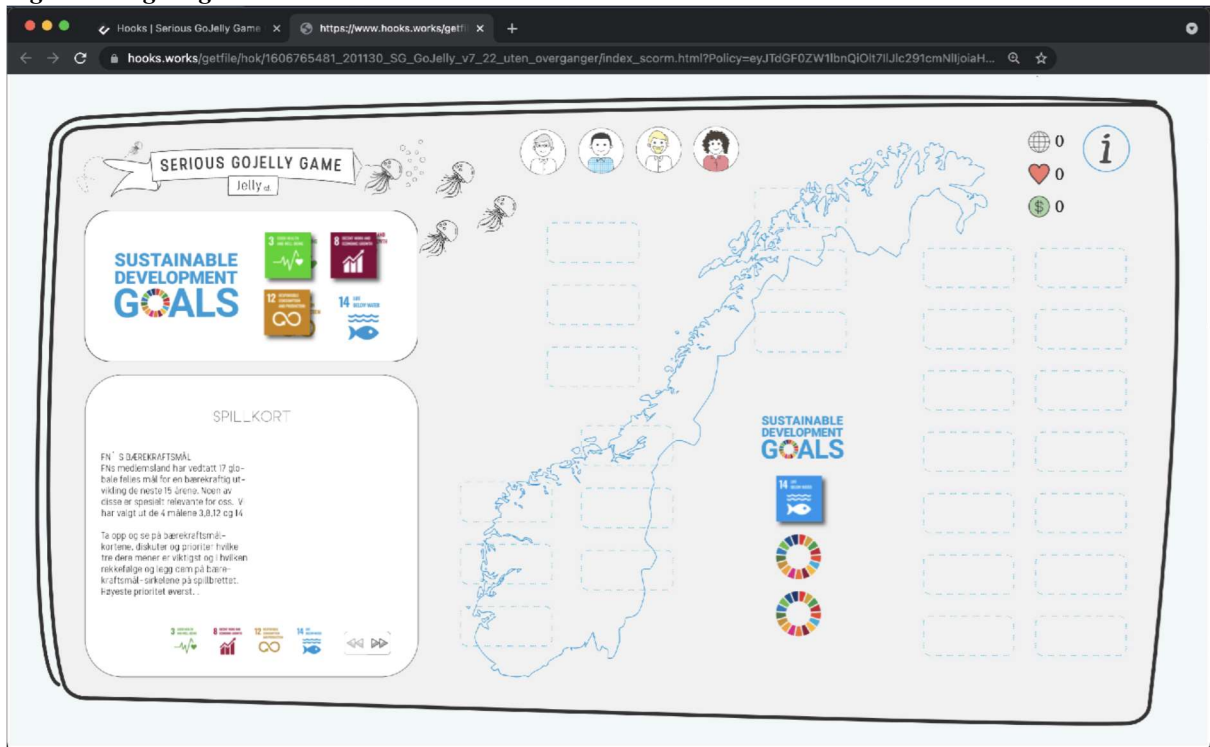
930 **Figure 4: Governance strategies where the player(s) must choose one of the alternatives and then assign the**
 931 **effect on three sustainability pillars.**



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934 **Figure 5: Digital game board.**



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