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1 **An overview of games for entomological literacy in support of sustainable**
2 **development**

3

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11

12 **Abstract**

13 Insects have a significant role towards achieving sustainable development, but the decline of
14 insect knowledge outreach efforts is dampening their impact. Revisiting the perspective and
15 approach to entomological literacy is required to respond to the evolving human needs for
16 sustainable living in light of the decline of insect biomass and biodiversity, and entomology. This
17 is also an opportunity to reflect on the interests about insects in the age of video games. Using
18 games for learning and education can be a viable strategy to advance entomological literacy
19 and support the sustainable development goals by potentially lowering the barriers to

20 accessibility, inclusion and participation. The dearth of research into games for entomological
21 literacy presents opportunities for researchers to explore this domain further.

22

23 **Introduction**

24 As ecosystem services and disservices provided by insects [1] affect all of the United Nations'
25 sustainable development goals (UN SDGs), research into insect-centric or insect-inspired
26 solutions has great potential to address current global challenges [2]. However this task is
27 under pressure in view of the decline of insect science, which includes the decrease or bias
28 against research funding [3–6], lack of courses being taught at universities [5], the decrease in
29 the number of scientists specializing in entomology [6] and, consequently, entomology outreach
30 efforts. There is a need to reinvigorate insect science from the ground up with entomological
31 literacy at its core if we are to respond to the growing challenges of sustainability. Advancing
32 entomological literacy, in particular, supports the SDG 4th challenge, which aims for the
33 provision of quality education for all that also incorporates sustainable development concepts
34 and practices. Beyond entomological literacy, studying insects is not only important for the sake
35 of it, but to science in general as it contributes to the understanding of broader scientific
36 concepts and applications [7,8].

37 Drawing inspiration from insects as solutions for SDG 4 [7,9–11], however, is far from
38 trivial. The decline of insect biomass and biodiversity across the globe decreases the frequency
39 of contacts between humans and a diverse community of wild insects [3,12], thus reducing
40 opportunities to learn from them. Moreover, society has adverse perceptions, reactions and
41 behaviours towards insects and other invertebrates [13,7,9], thus there is little interest in

42 learning about what is often referred to as “creepy crawlies”. This begs the question, how do
43 we overcome the challenges of entomological literacy when the traditional approaches are no
44 longer enough? Extending this to include the UN SDG perspective, how can we effectively use
45 games to educate people about insects and help them to face key issues in sustainability? We
46 have to revisit our approach to insect education to reflect the pressing need for a sustainable
47 way of life, as well as society’s increasing interests in entertainment. To this end, we can turn to
48 games.

49 In this paper we examine how research is making use of games to promote and advance
50 entomological literacy. We further explore the avenues to which research into games for
51 entomological literacy can advance within and outside the academic setting, thus providing
52 complementary ways for society to respond to the global challenges of sustainability. Using
53 games to pique the interest in insects of sustainable development stakeholders is a strategy
54 worthy of further investigation. A global survey of insect-related topics in Google Trends in the
55 past five years yielded an unexpected result, a topic related to a video game (see Box 1). This
56 challenges our assumption that queries about insects are mainly related to them being
57 problems for humans, either pests or disease vectors. This should make us rethink about the
58 perceptions and valuations of insects in the age of video games, and think about how we may
59 leverage that knowledge to advance entomological literacy. If insects are presented in non-
60 conventional means and in a positive light, it may be possible for people to become interested
61 in insects, and possibly even have more empathy for them [3].

62

63 **Games for entomological literacy and their relationships with sustainable development**

64 Using games for teaching and learning, while not the only solution, has several advantages,
65 such as effective learning outcomes, personal and social development, and user-centred
66 learning [14,15]. To get an overview of how research has approached the topic of games for
67 entomological literacy, we conducted a search in the Web of Science on all the documents in all
68 of the available databases of the platform for all the years until November 2019, using the
69 following search terms: (game OR serious game OR game science) and (education OR learning
70 OR teaching) and (insect OR entomology). After reading all the abstracts and removing
71 erroneous entries and articles from the same study, we were left with only 12 records [16–27]
72 (Figure 1). Three of the records were on games focusing on insect biology and ecology, which
73 supports SDG4, with students being the target users of the games [19,23,24]. Six games for
74 entomological literacy can be linked to other sustainable development goals [18,20–22,25,26].
75 Researchers studied the effectiveness of their games in terms of learning outcomes [19,23],
76 engagement of the students to the material [22,24], and cognitive abilities [17]. As examples of
77 studying insects beyond entomological literacy [7], a live action role-playing game was used to
78 teach about the natural history of a bumblebee, food webs and feeding relationships [24]
79 (Figure 2A), and a computer game was used to teach the concept of economic thresholds [27].
80 Also, researchers have been using games to foster collective learning and action, such as in crop
81 pest management. For example, the Azteca Chess board game was used to communicate the
82 complexity of biological pest control to coffee farmers [18]. A previous research of one of the
83 co-authors of this article described the use of a tabletop role-playing game to increase the
84 integrated pest management knowledge of farmers in the tropical Andes [28] (Figure 2B). For

85 disease control and in support of SDG 3, the ResistanceSim game (Figure 2C) is being used to
86 train stakeholders involved in malaria control in Africa and Southeast Asia within a
87 comprehensive training program and malaria prevention framework [21,29]. Linking
88 entomological literacy to practical or real world issues can have direct and knock-on effects on
89 other UN SDGs. Farmers learning about insect-informed agro-ecological practices, for example,
90 may reduce their use of chemical pesticides (SDG 6 and 12), thus improving their livelihoods
91 (SDG 1, 2 and 8) and safeguarding their health (SDG 3). Beyond the games themselves, the
92 deliberate and conscious conservation of insects resulting from improved entomological
93 literacy, together with the creation and strengthening of real-world and virtual communities
94 through individual and collective games, can establish long-lasting partnerships and ensure the
95 sustainability of insects' ecosystem functions and services (SDG 11, 14, and 15). It is worth
96 noting that games are often implemented through non-digital platforms, which is relevant to
97 resource-challenged educational institutions, research projects and outreach efforts.

98

99 **Advancing research into entomological literacy games to support sustainability**

100 While interest in research into games for learning has been increasing in recent years [15], we
101 are interested to know how much of this interest is directed towards insect science. This may
102 reveal the lack of research in this area, and therefore highlight the opportunity for further
103 exploration. To this end, we conducted a search in the Web of Science platform to obtain the
104 number of records on game research related to entomological literacy, and use that as our
105 proxy indicator. Our search was on all the documents in all of the databases for all the years

106 until November 2019 using the following search terms: (game OR serious game OR game
107 science) and (education OR learning OR teaching). The query results yielded 51,448 records
108 across 155 research areas, with 709 unclassified records (Figure 3). Compared with the top
109 research area, computer science, with half of the total volume of games research,
110 entomological-literacy-related research is clearly lagging behind (0.05%). Zoology and
111 environmental sciences hardly fare any better at 1.08% and 2.44%, respectively. We can take
112 stock of the research gaps, particularly in relation to the SDGs (Figure 1). Further research into
113 the effective development and use of games for entomological literacy in support of the SDGs
114 may be enhanced or sustained by advancements in technology and gaming. 3-D digital models
115 providing a detailed view of the morphology and anatomy of insects can be used as a platform
116 to appreciate the beauty of insects [30]. Also, virtual and augmented reality technologies can
117 provide immersive experiences to overcome the phobia or aversion to insects and arthropods
118 [31,32] (Figure 2D), which can impede the uptake of entomological knowledge. Digital social
119 networks and crowdsourcing can be used to promote [33], construct and share entomological
120 knowledge, such as the citizen science application iNaturalist developed by the California
121 Academy of Sciences and National Geographic. Incidentally, iNaturalist, is also a gamified
122 application [34], in which it publicly ranks users based on the number of identifications and
123 observations they have made. We can also look into the popularity of particular games and
124 applications to promote entomological literacy. The augmented reality-based game Pokémon
125 Go (Figure 2E), developed by Niantic and released in 2016, was created by Satoshi Tajiri based
126 on his childhood experience from collecting insects (Time, URL: <https://tinyurl.com/jkeplq>).
127 The entomological community was inspired with its enormous potential to entice people into

128 learning more about insects [35,(J Jackson, Deutsche Welle, URL: <https://tinyurl.com/te4h77>)].
129 Another example is Minecraft, in which a customized virtual world could be built and then
130 explored for environmental education, such as pollination [36] (Figure 2F). Experiential learning,
131 a pedagogic strategy, can be enhanced by following the principles of the mechanics, dynamics,
132 emotions framework, which outlines the key principles for gamifying an experience [34]. The
133 recent release of Google Stadia (Google, URL: <https://tinyurl.com/y3658j2>), a game-streaming
134 platform, opens the floodgates to ubiquitous learning using more complex and highly detailed
135 video games and requires only an internet connection and a display screen (SDG 9). The
136 growing access of women and children to mobile games and devices, such as smartphones, may
137 be an opportunity to increase their participation and inclusion in discussions and actions
138 addressing sustainable development issues (SDG 5 and 9). Using games to promote insect-
139 based food can support the growing industry of insect protein production for animal and
140 human consumption in which the game could be similar to Edible Games (J Sandercock, Game
141 Developers Conference, URL: <https://tinyurl.com/tbfrhah>) (SDG 2 and 13).

142 We have to take caution, though, and should not consider the use of games for learning
143 as the silver bullet. Some games have failed to live up to expectations [37–39], and there is a risk
144 of overloading the end-user with too much information [40]. Moreover, the cost of developing
145 customized or fit-for-purpose games and the associated equipment, limited access to reliable
146 internet, and the digital literacy required [41] could perpetuate or even exacerbate societal
147 inequalities (SDG 5 and 10). We have to take steps or make adjustments to minimize these
148 negative effects, such as modifying commercially available games, like Minecraft (A Fleck,
149 Microsoft, URL: <https://tinyurl.com/tu5sr8v>), to fit the purpose while reducing costs [42].

150 Tabletop and live action role-playing games are also strong options, in which some games may
151 only require pen and paper. Gaming and technological trends and advancements [43,(S
152 Bosman, Newzoo, URL: <https://tinyurl.com/rwdrnlf>)] are also closing this gap.

153 Research into systematic approaches for insect literacy that provides opportunities for
154 the target recipients to reflect on and apply the lessons they have learned into practical
155 situations, such as in sustainable development efforts, may prove to be one of the keys to more
156 effective development and use of entomological literacy games. For example, debriefing, a
157 guided analytical process in which the participant is afforded time to reflect, share and give
158 meaning to their experience [44], is often left out in the gaming process [45]. It is argued,
159 however, that learning is mostly concretized through this post-game analysis [44,45]. In
160 addition, systematic approaches to developing game products that can foster collective
161 learning and action are available, such as citizen science (see [46]) and companion modelling
162 (see [47]). Using games in the policy planning and implementation arena may allow equitable
163 participation of different members of communities in the formulation and implementation of
164 these plans [48,49], which may reduce the injustices that may arise from poorly planned and
165 implemented actions (SDG 16), and allow them to share the risks, rewards and responsibilities
166 for these actions. For example, involving policy designers and decision makers who market or
167 promote harmful pesticides, as well as farmers or communities who use them, in a collective
168 planning environment may socially compel the participants to change their existing practices
169 and policies for food production.

170

171 **Conclusions**

172 Advancing entomological literacy can help in achieving the UN SDGs. With the increasing
173 popularity of games, as well as games and gaming devices becoming more accessible, games for
174 entomological literacy can be a platform for inclusive and equitable quality education and, as an
175 extension, for supporting sustainable development initiatives. Nonetheless, this requires more
176 exploration and research. For example, a robust and unified method or framework for
177 evaluating the efficacy of games based on their goals for the target (users), as well as in relation
178 to the overall goals of the research linked to these games, is still non-existent. Research in the
179 application and efficacy of more accessible technologies, methods and equipment, such as
180 Google Cardboard© to improve game immersion and learning, as well as game distribution
181 services such as Steam© and Google Stadia© for delivering ubiquitous and accessible learning
182 platforms online, may allow overcoming the boundaries of learning, participation, and action.
183 Thus, we invite the readers to open their minds to the opportunities that abound in
184 entomological gaming. Let the games begin!

185

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189

190 **References and recommended reading**

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192 • of special interest

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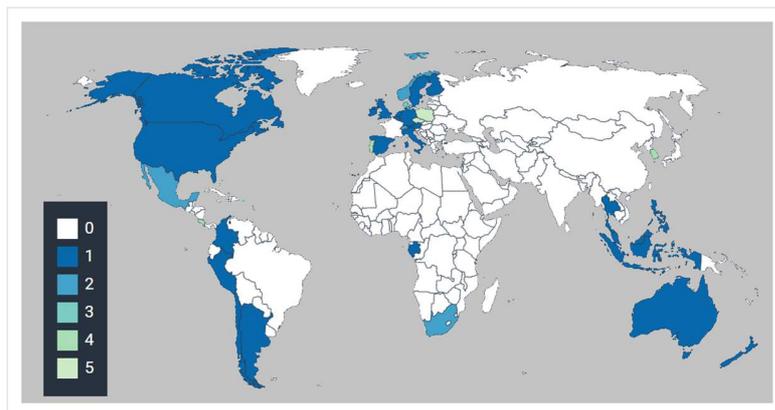
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327

Box 1. Interest on insects related to games

We ran a global Google Trend search for the topic of “insect” for the past 5 years and looked at related searched topics. Surprisingly, at the world level, the first topic associated with “insect” search is “glaive” - a weapon in the video game *Monster Hunter 4* and *Monster Hunter: World*. The insect glaive, in conjunction with an insect-like equipment called *kinsect*, imbues the player’s game character with insect-like abilities, which appeals to many players (Reddit, URL: <https://tinyurl.com/v3qccax>).

We then mapped the countries that had insect-related game topics (not just about *Monster Hunter*) within their respective top 5 list, with the highest rank shown in the world map below. Countries having no records or no insect-related game topics in the top 5 have a value of 0. North America, Australia, a large section of Europe and portions of South America and South-east Asia have strong games-related interest in insects.



329 Figure 1. The reviewed research articles and their links to the UN SDGs. We included additional
330 information about the games, namely, the users, the knowledge imparted and the platform of
331 the game.

332
333 Figure 2. Examples of insect-related games and game-related inspirations: (A) real-life
334 bumblebee game, in which students and teachers play different roles of bumblebees, cuckoo
335 bees and crab spiders, and they interact based on real behaviors of these animals [24]; (B) in
336 this tabletop role-playing board game for community integrated pest management literacy, the
337 player makes management decisions (coloured cards) to control the pests (circular tokens) in
338 their farm plots (grid) [28]; (C) the ResistanceSim game for training on Malaria control takes into
339 account different spatial and management scales, such as at the local or district level shown in
340 this photo [29]; (D) augmented reality allows the patient to control their phobia, in this case
341 cockroaches, without actually being exposed to these insects physically [31]; (E) Pokémon Go's
342 augmented reality interface and game design encourages the player to explore the outside
343 world (photo taken by one of the authors); and (F) Minecraft's virtual world for environmental
344 education can be designed to learn about insect pollination processes [36].

345
346 Figure 3. The distribution of records according to Web of Science research fields in % (log scale),
347 searched for all document types on all the available databases and years (Total N = 51,448 ,
348 period: 1900 – November 2019). The figure shows the top 10 research areas involved in games
349 research publications, as well as entomology and its associated fields, out of the total 155
350 research areas listed in the query.

		No poverty	Zero hunger	Good health and well-being	Quality education	Gender equality	Clean water and sanitation	Affordable and clean energy	Decent work and economic growth	Industry, innovation, and infrastructure	Reduced inequalities	Sustainable cities and communities	Responsible consumption and production	Climate action	Life below water	Life on land	Peace and justice, strong institutions	Partnerships for the goals	User	Systematic assessment of game reported? (Y/N)*
Research		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		
[16]	Martin et al., 2019																			Y
[17]	Kachergis et al., 2017																			Y
[18]	Garcia-Barrios et al., 2017	●		●	●				●				●			●				Y
[19]	Hong et al., 2017																			Y
[20]	Bell et al., 2016																			Y
[21]	Vontas et al., 2016																			N
[22]	Amelotti et al., 2016			●	●															N
[23]	Su & Cheng, 2013																			Y
[24]	Westgarth-Smith, 2004				●															N
[25]	Vivas & Guevara De Sequeda, 2003			●	●															Y
[26]	Chiarvalloti Neto et al., 2003			●	●							●								Y
[27]	Pieters et al., 1981																			N

 Students
  Farmers
  Stakeholders: Health sector
  Insect biology
  Crop pest management
  Computer or video game

 General Public: Children
  General Public: All
  Vector control
  ● Tabletop, board or live action role-playing game

*An "N" response does not imply that no assessment of the game was made. Rather, it is not present in the referenced article.



