1 ***The perception of palaeontology in commercial off-the-shelf video games and an***

2 ***assessment of their potential as educational tools.***

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14 *Video games now comprise the largest sector of the media entertainment industry. Hundreds of*

15 *video games, spanning a huge variety of genres and platforms, use extinct animals and/or*

16 *palaeontological themes as a basis for their gameplay. Because of this, many players, especially*

17 *children, spend long periods of time engaging with, and immersed in, palaeontological concepts*

18 *and themes. Indeed, video games may be the first medium of implicit or tangential science*

19 *communication they engage with, especially with regards to palaeontology. However, commercial*

20 *off-the-shelf video games are not primarily designed to be educational tools, and the proliferation*

21 *of some common tropes can disseminate harmful and/or unethical (mis)information regarding*

22 *palaeontology. This paper introduces the major types of palaeontological video games and*

23 *discusses their educational potential. Moreover, we highlight the most common palaeontological*

24 *tropes observed in video games, both positive and negative, to better inform science*

25 *communicators about the perception of palaeontology (and ancient animals) in this massively*

26 *influential medium. Furthermore, by highlighting common misconceptions and harmful tropes we*

27 *aim to bring awareness to game developers who may be unaware that they could be propagating*

28 *negative tropes about palaeontological science.*

29

1. Introduction

31 Video games are the largest and fastest growing sector of the media entertainment industry. In

32 2020, approximately 2.7 billion users generated an estimated $159.3 billion in revenue, more

33 revenue than the movie and music industry combined (Newzoo Global Games Market Report,

34 2020). The rise of games playable on mobile devices has massively increased the accessibility

35 of video games to a broad range of demographics, mainly because they do not require specialist

36 hardware, are often free-to-play, and have huge diversity in regard to subject matter and

37 necessary skill level. Furthermore, gaming related entertainment, such as live-streaming services

38 like the websites Mixer, Twitch, YouTube etc., are hugely popular, with over 12.4 billion hours of

39 gaming live-streams consumed in the first two quarters of 2020 (Stream Hatchet Video Game

40 Streaming Trends Report, 2020). Combined, this indicates that not only are video games

41 increasing in popularity but that, when not playing, many users will still engage with video games

42 by watching others play online via streaming services. As palaeontological science

43 communicators, we should appreciate the size of the captive audience, and how influential the

44 medium of video games is as a resource for engagement practices.

45 Broadly speaking, video games can be separated into two categories: educational and

46 commercial games. Educational games actively promote learning by introducing information and

47 engaging the user with specific content, known as 'Digital Game Based Learning' (DGBL; see

48 Habgood & Ainsworth, 2011). Video games that focus on specific STEM subjects have been

49 shown to be beneficial to both non-students and students by positively aiding learning outcomes

50 (e.g. Shute *et al.* 2013; Mani *et al.* 2016; Pringle *et al.* 2017 etc.), especially for students who

51 struggle with traditional teaching practices (Mayo, 2009). However, studies also indicate that

52 some users can find educational games patronising (Klopfer & Osterweil, 2013), or lose interest

53 rapidly and disengage, decreasing the likelihood of positive learning outcomes (Kerawalla &

54 Crook, 2005; Habgood & Ainsworth 2011). Furthermore, educational video games are typically

55 niche in their subject matter, difficult to programme (e.g. Pringle *et al.* 2017), difficult to implement

56 (e.g. Mani *et al.* 2016; Mozelius et. al., 2017), and require extensive funding to develop (Annetta,

57 2008; Mayo, 2009). These games are often made in association with specific outreach projects

58 with limited funding (e.g. Mani *et al.* 2016; Pringle *et al.* 2017), making protracted development

59 an impossibility (Mayo, 2009). It should also be noted that it can be difficult to monitor the

60 educational effectiveness of these educational video games (e.g. Mani *et al.* 2016) especially if

61 they are released to the public. Ultimately, educational video games are viable learning aids, but

62 they do not appeal to the wider public.

63 The second type of video games are commercial-off-the-shelf (COTS) games. These

64 games make up the overwhelming majority of the gaming ecosystem and are incredibly diverse

65 in their genres and themes. Typically, COTS games are developed to a much higher standard of

66 graphics and gameplay mechanics than educational video games (Kerawalla & Crook, 2005;

67 Mozelius *et al.*, 2017) and are designed specifically to capture the attention of the user by

68 motivating and challenging them in an interactive environment, often reinforcing this through

69   repetition and reward (Brown *et al.* 2014). Despite the dated perception that video games are
70   nothing more than a trivial time sink, evidence suggests that video games can have positive
71   benefits to cognition, motivation, and social skills in players (e.g. Granic *et al.* 2014). Furthermore,
72   COTS games can effortlessly provide early exposure to educational themes and concepts, even
73   if the specific COTS game is not primarily designed for this purpose. Because of the huge variety
74   in genres, engaging gameplay, ability to play online with friends, and high production quality, it
75   has been proposed that COTS games are a resource that could be incorporated into teaching
76   environments (Van Eck, 2006), with multiple studies undertaking utilising COTS in teaching
77   environments (e.g. Charsky & Mims, 2008; Mohanty & Cantu, 2011; Sun *et al.* 2015; Cadwell *et
78   al.* 2017 etc.). Recently, some COTS games have included specific sections of the game that are
79   focused on education: for example, *Assassin's Creed: Origins* (2017, Ubisoft Montreal) and later
80   instalments in the *Assassin's Creed* franchise contain a 'Discovery Tour' mode that removes
81   combat and quests in the game to allow players to explore the games' historical settings
82   accompanied with factual information and quizzes. Generally speaking, however, whilst
83   educational video games often sacrifice entertainment for accuracy, many COTS video games do
84   the opposite (Van Ecy; 2006 Mozelius *et. al.*, 2017; McGowan & Scarlett, 2021), and therefore
85   must be carefully vetted prior to integration into curricula, often leading to increased workload for
86   educators (e.g. Sun *et al.* 2015; Cadwell *et al.* 2017 etc.).

87   One important and often overlooked aspect of computer gaming is the potential for implicit
88   and tangential learning (Mozelius *et al.*, 2017; McGowan & Scarlett, 2021). Implicit (or
89   unconscious) learning occurs when learning takes place in an incidental manner without the
90   awareness of the person engaging in an activity (e.g. Frensch & Rünger, 2003). Conversely,
91   tangential learning is the semi-conscious process of self-education via exposure to a topic in an
92   already enjoyable, non-educational format (Brown *et al.* 2014). Many COTS games impart
93   complex scientific and historical content to their audiences by presenting the topic within fun and
94   engaging game mechanics in a non-scholastic format. However, it is also possible that any implicit
95   and tangential learning from a COTS game may be a completely unintended or entirely accidental
96   element of game design. Consequently, because COTS games are not primarily designed with
97   educational purposes in mind, inaccuracies either intentional (disinformation), or unintentional
98   (misinformation), can be incredibly impactful to less informed players, and can mislead audiences
99   about key concepts and even reinforce harmful stereotypes.

100   This is particularly pertinent to the science communication community, and especially so
101   in the field of palaeontology. For over 150 years, ancient organisms have inspired a plethora of
102   popular books, films, cartoons and toys. It should therefore be of no surprise that ancient life is a

103   popular topic for the video game industry. In fact, one of the first 3D games for the home computer
104   was *3D Monster Maze* (1982, J. K. Greye Software), a maze game where the player was chased
105   and, unless they could successfully escape, eaten by a *Tyrannosaurus rex* (Figure 1). Since then,
106   the diversity of palaeontological video game genres has greatly increased and is currently a
107   popular theme for COTS games. This means that a considerable number of people, particularly
108   children, will be introduced to the field of palaeontology through the medium of video games.
109   Because players repeatedly engage with a single video game and new games that contain
110   palaeontological themes are being released all the time, COTS games have a much greater reach
111   than traditional outreach events.

112   The aim of this paper is in two parts: 1) to familiarise science communicators with the
113   types of palaeontological COTS video games; 2) to identify and discuss common tropes and
114   misconceptions that often arise where scientific accuracy is compromised for entertainment value.
115   This paper seeks to raise awareness to science communicators of the perception of
116   palaeontology (and ancient animals) that the video game-playing public are exposed to, especially
117   those that have been introduced to the subject via these games. Furthermore, we highlight
118   harmful tropes (i.e. unethical behaviour, misogyny, racism etc.) to inform science communicators,
119   COTS game writers, developers, and video game artists who may be unaware that they are
120   propagating damaging tropes pertaining to palaeontological science.

121

122   ## *2. General introduction to palaeontological video games genres*

123   There is a huge diversity of video games that contain palaeontological content. In this review, we
124   focus on COTS video games that incorporate fossils and/or ancient animals as one of the playable
125   or interactive aspects of the game. In this review we do not discuss COTS games that only
126   incorporate ancient animals as 'set dressing'. Examples include games such as *The Last Of Us*
127   *Part II* (2020, Naughty Dog), *Batman: Arkham City* (2011, Rocksteady Studios), and *BioShock*
128   (2007, 2K Boston) that feature levels in museums containing skeletons or animatronic replicas of
129   extinct animals, or *Battlefield* 4 (2013, DICE), which features a hidden 'easter egg' that allows the
130   players to summon a giant *Otodus megalodon* during live multiplayer matches. Another common
131   use of ancient animals is purely cosmetic; many multiplayer games feature 'skins' that the players
132   can unlock to customise their characters, and these often resemble ancient animals e.g. dinosaur
133   outfits in *Fortnite* (2017, Epic Games), and dinosaur themed armoured suits in *Destiny 2* (2017,
134   Bungie Inc.) (Figure 2). These 'skins' are purely aesthetic changes that do not alter the core
135   gameplay and will not be discussed further.

136   In order to understand the tropes commonly seen in palaeo-video games, it is important
137 to identify the major categories of palaeo-video games that are available on the market. Despite
138 the diversity of game types and styles (Figure 3), most games align with one of the following
139 categories (though some span multiple): 1) ancient animals as adversaries (Figure 2a); 2) ancient
140 animals as tools (Figure 2b); 3) fossils as collectables (Figure 2c); 4) ancient animal management
141 simulators (Figure 2d); and 5) ancient animal simulators (Figure 2e).

142

143 *2.1 Ancient animals as adversaries*

144 This category is, by far, the most common type of palaeontological video game (Figure 3d). Many
145 video games use ancient animals (typically dinosaurs and pterosaurs) as adversaries that must
146 be defeated (i.e., killed) in order for the player to proceed and continue the game. In this type of
147 game, the ancient animals are programmed to be hostile if approached and/or will actively hunt
148 the player. Examples include *The Legend of Zelda* (1986, Nintendo EAD), *Turok: Dinosaur Hunter*
149 (1997, Iguana Entertainment; Figure 2a), *Trespasser* (1998, DreamWorks Interactive), *Dino Crisis*
150 (1999, CAPCOM), *Tomb Raider* (1996, Core Design), *Peter Jackson's King Kong: The Official*
151 *Game of the Movie* (2005, Ubisoft Montpellier), etc.

152   Another type of palaeo-video game that falls within this category is the 'wave shooter', in
153 which the player fights off waves of hostile enemies with a suite of exotic weapons in order to
154 progress. The enemies in these games are presented as cannon fodder that exhibit little or no
155 natural behaviour, swarming en masse to overwhelm the player. Examples include *Dino Stalker*
156 (2002, CAPCOM), *Dino D-Day* (2011, Digital Ranch), *Dinosaur Hunt* (2015, Racing Bros),
157 *Carnivores: Dinosaur Hunter (Reborn)* (2015, Digital Dreams Entertainment LLC), *Wrath of the*
158 *Goliaths: Dinosaurs* (2018, Ascendence Studios), *Hunt: Primal Reptiles* (2020, HugeLittleStudio),
159 *Prehistoric Hunt* (2020, Antiproto Studios), and *Second Extinction* (2020, Systemic Reaction).
160 Some games subvert this genre and allow the option to play as the ancient animals in order to
161 hunt and kill humans, such as *Primal Carnage* (2012, Lukewarm Media) and *Orion Prelude* (2012,
162 DANKIE).

163   Generally, category 1 games offer very limited educational content. At best, the player can
164 access a glossary of the hostile units which may contain some scientific information, however,
165 many of these games rely heavily on tropes such as monsterification to make the enemies appear
166 and behave more frightening or lethal. In fact, in most category 1 games, the ancient animals
167 could be replaced by any other generic adversaries (e.g. aliens or zombies) with little impact to
168 the core gameplay.

169

170 *2.2 Ancient animals as tools*

171 Another common use of ancient animals in COTS games is as a tool to help the player progress

172 through the game. One of the most famous and recognisable examples is Yoshi, a fictional

173 omnivorous theropod dinosaur who first appeared in *Super Mario World* (1990, Nintendo EAD;

174 Figure 2b). Yoshi was a mount for the Mario brothers in their adventures to rescue Princess

175 Peach, but Yoshi's popularity promoted him to full sidekick status and has spawned several

176 dedicated sequels (e.g. *Yoshi's Story,* 1997, Nintendo EAD). A variety of other games allow tamed

177 ancient animals to be utilised as mounts, such as *Far Cry Primal* (2016, Ubisoft Montreal), *Ark:*

178 *Survival Evolved* (2017, Studio Wildcard), *Total War: Warhammer I* and *II* (2016, 2017, Creative

179 Assembly), and *World of Warcraft: Battle for Azeroth* (2018, Blizzard Entertainment), with some

180 games even going so far as to mount weapons such as machine guns and cannons, to ancient

181 animals e.g. *Nanosaur* (1998, Ideas From the Deep), *Dino D-Day*, and *Total War: Warhammer II.*

182 Ancient animals as tools are also featured in the COTS game sub-genre role-playing

183 games (RPGs). In the context of palaeontology, the most famous examples are the *Pokémon*

184 games, in which a diverse group of Pokémon are based on or inspired by ancient animals. In

185 these games the player can catch, train, and fight the creatures in sanctioned competitions in

186 order to become the best trainer in their respective worlds. Pokémon fossils can be found, revived,

187 and used to battle other trainers as the player progresses through the game (e.g. *Pokémon*

188 *Red/Blue*, 1999, Game Freak). Similarly, the *Fossil Fighters* series (2008, Nintendo EAD) allows

189 players to take part in detailed fossil excavations, revive the discovered dinosaurs (referred to as

190 vivosaurs), and train them to fight in order to complete the main story.

191 Similar to category 1 games, category 2 games have very limited educational content but

192 may have some information about the ancient animals in databases or glossaries.

193

194 *2.3 Fossils as collectables*

195 Collectables are a common aspect of COTS games: items found throughout the game setting that

196 the player can collect as they progress and explore through the game. These collectables are

197 often an optional side quest separate to the main storyline, that provide additional worldbuilding

198 or upgrades, but which in some games are used as resources to craft tools and materials.

199 Fossils are frequently a form of collectible seen in COTS games. For example, *Red Dead*

200 *Redemption 2* (2018, Rockstar Games), features a side quest where the player is tasked to locate

201 30 fossil specimens across the game world in order to assist an aspiring palaeontologist. Another

202 example is in the Pokémon franchise; as mentioned above, fossils can be found and resurrected

203 by the player in order to complete the secondary objective of the game; filling the digital Pokémon

204   encyclopaedia, or Pokédex, with every type of Pokémon that can be found in the game world (e.g.
205   *Pokémon Red/Blue*).
206   Most other games use fossils as a natural resource, alongside crystals, ore, geodes etc.
207   that can be used to collect, sell, or build other objects. In *Minecraft* (2011, Mojang), *The Sims 4*
208   (2014, Maxis), *Starbound* (2016, Chucklefish), *Stardew Valley* (2016, ConcernedApe), and
209   *Animal Crossing: New Horizons* (2020, Nintendo EAD; Figure 2c) players can collect fossils for a
210   variety of reasons — from displaying in virtual museums or in their own personal collections, to
211   even being used as fertiliser! However, in the majority of category 3 games, fossils are also used
212   as (or associated with) in-game financial resources as a tradable commodity. This has
213   implications for the public perception of fossil collecting (see *Representing ethics in*
214   *palaeontology*).
215   Virtual fossil collectibles are almost always based on real organisms and often include
216   database entries or facts pertaining to the items that can be collected. This has enormous
217   potential for educating the player, provided the information is well researched. However, category
218   3 games can easily impart misinformation or even disinformation especially when presented in an
219   otherwise informative context.
220

221   *2.4 Ancient animal management simulators*
222   'Construction and management simulations', sometimes referred to as park management
223   simulators (or park sims) are games where the goal is to construct a financially viable park or zoo
224   by managing the construction, park layout, guest management, animal welfare, and breeding
225   programmes with often very limited resources. Ancient animals tend to be a common focus for
226   park sim games, and they often have a diverse variety of organisms that are modelled realistically
227   and tend to exhibit 'naturalistic' behaviours (although some games are heavily stylized and/or
228   simplistic for aesthetic reasons) for the player to engage with. There have been several park sim
229   games based on the Jurassic Park franchise, e.g. *Jurassic Park III: Park Builder* (2001, Konami),
230   *Jurassic Park: Operation Genesis* (2003, Blue Tongue Entertainment), *Jurassic Park Builder*,
231   (2012 Ludia) and *Jurassic World: Evolution* (2018, Frontier Developments; Figure 2d), but
232   independent franchises based on ancient animals are also popular e.g. *DinoPark Tycoon* (1993,
233   Manley & Associates), *Zoo Tycoon: Dinosaur Digs* (2002, Blue Fang Games), and *Parkasaurus*
234   (2020, Washbear Studio).
235   Category 4 games often contain the most detailed compendiums on ancient organisms,
236   allowing the player to find information regarding their required virtual living conditions and about
237   the relevant science and/or discovery of the organism. They can also contain detailed information

238   about fossil sites, fossilisation processes, phylogenetic relationships, and evolutionary processes.

239   As with previous categories, this information can yield useful educational content if accurate, but

240   be misleading if incorrect or disinformation is presented.

241

242   *2.5 Ancient animal simulators*

243   The last decade has seen the emergence of 'survival simulators' — games where the player can

244   control an individual animal through an entire life cycle in a natural, open world, environment.

245   While many COTS games allow the player to play as an ancient animal e.g. *Yoshi's Story*, *Project*

246   *Bolan (Dinosaur Game)* (2014, Google), *DinoRun DX* (2015, PixelJAM Games) etc. within such

247   games, the player's avatar could be replaced by any other organism without altering the gameplay

248   experience and are not the focus of this category.

249   In survival simulators, the player's ancient animal avatar must survive by finding water and

250   food (by hunting A.I. controlled animals or potentially other players) while avoiding natural hazards

251   and being predated themselves. Typically these games have focused on dinosaurs e.g. *Saurian*

252   (2017, Urvogel Games, LLC; Figure 2e), *The Archotek Project* (2017, The Archotek Project

253   Team), *Beasts of Bermuda* (2018, Sastrei Studios, LLC), *Dinosaurs: Prehistoric Survivors* (2018,

254   Arcupion Art), *The Beasts of 9500* (2020, Dragons), and *Path Of Titans* (2020, Alderon Games)

255   etc., however, some games do focus on non-dinosaurian animals groups such as early hominids

256   e.g. *Ancestors: The Humankind Odyssey* (2019, Panache Digital Games). Survival simulators

257   tend to market themselves as being as scientifically accurate as possible in both their palaeo-

258   environmental and animal reconstructions (e.g. *Saurian*).

259   Another genre of game that fits within this category allows the player to visit ancient

260   ecosystems as a passive observer. Video games such as *Abzû* (2016, Giant Squid Studios), allow

261   the player to swim through ocean environments inhabited by a plethora of ancient aquatic

262   organisms from throughout geological time. *Robinson: The Journey* (2016, Crytek) utilises virtual

263   reality headset technology to create an immersive experience for the player who must journey

264   through a world inhabited by dinosaurs. This genre of game introduces the player to a diverse

265   range of flora and fauna from the ancient past but is relatively uncommon.

266

267   ### 3. Common palaeontological video game tropes

268   Within the context of this paper, a 'trope' is a recurring theme or motif that occurs across video

269   games. Although many tropes are considered clichés, they are still commonly used throughout

270   popular entertainment as recognisable touchstones to provide familiarity to the audience. Many

271   tropes seen in COTS video games are shared across the entertainment industry (especially in

272 television and film), however, due to the interactive medium of video games, some tropes are
273 unique to the format. Here we identify some of the most common tropes that appear in video
274 games, to highlight how palaeontological science is represented in pop-culture and the
275 entertainment industry, and to demonstrate that some tropes propagated by the video game
276 industry may be scientifically misleading and/or perpetuate harmful stereotypes.

277

278 *3.1 Ancient death machines: monsterification*

279 The most frequent use of ancient animals in video games is as enemies for players to combat.
280 Typically, these animals are designed to appear vicious, frightening, and brutish and this known
281 as 'monsterification'. This is often achieved by 'shrink wrapping' (reducing the organisms' soft
282 tissue until they are just skin and bone), increasing the animals body size to exaggerated
283 proportions, and grotesquely exaggerating features like claws, teeth, and horns. However,
284 monsterification is not limited to an organism's appearance — it can also include behaviour such
285 as being unrealistically aggressive, erratic and, most often, mindlessly and noisily torpedoing
286 towards their prey. By consciously combining these aspects, ancient animals are made to appear
287 more terrifying while also physically dissociated from real animals, meaning that players have a
288 guilt-free experience slaughtering them. Interestingly, Jański (2016) found that when extant
289 animals were used as background assets or companions for the player in video games, they were
290 more likely to be accurately represented, whereas when animals were depicted as enemies or
291 tools, their appearance and behaviour was more likely to be inaccurate, exaggerated, objectified
292 and even monsterified. Indeed, some games actively task the player to 'monsterify' ancient
293 animals: *Jurassic World: Evolution* encourages the player to breed dinosaurs to create hyper
294 aggressive monsters in order to have them fight each other for the entertainment of park guests.

295   Monsterification is not a novel concept nor is it unknown to science communicators. From
296 as early as the 19th century, palaeo-reconstructions have liberally and creatively portrayed
297 ancient life provocatively as monsters to stir the imagination and these images have permeated
298 into modern popular culture. However, for science communicators there are some important
299 aspects of monsterification that are not normally considered: 1) Monsterification is not restricted
300 to carnivorous animals in video games. Examples such as *Orion Prelude*, *Dinosaur Hunt* and
301 *Second Extinction* etc. utilise hyper aggressive herbivores such as stegosaurs, ceratopsians, and
302 ankylosaurs as opponents for the player to dispatch; 2) Monsterification is not limited to dinosaurs.
303 For example, *ARK: Survival Evolved* applies some degree of monsterification to almost every
304 animal in the game - several taxa are much larger than their fossil remains indicate (e.g.
305 *Diplocaulus, Paraceratherium* etc.), while the giant fish taxon, *Leedsichthys*, is coated in jagged

306   spikes and scutes, and is depicted as highly aggressive despite fossil evidence suggesting they

307   were filter feeding organisms. Similarly, *Far Cry: Primal* depicts ice age mammals as colossal,

308   aggressive monsters, and in the case of some animals, such as mammoths, twice the size of their

309   largest fossil remains; 3) Extreme monsterification can lead to a situation where ancient animals

310   are indistinguishable from and/or confused with mythical creatures. In *ARK: Survival Evolved* a

311   wide variety of ancient animals live alongside fictional animals such as wyverns, basilisks and

312   gryphons that the player can also interact with and tame. In-game information and even

313   achievements do not differentiate between the mythical and real animals which could lead to

314   confusion for some players.

315   Monsterification of ancient animals is not the same trope as video game monster designs

316   being heavily based on the appearance of ancient life. This is a very common trope in video

317   games, with examples including *Monster Hunter Rise* (2021, CAPCOM), where many of the

318   monsters clearly resemble theropod dinosaurs, and *Horizon Zero Dawn* (2017, Guerrilla Games)

319   where a post-apocalyptic world is populated by an ecosystem of mechanical creatures loosely

320   based upon extinct megafauna, including sauropod and theropod dinosaurs, as well as terror

321   birds, giant crocodyliforms and cave hyenas.

322

323   *3.2 Fossil = dinosaur =* Tyrannosaurus*: lack of palaeodiversity*

324   Since their discovery in the 1800's, dinosaurs have captured the public imagination. Today, that

325   popularity has continued, as dinosaurs dominate popular culture— so much so that they have

326   become almost synonymous with ancient life in the entertainment industry. The video game

327   industry is no different, with the vast majority of video games that incorporate ancient animals

328   featuring only dinosaurs (Figure 3). The perpetuation of this trope poses a challenge to science

329   communicators, as it instils a false impression to the audience of the lack of complexity to ancient

330   ecosystems, as well as diminishing ancient diversity and species distribution through geological

331   time and space.

332   Yet, even within this trope, the representation of dinosaur diversity is typically limited to a

333   handful of 'iconic' dinosaur species that are perpetually recycled by the entertainment industry

334   (Figure 4). Many of these species are well documented from North Americans fossil sites like the

335   Morrison or Hell Creek Formation, such as *Tyrannosaurus*, *Stegosaurus*, *Triceratops,*

336   *Brachiosaurus* etc., while other species that are commonly used are typically predatory (e.g.

337   *Velociraptor*, *Spinosaurus* etc.). Within the video game industry, this recycling of dinosaurs serves

338   a practical purpose: for smaller game developers, building new digital assets can be highly labour

339   intensive and costly. It makes commercial sense to use pre-made, often free, resources (e.g. 3D

340 models, animations, sound effects and reference material) to recreate popular and recognisable
341 dinosaurs, despite this further oversaturating their prevalence in the video game market place.
342 Another group of ancient animals that falls within the overused trope are the 'ice-age' animal pair
343 of the woolly mammoth (*Mammuthus primigenius*) and the sabre-toothed cat (*Smilodon sp.*). As
344 charismatic mega-mammals often used in media, they are recognisable to the public and often
345 used as more relatable monsters than dinosaurs in some video games (e.g. *Far Cry: Primal*; *The*
346 *Elder Scrolls V: Skyrim*, 2011, Bethesda Game Studios).

347 However, in recent years, there is a growing number of games that use a greater diversity
348 of dinosaur species as an active selling point to market the game. Park building games such as
349 *Jurassic World: Evolution* allows the player to send teams of scientists to real world fossil sites to
350 collect DNA from a host of lesser- known dinosaur species such as *Baryonyx*, *Huayangosaurus*,
351 *Proceratosaurus*, *Carcharodontosaurus*, *Tsintaosaurus* etc. Dinosaur simulator games such as
352 *Saurian* often feature lesser-known dinosaurs, while *Ark: Survival Evolved* features an abundance
353 of relatively obscure dinosaurs (e.g. *Yutyrannus*) but also Permian therapsids (e.g. *Moschops* and
354 *Lystrosaurus*), Mesozoic birds (e.g. *Ichthyornis* and *Hesperornis*) and Cenozoic mammals (e.g.
355 *Chalicotherium* and *Phiomia*). Although, many of these animals are still monsterified, and the
356 game proves the point of this section by referring to every ancient animal in the game as a
357 dinosaur in the in-game information.

358 As new games seek to find a niche within the gaming ecosystem, there are a number of
359 popular video games that feature and draw attention to even more obscure palaeo-taxa and time
360 periods. The hugely popular game, *Animal Crossing: New Horizons* tasked players with finding
361 fossils for display within a local museum and in so doing introduced players to a variety of
362 relatively niche groups such as *Anomalocaris*, *Acanthostega*, *Eusthenopteron* and
363 *Myllokunmingia.* Interestingly, these fossils (and others found by the player) are displayed in a
364 large phylogeny demonstrating evolutionary patterns in a simple but highly informative manner.
365 Another game, *Abzû*, features a large number of obscure aquatic ancient animals such as
366 ammonoids*, Anomalocaris*, *Arandaspis, Diplocaulus, Archelon* etc., although there is no context
367 or distinction of where/when these organisms lived for the player. *Ancestors: The Humankind*
368 *Odyssey* avoids this trope entirely by being specifically set in Miocene Africa, including a suite of
369 time-specific organisms such as *Stegotetrabelodon*, *Machairodus* and *Enhydriodon.* All of these
370 games introduce the player to organisms and concepts that they would have had limited (if any)
371 exposure to in other types of media.

372

373 *3.3 "Did you know...?": palaeotrivia and palaeodatabases.*

374   In order to help the player understand complex topics or to introduce elements of story, many
375   video games feature in-built encyclopaedias or glossaries containing fact-files about characters,
376   objects and locations integral to the game's setting. In games that feature palaeontological
377   themes, fact files, databases, and bonus trivia provide the ideal opportunity for optional, longer-
378   form, educational content that have the potential to inform and provoke further investigation from
379   players, especially those who were not necessarily attracted to the game for the science.

380   In-game encyclopaedias can be extremely informative. This is particularly common in park
381   management games such as *Jurassic World: Evolution* and the *Zoo Tycoon* series (2001–2017,
382   Blue Fang Games) that feature highly detailed databases about each ancient animal that can be
383   found in game, often incorporating facts pertaining to the organism such as where and when the
384   animal was discovered as well as general information. This information is not necessary to play
385   the game, but because such databases are detailed and well researched, they often add to the
386   'scientific' aesthetic of these types of games and are useful educational tools.

387   More typically encountered is the usage of 'palaeo-facts' within different elements of the
388   game. One excellent example is *Animal Crossing: New Horizons*, where Blathers, the strigiform
389   museum curator, will regale the player with light-hearted but informative trivia about each fossil
390   that is presented to the museum. Another example that is commonly employed is the use of
391   'palaeo-facts' to entertain the player on loading screens (i.e. a picture the player must watch while
392   the game is initialising). *LEGO Jurassic World* (2015, TT Fusion) uses this tactic to deliver bite-
393   sized informative facts about many of the dinosaur species encountered in the game.

394   Generally speaking, the incorporation of 'palaeo-facts' and databases are a good resource
395   for science communicators— assuming they are well researched and do not present
396   misinformation as facts. *The Sims 4* is a perfect example of misinformation being presented
397   alongside factual information. Various fossils can be found throughout the game world - including
398   trace fossils, trilobites, plants, and raptor dinosaur claws. However, issues arise because other
399   fossils items, ranging from the ridiculous (fossilised cow udders) to the bizarre ('perfectly
400   preserved moustaches') are presented as genuine fossil remains. While clearly light-hearted and
401   for comedic effect, the indiscriminate mixing of real and fake fossils is problematic and would not
402   necessarily be discernible for all players.

403   Tangentially, many of the games mentioned in this section have large, dedicated player
404   fan-bases who often form distinct online communities. In order to assist with completing aspects
405   of the games, many players create, edit and maintain sizable publicly editable online 'wikis' (an
406   online database resource). These online encyclopaedias not only provide game specific

407 information but often contain further reading and palaeo-trivia for interested players making them

408 a useful educational resource, however, the degree of moderation and fact checking varies wildly.

409

410 *3.4 The depiction of palaeontological science*

411 The perception of palaeontology as a scientific discipline is difficult to gauge in computer games.

412 Most palaeo-video games convey good palaeontological communication by explicitly integrating

413 physical and biological processes into gameplay and world-building that will, either directly or

414 indirectly, increase the knowledge of the player. However, most games typically focus on very

415 specific aspects of palaeontology (e.g. fossil collection, genetics, evolution) and can take creative

416 liberties in order to make engaging gameplay mechanics. This can mean that the player may get

417 an inaccurate or misleading representation of palaeontological science. We discuss some of

418 these below.

419

420 3.4.1 *Geological processes*

421 Though it is often taken for granted, many open world video games heavily rely on aspects of

422 climate, topography, biomes and even natural disasters to create realistic settings, the exploration

423 of which can subtly communicate basic earth science to the player. For example, *American Truck*

424 *Simulator* (2016, SCS Software) allows players to take virtual road trips across a scaled down

425 version of the United States including many famous North American fossil localities (e.g. Dinosaur

426 National Monument, Colorado, USA). Enormous effort is taken to accurately capture the surface

427 geology, flora and fauna and how climate varies from east to west. Other games incorporate

428 geological processes to build the game world for the player to explore. *Subnautica* (2018,

429 Unknown Worlds Entertainment) is an underwater survival/horror game based in the crater of a

430 guyot (a submerged volcanic seamount) on an alien planet. The explorable map is separated into

431 distinct biomes, some of which contain large fossilised remains that have been preserved

432 because of the specific environmental conditions of that area. The processes of how these fossils

433 form (e.g. taphonomy) is explained to the player by scanning the fossils with scientific equipment

434 in their inventory.

435 As computing power increases, greater graphical fidelity allows more accurate geological

436 features to become standard in computer gaming and as a tangential effect this can be used by

437 science communicators in engagement activities. During the recent COVID-19 pandemic, where

438 travel was restricted, some academic institutions created virtual field trips for their students using

439 technology commonly utilised by video gamers (e.g. VR headsets; Klippel *et al.* 2019).

440 Furthermore, video game engines allow complex geological features to be explored in ways that

441   would be difficult for actual students in the field (e.g. utilising aerial imagery; Klippel *et al.* 2020).
442   This demonstrates that video games have great potential for geological engagement, especially
443   for players who are unable to access key sites due to travel restrictions or accessibility issues,
444   not to mention the reduced environmental cost associated with virtual fieldwork.
445
446   3.4.2 *Depicting evolution*
447   Evolution is a common theme in video games. It should be noted that the term 'evolution' is,
448   however, used to encompass a host of different game mechanics that do not accurately represent
449   the biological process and this may skew the player's understanding of the phenomenon. One
450   example of the term 'evolution' being misused is as a levelling up mechanic. In the *Pokémon*
451   franchise, the Pokémon 'evolve' into larger, more powerful forms as they gain more experience
452   and level up, despite the process actually being a type of metamorphosis.
453   Another common misuse of the term evolution applies to games where novel
454   morphological traits are acquired via predation. In *Spore* (2008, Maxis) players must guide the
455   'evolution' of their own custom creatures from microscopic organisms to an interstellar empire by
456   acquiring new evolutionary traits by scavenging them from the creatures they ingest. This
457   depiction of 'evolution' is also seen in *E.V.O.: Search for Eden* (1992, Enix) where the main
458   character begins as a generic fish, and must acquire teeth, jaws, limbs, and other features by
459   eating prey items as they advance through levels inspired by different geological eras. This
460   gameplay mechanic re-enforces the trope that evolutionary changes are a result of a conscious
461   decision by an organism as opposed to random traits that are coincidentally beneficial (to better
462   survive in the environment, for example) and thus are more likely to be passed to the next
463   generation via natural selection.
464   Other games tackle evolution as a gradual process with greater nuance, however many
465   of these games are limited by the need for fun game mechanics. In *Cell to Singularity: Evolution*
466   *Never Ends* (2018, Computer Lunch) the player clicks or taps the screen to acquire currency,
467   which is spent to advance Earth history in short steps. The game is presented as a branching tree
468   with each node representing a new species or event, however the order in which evolutionary
469   milestones are achieved is entirely arbitrary, presenting evolution as a simplified linear checklist
470   of sequential events. Even games that accurately depict ancient organisms and past
471   environments often portray the processes of evolution poorly. *Ancestors: The Humankind*
472   *Odyssey* depicts the evolution of early humans as distinct leaps from one species to next as
473   opposed to multiple species coexisting at the same time. Similarly, the game also refers to the
474   levelling up mechanic of learning new skills and abilities, such as being able to use tools, as

475   'evolution'. By presenting evolution as an oversimplified, linear process, it also reinforces the

476   outdated notion that humans are the pinnacle end product of evolution.

477   Conversely, some games approach evolution from a palaeontologist's perspective, using

478   fossils to infer evolutionary patterns. In the puzzle game *Fossil Corner* (2021, Overfull Games),

479   the player is given a box of procedurally generated fossils and is tasked with resolving their family

480   tree by observing morphological character changes through each generation. This introduces the

481   player to the concepts underlying maximum parsimony, a method to generate phylogenetic trees

482   for extinct organisms commonly used by palaeontologists. As such, *Fossil Corner* is a good

483   example of Digital Game Based Learning (DGBL).

484   While video games are potentially a great way to introduce players to the complex process

485   of evolution, it should be remembered that COTS games must prioritise delivering engaging

486   gameplay far above educational content.

487

488   *3.4.3 Cloning and resurrecting extinct animals*

489   One aspect of palaeontological science that consistently arises in video games is cloning/de-

490   extinction. The *Jurassic Park* (Crichton, 1990) franchise popularised the concept of extracting

491   genetic information from fossiliferous material in order to clone ancient animals. This concept

492   pervades video games based on the franchise such as *Jurassic World: Evolution but* is also

493   prevalent in many other video games. For example, in *Terraria* (2011, Re-Logic), ancient amber

494   is one of many natural resources that can be collected by the player and each piece has a tiny

495   chance of containing a fossil mosquito. The player can then process the fossiliferous amber using

496   an 'extractinator' to resurrect a pet baby dinosaur. In *Pokémon Red/Blue* the player receives a

497   fossil as a reward and can take it to a laboratory on Cinnabar Island, where a scientist will

498   resurrect the extinct Pokémon. This is taken to the extreme in *Pokémon Sword* and *Pokémon*

499   *Shield* (2019, Game Freak), where the palaeontologists take the player's fossils, splice them

500   together, and resurrect them into horrific, often unviable, chimaeras.

501   It is often not made clear to players that, currently, we are not able to 'resurrect' extinct

502   animals, nor can we extract viable genetic material from fossils. Generally, there is very little

503   nuance in video games regarding the depiction of the growing field of palaeo-proteomics (i.e., the

504   study of ancient proteins) and the recent advances that have been made in the last decade (see

505   Buckley *et al.* 2018). Furthermore, there is very little discussion in any video games about the

506   ethical considerations of de-extinction and this should be considered by science communicators

507   when discussing this popular and exciting field of science.

508

509   3.4.4 *Keeping up with science*

510   Most media is dated by the science it is based on. A classic example is the *Jurassic Park*

511   franchise, which was lauded for its exciting and scientifically accurate dinosaurs when the first

512   film was released in 1993. However, as the series has progressed, it has chosen to maintain a

513   distinct aesthetic rather than keeping up-to-date with the current scientific understanding.

514   Similarly, while video games can be limited by graphical constraints (due to the computing power

515   of the consoles or graphics cards they are designed for; see Figure 4), many games choose to

516   be scientifically inaccurate because of the need for recycled assets or because they have a

517   specific aesthetic (e.g. *Jurassic World: Evolution*). However, unlike other types of traditional

518   media, modern video games do not necessarily need to suffer from ageing. This is because PC

519   and (most) game consoles are connected to the internet, meaning game developers (and even

520   fan communities) can issue updates and 'mods' (modifications) that update gameplay, graphics,

521   or visual assets indefinitely after the games are released. Therefore, new fossil discoveries can

522   be incorporated into game updates to keep games scientifically up-to-date. However, this relies

523   on the game developer issuing updates, which may not be viable due to financial or time

524   constraints. One example of this is *Animal Crossing: New Horizons*, which was released in March

525   2020. The game contains a skeleton of *Spinosaurus* that the player can find, accession, and

526   mount in their museum. Three weeks after the games release, however, Ibrahim *et al.* (2020) was

527   published, which detailed a new *Spinosaurus* specimen from Morocco that had a previously

528   unknown tail section that was of significant scientific and public interest. This hype caused

529   considerable media interest in whether the game developers of *Animal Crossing*, Nintendo

530   Entertainment Analysis & Development Division (EAD), would update the visual asset in line with

531   this new discovery (Watts, 2020; Rochlin, 2020). As of publication, the *Spinosaurus* model in

532   *Animal crossing* has not been updated.

533   Inevitably, any released COTS video game will be overtaken by palaeontological

534   advances and rendered out-dated, especially if developers are no longer working on updates for

535   the game. From a science communication perspective, outdated game design can still be used

536   to engage with the public, allowing scientists to communicate up-to-date science, but also the

537   history of scientific thought, and to explore the ever-shifting process of scientific discovery, to our

538   audiences.

539

540   3.4.5 *Depicting palaeontological fieldwork*

541   Collecting raw materials is an extremely common game mechanic, and often many games use

542   fossils as a resource. In most of these games, fossils are acquired by approaching specific types

543   of rock and breaking them with a tool (e.g. *The Sims 4; Stardew Valley, No Man's Sky,* etc*.)* or by

544   digging holes in specific locations (e.g. *Animal Crossing: New Horizons* etc.) In *Red Dead*

545   *Redemption 2*, fossils can just be collected off the ground (albeit often in hidden or difficult to

546   reach locations) while fossils can be found in *Stardew Valley* by just fishing in streams in

547   fossiliferous areas. Because fossil extraction is so common in video games, it can give the

548   impression that fossil extraction is effortless and that fossils are a common occurrence in all rock

549   types.

550   Some games do take a more nuanced approach to fossil collection. In *Starbound,* fossils

551   can only be uncovered with specialised tools, such as brushes and rock hammers, and failure to

552   carefully extract the fossil bearing rock permanently destroys the fossil. Once collected, fossils

553   can be placed in customisable display cabinets at the player's base, which features a placard with

554   basic trivia. *Tap! Dig! My Museum!* (2019, Oridio) is a mobile game where the player manages a

555   museum, but also takes part in prospecting and excavating dinosaur skeletons. By tapping the

556   screen, the player can remove layers of rocks piece by piece to find individual bone elements.

557   Although highly stylised, the game does represent the processes of uncovering and transporting

558   fossils in a fieldwork setting.

559

560   3.4.6 *Representation of ethics in palaeontological video games*

561   Palaeontology has a long colonial history with deep rooted extractive and exploitative practises

562   (Monarrez *et al.* 2021). Because many harmful practises (such as the erasure of indigenous

563   contributions, the illegal acquisition/removal of fossil material from their country of origin by higher

564   income countries, the refusal to repatriate fossil material, etc. — see Monarrez *et al.* 2021, Raja

565   *et al.* 2021) are so ingrained within palaeontological science, they often appear within video

566   games unchallenged with little objective analysis. For example, to clone more dinosaurs and

567   expand your park in *Jurassic World: Evolution,* the player must send dig teams to sites across the

568   globe to extract more fossil genetic material. These dig sites are based on real-world localities,

569   which is a good educational tool. However, many of these sites have strict laws governing the

570   removal and sale of fossils, for example Mongolia, where it has been illegal to remove fossils from

571   the country for almost 100 years. This is ignored in gameplay, obscuring a complex legal and

572   ethical situation which players could learn from.

573   One of the most contentious ethical issues facing palaeontology is the buying and selling

574   of fossils (Shimada *et al.* 2014) especially in relation to the illegal exportation and smuggling of

575   fossil material (e.g., Pérez Ortega, 2021) and the consequences of this illicit trade e.g. fuelling

576   humanitarian crises in Myanmar (Dunne *et al.* 2021; Raja *et al.* 2021). It is extremely common for

577   video games to casually incorporate the selling of fossils into gameplay. In virtually every game
578   featuring fossils as collectibles, excess fossils exist purely to be sold for profit. For example, in
579   *Jurassic World: Evolution*, the game is designed so that any fossil found by the player that is not
580   a dinosaur must be sold instantly to raise funds for the player. In the space exploration game *No*
581   *Man's Sky* (2016, Hello Games), the players can journey between planets and can find fossils on
582   the worlds they visit, however, these fossils serve no function other than to be sold for in-game
583   currency. Even in games that otherwise represent museum curation and fossil finding in a positive
584   and educational manner such as *Animal Crossing: New Horizons*, fossils are among the most
585   financially valuable natural resources available. Once a fossil has been donated to the museum
586   by the player, any duplicates found can be sold at the local market for in-game currency. These
587   games do little to challenge unethical practises and normalise the commercialisation of
588   fossiliferous material as a standard procedure within the palaeontological community. We
589   therefore suggest that it is vital that science communicators are aware of this and incorporate
590   issues such as ethical fossil extraction and fossil ownership into public engagement to counter
591   this narrative where possible.
592
593   *3.5 Male, pale and stale: the depiction of palaeontologists in video games*
594   COTS video games introduce the public to palaeontologists and allied workers, however, the
595   diversity of and representation of palaeontologists in video games is very limited.
596   Often scientists and/or palaeontologists are portrayed in video games as old, white men
597   often resembling Charles Darwin (e.g. Professor Snail in *Stardew Valley* etc.). Another common
598   trope is the perpetuation of the 'Indiana Jones stereotype' (Fitzpatrick, 2020). For example,
599   *Dinosaur Fossil Hunter* (Demo released 2020, Pyramid Games) is a 'palaeontologist simulator'
600   which aims to simulate fossil discovery, digging, and extraction (even tasking players with
601   jacketing fossils in plaster). However, at the time of publication, the game uses only a white male
602   character model to market the game — complete with stereotypical fedora. Not only does the
603   reliance on these characters re-enforce the perception of palaeontology as a white male
604   dominated science (Panciroli, 2017), but they also propagate the 'brilliant lone scientist' trope
605   (Black, 2019), failing to showcase the collaborative work that is actual palaeontological science
606   and fieldwork.
607   Some palaeo-video games do have more diverse casts. However, these characters are
608   always able bodied, often poorly fleshed out characters, and are typically plagued with
609   questionable motives and ethics. For example, in *Jurassic World: Evolution* the player must liaise
610   with Dr Kajal Dua, the head of the science division. However, her character has almost no

611 backstory and often undermines her position as a scientist by tasking the player to undertake
612 ethically dubious missions such as cloning dinosaurs specifically bred to be hyperaggressive
613 when combatting other dinosaurs. Likewise, the cowboy simulator *Red Dead Redemption 2* has
614 the player meet an older white woman digging up fossils on the American frontier of 1899. The
615 player learns that she, like many women in the nineteenth century, has been rejected from several
616 universities and that no other academics take her scientific ideas seriously. She resembles and
617 is most likely inspired by Mary Anning, the most famous of the multitude of female
618 palaeontologists overlooked by their male peers. After the player collects a number of fossils from
619 across the game world to help her with her research, she assembles a biologically impossible
620 chimaera, and reveals herself to have been a terrible scientist all along. The game could have
621 included some genuine information about the infamous Bone Wars of early American
622 palaeontology, and about women fighting for their place in science but, by including a female
623 character who validates every rejection she was served, a potentially interesting characterisation
624 and story (and the potential to educate players on such) was lost.

625 Historically and stereotypically, able bodied white men have dominated the narrative of
626 palaeontology, and this in turn has shaped the depiction of palaeontologists in media, especially
627 video games. The systematic lack of diversity in the earth sciences, especially palaeontology, is
628 well known (Bernard & Cooperdock, 2018; Warnock *et al.* 2020). One potential aspect that
629 contributes to the lack of diversity (amongst many) in palaeontology, is the lack of minority role
630 models (Panciroli, 2017). The poor representation seen in COTS video games fails to counteract
631 this — if minority players, who may be prospective students and future scientists, do not see role
632 models represented in games and only see white male faces, they may be discouraged from
633 pursuing their interest in earth science. This is especially relevant to games that are marketed as
634 'palaeontologist simulators' but only contain white, able bodied, male characters.

635

636 *3.6 Perpetuation of harmful, misogynistic, and racist tropes in palaeo-games.*

637 Video games have a history of perpetuating problematic tropes, especially ableism, sexism,
638 misogyny, and racism. Although these tropes are not specific to palaeo-video games, they do
639 warrant attention from science communicators as they can have an impact on how palaeontology
640 may be perceived by players.

641 A common problematic video gaming trope is the hypersexualisation of women (Beasley
642 & Standley, 2002). Evidence shows that the negative representation of women in video games
643 can have severe negative effects for female gamers including self-objectification and low levels
644 of self-efficacy (see Gestos *et al.* 2018). One of the most egregious examples of casual

645 hypersexualisation seen in a palaeo-video game is found in *Trespasser* (1998, DreamWorks
646 Interactive), where the player's character, Anne, is stranded on a dinosaur infested island. The
647 game does not feature any visual cues for the player (i.e. health or ammunition counters) and so
648 in order to check the health of the character, the player must actively look down to check a heart
649 shaped tattoo on her breast that fades as the player is closer to death. Analysis has shown that
650 hypersexualisation of women video game characters has decreased since the 1990s (Lynch *et*
651 *al.* 2016), with a notable example being the de-sexualisation of Lara Croft, the protagonist of the
652 *Tomb Raider* franchise, in recent games. While female lead characters are becoming more
653 commonplace (e.g. Aloy, the lead character in *Horizon Zero Dawn*), it should be noted that Lynch
654 *et al.* (2016) found COTS video games still typically depict female characters in secondary roles
655 and that these characters are more sexualised than their male counterparts. Furthermore, within
656 palaeontological video games, sexist and misogynistic tropes can also be coupled with racism
657 often thanks in part to the perpetuation of the "lost world" fantasy genre which pervades palaeo-
658 adjacent culture. Based on the Arthur Conan Doyle book *The Lost World* (1912), where an ancient
659 ecosystem is found in the Amazon basin by white explorers, this genre combines palaeontology,
660 colonialism, and the mystification and exotification of indigenous cultures (see Harrer 2018). Many
661 aspects of this sub-genre are harmful, propagating damaging stereotypes, economic oppression,
662 and cultural appropriation. Care should be taken by scientific communicators to not disseminate
663 these damaging tropes if using video games as part of their engagement, but also take further
664 action by actively highlighting and challenging these practises within our field.

665

666 4. *Conclusion*

667 Video games are culturally prolific, and this sector is rapidly becoming one of the largest
668 entertainment markets in the world. Palaeontological themed video games are extremely popular,
669 and because of this, increasing numbers of the public are being exposed to ancient animals and
670 palaeontological science, far eclipsing engagement efforts that can be undertaken by scientists
671 and allied palaeo-workers. Many COTS video games have a positive impact on the audience and
672 may promote an active interest in palaeontology. Many contain elements of good science
673 communication;and some games, especially dinosaur simulators, strive for scientific accuracy.
674 However, as with most types of media, palaeontological video games can contain a suite of
675 negative and potentially damaging tropes. Many of these tropes are widespread issues in the
676 gaming industry (e.g. poor representation, monsterification, hypersexualisation, etc.), but their
677 presence in palaeontological video games specifically impacts their use as science
678 communication tools. As science communicators we should undertake careful examination before

679 using specific COTS video games as educational tools. Furthermore, we should challenge
680 harmful tropes in our engagement and outreach efforts to the public and, if possible, to COTS
681 video game developers. By raising awareness of these damaging tropes, we can relegate them
682 into extinction.

683

692

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694 **Conceptualization**: Clements, Atterby. **Methodology**: Clements, Atterby, Cleary, Dearden,
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696 Clements, Atterby, Cleary, Dearden, Rossi. **Data Curation:** Clements, Atterby. **Writing - Original**
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704

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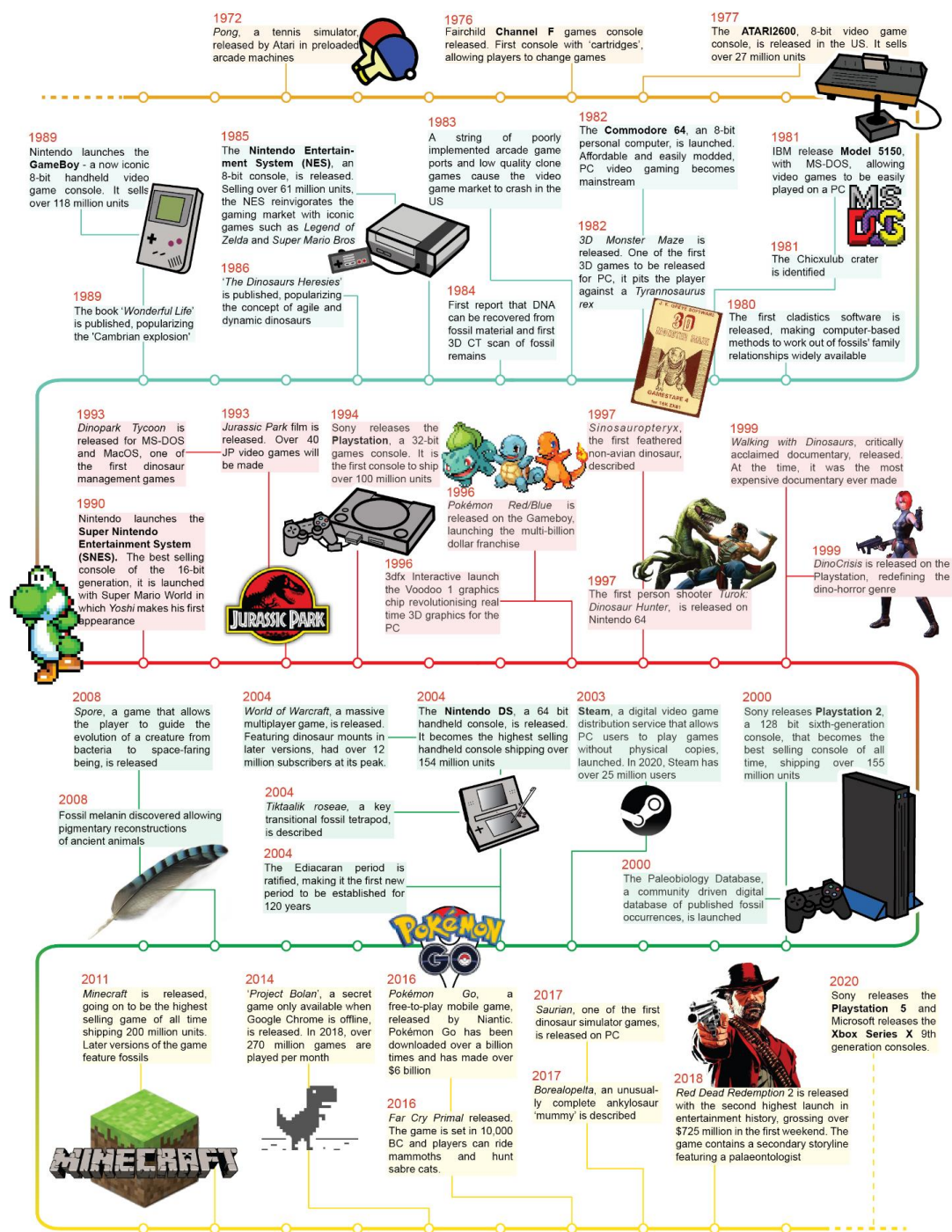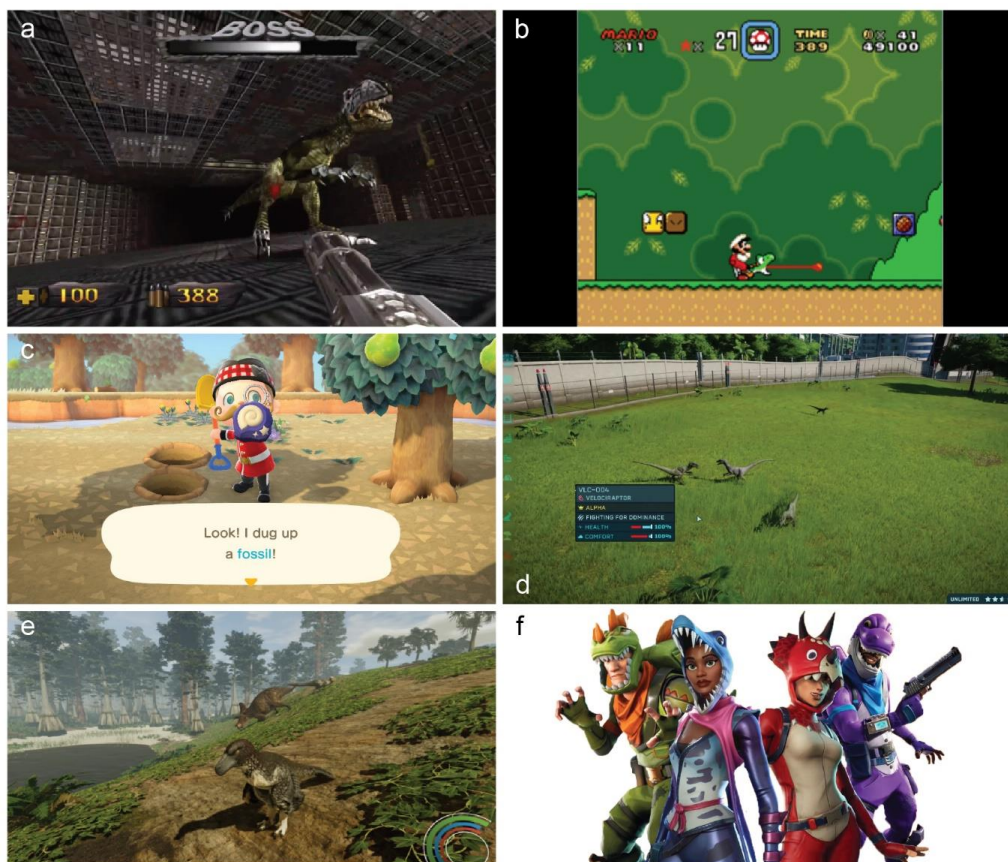
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713 Figure 1. A timeline of major events in palaeontology, video games, and palaeontological video

714 games between 1970–2020.

Figure 2. Screenshots of COTS video games that represent the 5 categories of palaeontological video games outlined in this paper. a) Ancient animals as adversaries. The player is fighting a cybernetically enhanced *Tyrannosaurus* armed with laser shooting ocular augments and fire breath in *Turok: Dinosaur Hunter* (1997, Iguana Entertainment). b) Ancient animals as tools. Mario riding Yoshi in *Super Mario World* (1990, Nintendo EAD). c) Fossils as collectables. The player discovers a fossil in *Animal Crossing: New Horizons* (2020, Nintendo EAD). d) Ancient animal management simulators. A paddock of velociraptors exhibiting modelled in-game behaviours (the alpha is fighting for dominance of the pack). *Jurassic World: Evolution* (2018, Frontier Developments)*. e) Ancient animal simulators. The player's avatar, a *Dakotaraptor*, sits near a water body while *Triceratops* and *Pachycephalosaurus* graze in the background. *Saurian*, (2017, Urvogel Games, LLC). f) Examples of cosmetic items that are based on ancient animals from *Fortnite* (2017, Epic Games) - often these only change the players character models (and not core gameplay mechanics) and are known as 'skins'.
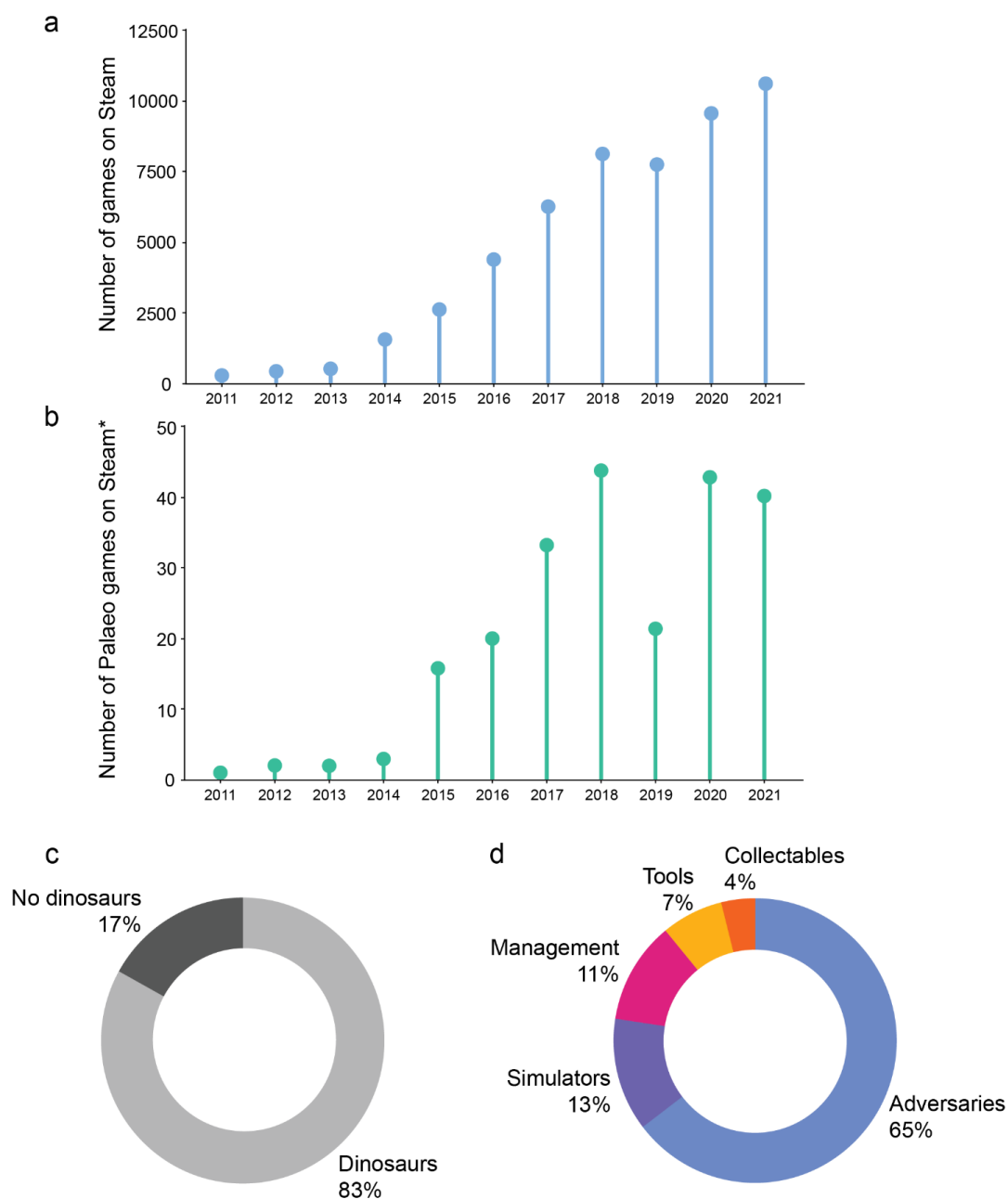
Figure 3. a) Number of PC games released per year on Steam, the largest video game digital
distribution service. b) Number of games released that utilise palaeontological keyword 'tags' on
Steam. c) Percentage of palaeontological COTS video games on Steam that contain dinosaurs
versus those that only contain non-dinosaurian ancient animals (excluding crown group birds). d)

734 Breakdown of palaeontological COTS video games on Steam by categories identified in this
735 paper. Source a: https://steamdb.info/ (accessed March 2022). Source b, c, d: https://statista.com
736 (accessed March 2022). A full list of the palaeontological COTS video games on Steam and 'tags'
737 searched can be found in the supplementary material.
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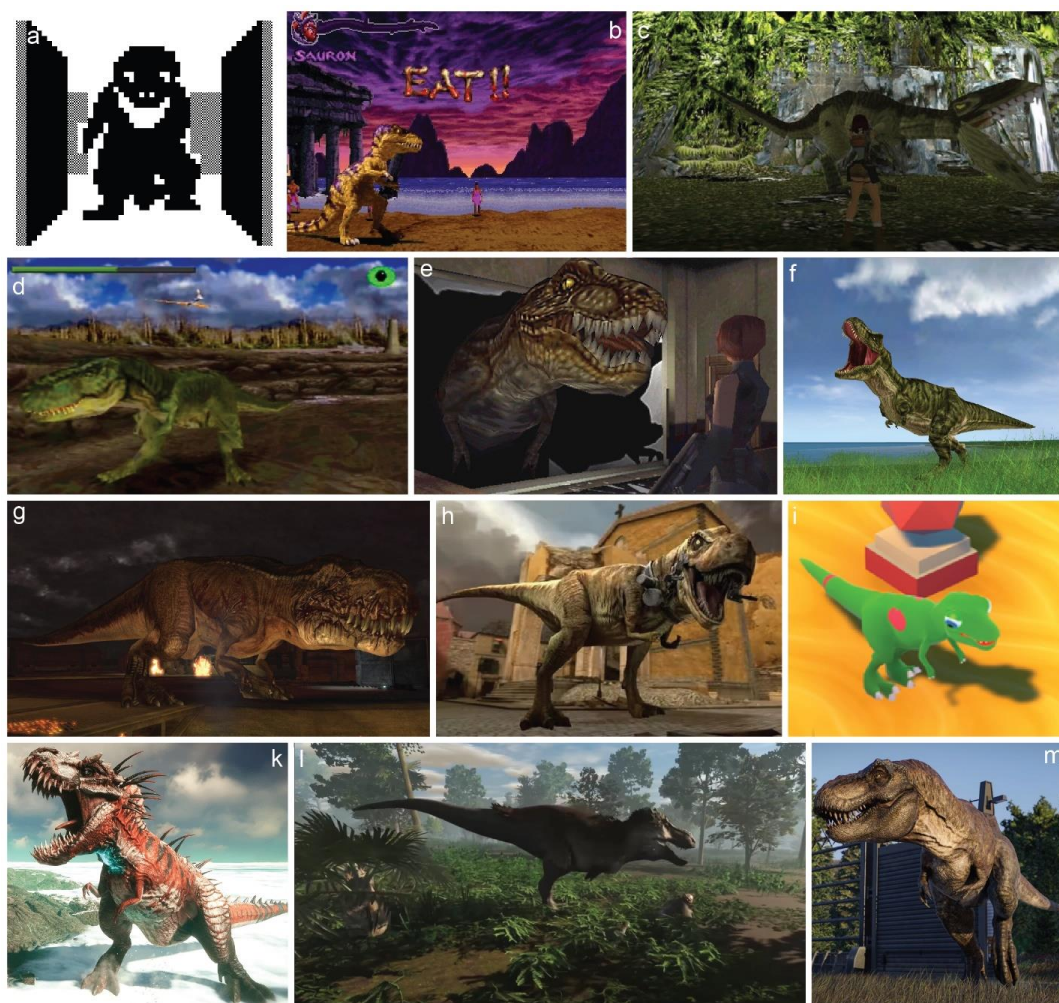
Figure 4. The representation of *Tyrannosaurus rex* in COTS video games through time. a) *3D Monster Maze* (1982, J. K. Greye Software). PC. b) *Primal Rage* (1994, Midway Games West Inc) Super Nintendo Entertainment System. c) *Tomb Raider* (1996, Core Design). Playstation. d) *The Lost World: Jurassic Park* (1997, DreamWorks Interactive). Playstation. e) *Dino Crisis* (1999, CAPCOM). Playstation. f) *Jurassic Park: Operation Genesis* (2003, Blue Tongue Entertainment). PC. g) *Turok* (2008, Propaganda Games). PC. h) *Dino D-Day* (2011, Digital Ranch). PC. i) *Parkasaurus* (2020, Washbear Studio). PC. j) *Second Extinction* (2020, Systemic Reaction). PC. k) *Saurian* (2017, Urvogel Games, LLC). PC. l) *Jurassic World: Evolution 2* (2021, Frontier Developments). PC.

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