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USING POP-CULTURE TO ENGAGE STUDENTS IN THE CLASSROOM

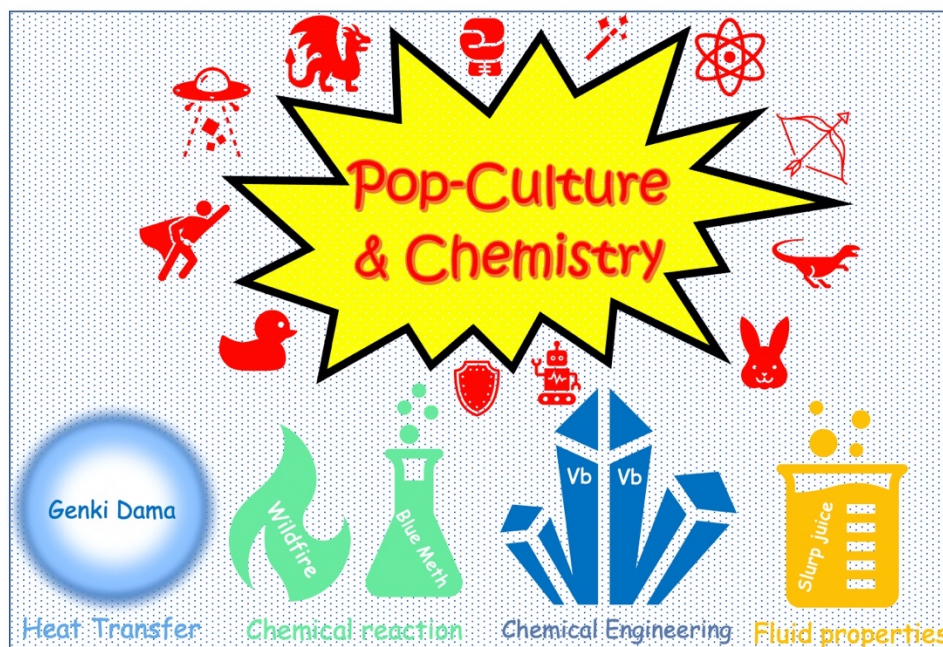
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■ ABSTRACT

Herein, we describe how video games, TV shows or movies have been used to provide an innovative framework for students to think about chemistry and chemical engineering. The main objective of this paper is to show how science can be linked with pop culture, to provide educators with recent materials to use in classrooms, and to discuss the benefits and limitations of such tools. The videogames Fortnite, Spiderman and Angry Birds, the TV shows Game of Thrones and Breaking Bad, the Marvel movies, and the animated programs Raving Rabbids and Dragon Ball are used to illustrate different approaches to engage with students and encourage them to learn in a more recreational environment.

■ GRAPHICAL ABSTRACT



■ KEYWORDS

General Public, Chemical Engineering, Collaborative / Communication / Writing, Humor / Puzzles / Games, Reactions / History, Philosophy/ Inquiry-Based/Discovery Learning, Physical Properties, Student-Centered Learning

31 ■ INTRODUCTION

32 Attracting a general audience to chemistry and chemical engineering topics is a
33 significant challenge^{1,2} and developing stimulating, alternative teaching methods is
34 important for educators in all disciplines. In several articles, authors describe aspects
35 of popular culture³ to teach chemistry using resources that are part of everyday life to
36 engage students more effectively. Chemistry classes have been supplemented with
37 material from arts such as music⁴⁻⁷ (including jazz⁸ and opera^{9,10}) and paintings¹¹⁻¹³
38 (including fashion art¹⁴), history¹⁵⁻¹⁸, archaeology¹⁹⁻²¹, or literature²²⁻²⁷. As examples,
39 educators illustrated chemistry with a Shakespeare's play²⁸ while others found
40 inspiration in detective cases where chemistry was used by the perpetrator of a crime or
41 in their identification^{29,30}. The chemical references from Ian Fleming's *James Bond*³¹
42 series of novels were used to illustrate chemical reactions and substances (sedatives,
43 rocket fuels, *etc.*). The *Harry Potter* novel series also offered an opportunity to reproduce
44 wizardry experiments³² in a chemistry lab (*e.g.* with invisible and color-changing inks,
45 colored flame in a jam-jar). Famous characters from the *Sherlock Holmes* stories (from
46 Conan Doyle's novels) have been used to create a fictional mystery based on
47 chemistry³³⁻³⁵, as has a murder novel of Agatha Christie³⁶. Michael Crichton's novel
48 *Jurassic Park*³⁷ has been an inspiring source of discussions on the chemical defense of
49 plants or chemicals used by animals for communication. Cartoons^{38,39} and comic
50 books⁴⁰ can also illustrate chemical principles (*e.g.* microscale chemistry in *Archie's*
51 comic book⁴¹ or general chemistry in *Dick Tracy*⁴²⁻⁴⁵, *DC Comics*⁴⁶ or *Marvel comics*⁴⁰).
52 Recently, lab safety rules have been presented to students with comics⁴⁷, graphic novels
53 and mangas⁴⁸. Beyond novels and comics, movies are currently one of the biggest
54 providers of pop-culture^{49,50}. The list of movies used to illustrate chemistry is
55 impressive, including for example *Apollo 13*⁵¹, *October Sky*⁵², *Star Trek*⁵³ and many
56 others⁵⁴⁻⁵⁸. The omnipresent *Marvel* franchises often invoke various areas of chemistry
57 and chemical engineering such as nanotechnology in the suits of *Iron Man*⁴⁰, properties
58 of the fictional metal vibranium in *Black Panther*⁵⁹, the quantum realm in *Ant-Man*⁶⁰, or
59 material sciences in *Spider-Man*⁶¹. Television is also a good way to illustrate chemistry⁶²

60 and famous shows used for this purpose include *The Price is Right*⁶³, *The Big Bang*
61 *Theory*⁶⁴, *CSI*⁶⁵, *The Simpsons*⁶⁶, *Bones*⁶⁷, *ER* and *House*⁶⁸. Trending games⁶⁹⁻⁸⁹ are also
62 an interesting pathway to involve students in general chemistry courses⁹⁰⁻⁹⁷. Educators
63 have included pop-culture elements to solve educational escape games, *e.g.* to unveil
64 the name of a super hero (Clark Kent from *Superman*) or famous gimmicks of a
65 character^{88,98} such as “Bazinga” from the TV series *The Big Bang Theory*. Moreover,
66 while many educators have successfully used pop-culture themes to introduce their
67 students to scientific concepts, educators have continually tried to use new techniques
68 to engage their students, such as the creation of a Science Café on the pop-culture
69 theme⁹⁹. Video games¹⁰⁰ have become an increasingly important part of the
70 entertainment industry, and they are also considered a form of art¹⁰¹; surprisingly the
71 use of videogames to illustrate chemistry or chemical engineering¹⁰² is relatively
72 unexplored in the literature even though pedagogical videogames exist¹⁰³⁻¹⁰⁵. Video
73 games being used directly in education is an increasingly popular research topic and
74 even just playing commercial video games has been shown to benefit important skills in
75 adult learners like effective communication, executive function, and resourcefulness¹⁰⁶⁻
76 ¹⁰⁸. Though these examples have been focused on skills-based learning, using video
77 games for content-based learning in chemistry such as described below is beginning to
78 be explored. The most notable example can be seen in the recent work by Smaldone, *et*
79 *al.* where the authors presented a modified version of the popular video game *Minecraft*
80 called *PolyCraft World*. In the game, the player collect resources and uses chemical
81 refinement and synthesis techniques to craft equipment and materials in the game¹⁰⁹.
82 Initial results indicated that students who played the game learned advanced chemistry
83 even without grading incentive or traditional classroom instruction. Given the difficulty
84 of creating an engaging game content *de novo*, finding existing popular games to modify
85 or for insight into how games can be used for educational purposes like *PolyCraft World*
86 is an important resource. The main objective of this paper is to explore recent pop-
87 culture references and the untapped potential of videogames for teaching purposes and
88 more broadly propose new approaches to link chemistry/chemical engineering and pop

89 culture. We present a range of activities inspired by videogames but also TV shows and
90 recent movies, with their context and materials for implementation by the wider
91 community. In a first section, three different activities that have been applied with
92 students will be presented and the feedbacks from students' are discussed; in a second
93 section, some additional activities used for outreach events are described.

94 ■ ACTIVITIES

95 We report here activities related to the videogames Fortnite, the TV shows Games of
96 Thrones and Breaking Bad and the movie Black Panther. All these activities were tested
97 and evaluated with students' (see supplementary information for more details about the
98 activities).

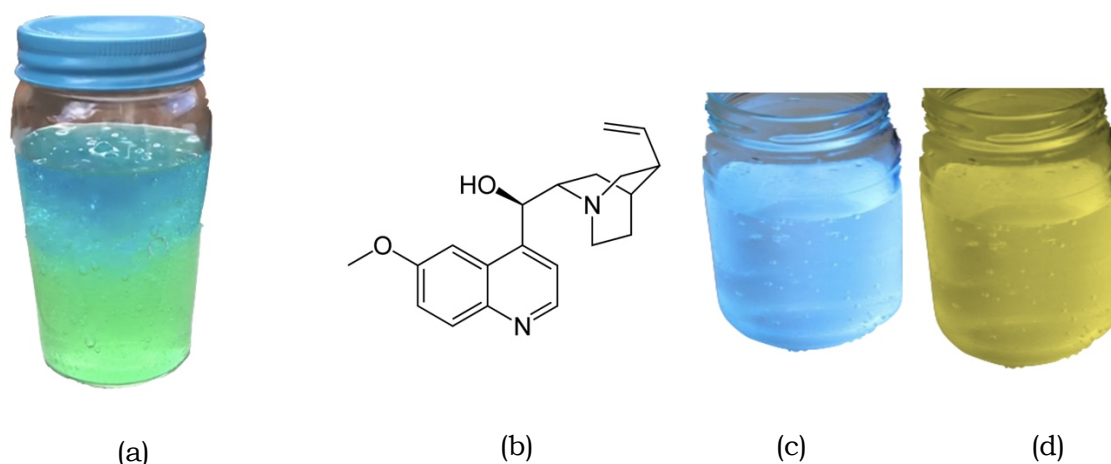
99 FORTNITE

100 *Fortnite* is an online video game developed in 2017 by Epic Games. The game mode
101 includes a free-to-play battle royale game where up to 100 players fight in increasingly
102 smaller spaces to be the last person standing. The game has cartoon graphics and does
103 not present graphic violence such as bloodshed. Fortnite Battle Royale became a
104 resounding success, drawing in more than 125 million players in less than a year and
105 earning hundreds of millions of dollars per month. In early 2018, students of
106 Tippecanoe High School in Ohio, USA, used a social media platform to challenge their
107 professor to have a *Fortnite*-based final exam in chemistry. Although there is no report
108 on how this story ended, it motivated the authors of this article to develop a new
109 *Fortnite*-based protocol for chemistry classes that could be used by teachers facing a
110 similar situation.

111 The videogame *Fornite* is more oriented toward physics than chemistry (*e.g.* bullet
112 and rocket trajectories, amount of force per impact of projectiles, etc.). Nevertheless, in
113 the game, once players have landed on the map, they must scavenge for weapons,
114 resources and other items. The objective of this activity is to reproduce in the lab
115 several items present in the Fortnite video game to illustrate simple chemical reactions.
116 One of these items is the “*slurp juice*”, a consumable that adds shield and health points
117 to the character. This item is represented by a two-colored viscous fluid with beads in a

118 jar, which could be prepared in the chemistry lab with a teacher. The fluids can be
119 made as slime paste using common material (hot water, a spoonful of borax, and glue)
120 or chemical products (water, polyvinyl alcohol, and boric acid) in order to illustrate the
121 mechanism of polymerization of polyvinyl alcohol¹¹⁰. This activity is recommended for
122 middle school students', high school students' or even for beginners in chemistry at
123 University level. Materials and methods for this activity are detailed in the
124 supplementary information. Some glass beads and dyes (green for the bottom fluid and
125 blue for the top fluid) can be added after the polymerization in order to improve the
126 resemblance to the “real” *slurp juice* as depicted in Figure 1.a. The polymer unique
127 properties (of both a solid and a liquid) can first be discussed in the classroom. Then
128 experiments can be planned to answer the following questions:

- 129 i) How can you make the polymer stretch the farthest?
130 ii) Does the amount of borax added change the slime structure?
131 iii) What method of storage will make the polymer last the longest?
132 iv) What brand of glue makes the stretchiest polymer?
133 v) Does the amount of water added to the glue affect the gooeyness of the
134 potion?



135 **Figure 1.** Example of *Fortnite* items that can be made in the chemistry lab: (a) “*slurp juice*” (b) the quinine
136 molecule (c) “*shield potion*” (d) “*stink bomb*”.

137 A second famous item in the game is the “*shield potion*”, a glowing blue liquid in a jar
138 with gems floating inside. This item can be easily made using tonic water and a black
139 light. The quinine (Figure 1.b) in tonic water will glow blue¹¹¹⁻¹¹³, and the carbonic
140 bubbles can perfectly mimic the gems (Figure 1.c). This experiment highlights the
141 phosphorescence properties of quinine but fluorescein could also be used to show
142 fluorescence effects ¹¹⁴. Other products, such as energy drinks with B vitamins, milk,
143 vanilla ice cream, caramel, and honey (to give a yellow color) could be used to produce a
144 “*stink bomb*” (Figure 1.d) by adding few spoonfuls of table vinegar and hydrogen
145 peroxide or directly with luminol to illustrate chemiluminescence¹¹⁵⁻¹¹⁷. The “*stink*
146 *bomb*” can also illustrate chemical reaction and gas-liquid equilibrium as it is composed
147 of ammonium hydrosulfide (NH₄SH), an unstable compound that decomposes into
148 ammonia and hydrogen sulfide. As soon as the container is broken (open), the dissolved
149 ammonium sulfide rapidly decomposes and liberates copious amounts of the pungent
150 gas.

151 **GAME OF THRONES**

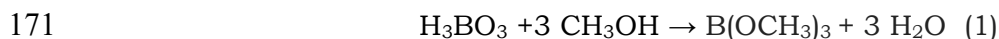
152 *Game of Thrones* is an American fantasy drama television series created by David
153 Benioff and D. B. Weiss for HBO in 2011¹¹⁸. It is an adaptation of *A Song of Ice and Fire*,
154 George R. R. Martin's series of fantasy novels, the first of which is *A Game of Thrones*,
155 first published on August 1, 1996¹¹⁹. “Blackwater” is the ninth and penultimate episode
156 of the second season of HBO's medieval fantasy television series. The entire episode is
157 dedicated to the climactic Battle of the Blackwater, in which the Lannister army,
158 commanded by acting Hand of the King, Tyrion Lannister, defends the city of King's
159 Landing. This episode is famous for its epic wildfire explosion during the Battle of
160 Blackwater Bay. In the series, wildfire is a flammable liquid that is created and
161 controlled by an Alchemist's Guild. When ignited, it can explode with tremendous force
162 and the resulting fire cannot be extinguished with water. Wildfire is identifiable by the
163 distinctive green hue of its flames and a bright green color in its liquid state.

164 The objective of this activity is to reproduce the flame. This activity is recommended as
165 a demonstration only for high school or university students' but the wildfire must be

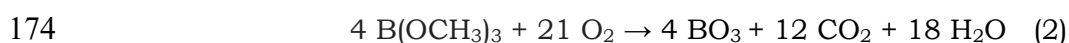
166 made in the lab only by the educator with screen protection and a safety disclaimer^{48,120}
167 (see hazard section).

168

169 When mixing boric acid with methanol; the reaction occurring is the synthesis of
170 trimethyl borate, B(OCH₃)₃ depicted in Figure 2.a, and is as follows:



172 Trimethyl borate burns distinctively green, as represented in Figure 3.a, due to the
173 presence of boron:



175 The experiment can be carried out with common products such as gas line antifreeze
176 (methanol) and laundry booster/cleaning agent (borax - sodium borate) although this
177 gives a mixture of orange and green flames due to the presence of sodium with the
178 borate. This experimentation could be completed with the flame test to discuss the
179 effect of ion on the flame color¹²¹, as done for the older pop culture reference *Harry*
180 *Potter*³². More information about the experiment is given in the supplementary section.

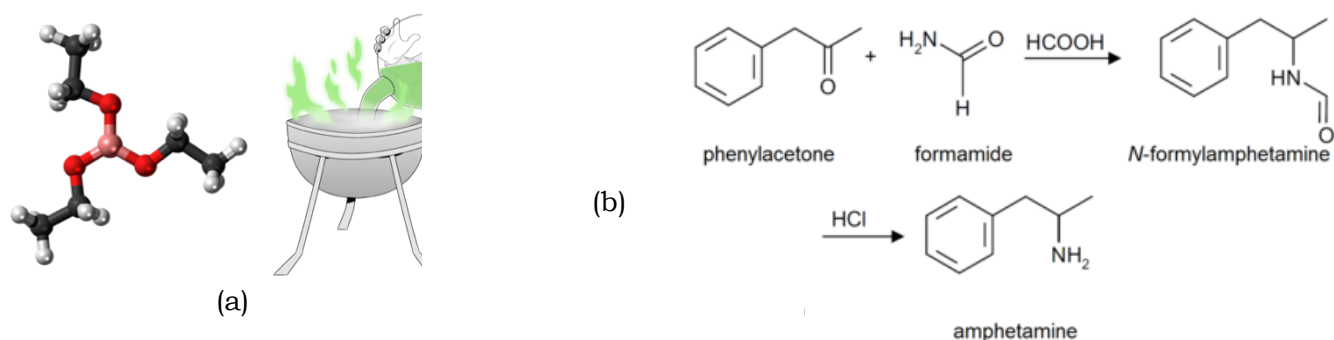
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182 **BREAKING BAD**

183

184 *Breaking Bad*, a crime drama television series created by Vince Gilligan in 2008¹²² for
185 AMC, also offers numerous opportunities for use in classroom. The chemist protagonist,
186 Walter White, chooses to stop using his chemistry skills to teach for an immoral world
187 of drugs, death, destruction and destabilization¹²³. In order to promote the positive
188 value of chemistry, we hereby propose having students work on a similar but useful
189 molecule, dextroamphetamine. Unlike the methamphetamine in *Breaking Bad*,
190 dextroamphetamine is a central nervous system stimulant that is prescribed for the
191 treatment of attention deficit hyperactivity disorder and narcolepsy¹²⁴. The synthesis of
192 this molecule is depicted in Figure 2.b. The proposed activity for organic or chemical
193 engineering students is, like the main character of the series, to build the chemical
194 process on paper from the raw data (solubility in water, boiling point, fusion point,
195 reaction enthalpy, etc.) as depicted in the supplementary section. This activity is

196 recommended as a project support for university students' in chemistry or chemical
197 engineering.



198 **Figure 2.** (a) The triethyl borate molecule and an illustration of the “green fire” reaction from Game of
199 Thrones (b) Synthesis of the dextroamphetamine
200 Many other references from this series can be used for illustration, such as the reaction
201 of hydrofluoric acid with silicon material (bath tube), the chemical composition of the
202 human body (63 % hydrogen, 26 % oxygen, 9 % carbon, 1.25 % nitrogen, 0.04 %
203 sodium, 0.25% of calcium, 0.00004% iron and 0.19 % phosphorus), chirality of
204 molecules and its possible consequences (such as Thalidomide^{125,126}), explosives, and
205 ricin poisons¹²⁷. As discussed later, an activity with such a controversial series must be
206 well supervised by educators.

207 BLACK PANTHER

208 Movies are the pop culture medium that is most widely used to illustrate science and
209 chemical concepts, especially science fiction and superhero movies. *Black Panther* has
210 been used recently to encourage students to think about an imaginary element, called
211 Vibranium⁵⁹. In the movie, Wakanda’s economy focuses on the production and use of
212 this element, which has extraordinary chemical and physical properties. In this activity,
213 the students were questioned on the possible place of Vibranium in the periodic table
214 and its properties. The students' were separated in several groups and have to build a
215 product with this element. A majority of the students developed a process to build the
216 Vibranium steel, based on classical steel production (depicted in the supplementary
217 section) whereas only very few groups worked on super-plastics or super-fertilizers
218 based on vibranium. This overwhelming representation of steel production must be due

219 to the influence of the movie, then an idea to avoid this behavior could be to impose a
 220 different product for each group, or to ask students for an alternative to the steel
 221 application. This activity is recommended as a project support or a discussion for
 222 university students' in chemistry or chemical engineering. The periodic table is a
 223 chemical concept that is easy to link with pop culture, and a large number of films
 224 include an element in their title⁵⁶. Many fictional elements are also present in the
 225 movies¹²⁸ (Table 1). As an activity for students, they could be asked to find an
 226 occurrence in a movie of a real or a fictional element and to discuss the properties of
 227 both, and to develop their creativity by linking these elements with the Mendeleev
 228 periodic table. Having a strong knowledge of the periodic table is also fundamental to
 229 understand the basic principles of chemistry and different strategies and games have
 230 been proposed to help students memorize the position of each element in the periodic
 231 table^{129,130}. Recently, different periodic tables have been designed using fictional
 232 characters to be used as a mnemonic for high school students. For example, Disney
 233 characters have been organized in the periodic table relating each character to a
 234 property of the element (*i.e.* Boron (B) = Bambi, *Bambi* was Disney's fifth movie)¹³¹
 235 whereas Marvel, DC and Asterix characters have been periodically distributed in the
 236 periodic table by choosing characters whose names are reminiscent of the elements (*i.e.*
 237 Magnesium (Mg) = Magneto)^{132,133}. This can be also an activity to be carried out in class
 238 where each student could choose other pop culture characters (*i.e.* The Simpsons, Star
 239 Wars) or popular public figures (*i.e.* soccer players, rock stars) they like best in order to
 240 organize them in the periodic table according to their properties and/or names. Besides
 241 being a strategy to increase the attention of younger students for introducing the
 242 periodic table in classroom, relating the elements of the periodic table to pop culture
 243 characters is a very useful strategy to help memorize the groups and periods as well as
 244 to explain the properties of each element.

245
 246
 247
 248

Table 1. List of fictional elements present in pop-culture media

Name	Assumed Symbol	Reference
-------------	-----------------------	------------------

<i>Adamant</i>	Ad	The Lord of the Rings (books, movie), Final Fantasy (videogame)
<i>Adamantium</i>	Am	Marvel Comics (comic book)
<i>Bavarium</i>	Ba	Just Cause 3 (videogame)
<i>Bolognium</i>	Bo	The Simpsons, Futurama (TV shows)
<i>Dilithium</i>	Di	Star Trek (movie and series)
<i>Divinium</i>	Dv	Call of Duty series (videogame)
<i>Duranium</i>	Du	Star Trek (movie and TV series)
<i>Feminium</i>	Fm	Wonder Woman (comic book)
<i>Jerktonium</i>	Je	SpongeBob SquarePants (TV animation show)
<i>Kryptonite</i>	Ky	DC Comics (comic book)
<i>Mithril</i>	Mi	Terraria/Final Fantasy (videogames)
<i>Redstone</i>	Re	Minecraft (videogame)
<i>Saronite</i>	Sa	World of Warcraft (videogame)
<i>Transformium</i>	Tr	Transformers: Age of Extinction (movie)
<i>Valeryan</i>	Va	Game of Thrones (TV series)
<i>Vibranium</i>	Vb	Marvel Comics (comic book)

249

250 ■ HAZARDS

251 Boric acid can be irritating for the eyes, skin, nose, throat and lungs, so it is
 252 recommended to wear rubber gloves when handling cleaning products, to wash away
 253 any cleaning product with water, and to avoid contact with nose, mouth, and eyes.

254 Boric acid is classified as toxic to reproduction and should not be handled by students.

255 The reaction involves fire therefore it should be conducted by a trained person in a safe
 256 area with a use of a protection shield. Prepare a lid to cover the container in order to
 257 quench the fire. Do not attempt to refill the container during or after the experiment.

258 Methanol can cause metabolic acidosis, neurologic sequelae, and even death, when
 259 ingested, so it is recommended to wear rubber gloves when handling cleaning products,
 260 to wash away any cleaning product with water, and to avoid contact with the nose,
 261 mouth, and eyes. Personal protective equipment such as dust mask, eyeshields, face
 262 shields and gloves should be used for the manipulation of the resazurin dyes.

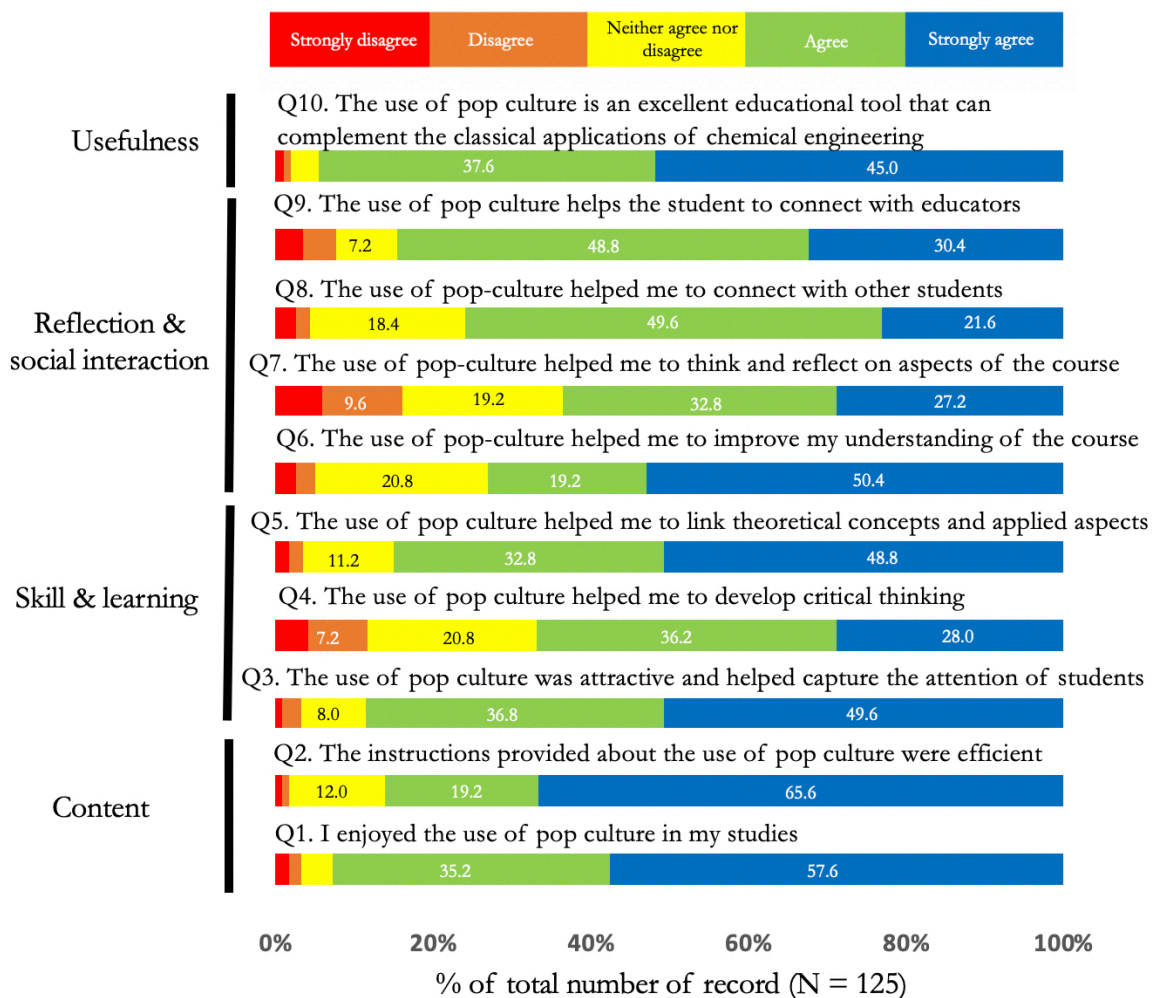
263 ■ STUDENT'S EVALUATION AND DISCUSSION

264
 265 Students from three separate courses used these activities ("Fortnite", "Game of Throne",
 266 "Breaking Bad" and the "Black Panther") after attending a series of lectures (10 h) covering
 267 the topic of chemical engineering. The first two activities were used as a demonstration tool
 268 while the last two were done as a supplementary homework project. A total of 125 students
 269 participated to these activities and came from either a Chemical Engineering course (class 1,

270 53 students, in 2018; class 2, 51 students, in 2019) or a Chemical reaction master course
 271 (class 3, 21 students, 2019).

272 At the end of the activity, the teacher invited all students to evaluate the activities by
 273 completing a printed form containing ten questions with responses based on a Likert¹³⁴
 274 scale (the response rate was 95%). Data are presented in Figure 3. In general, all statements
 275 showed high levels of agreement (“agree” and “strongly agree”) on the benefits of pop culture,
 276 ranging from 60% to 92.8% of those surveyed.

277



278

279 **Figure 3.** Student responses relating to the use of pop-culture in the courses. Total number of
 280 respondents = 125 (academic year 2018/2019).

281

282 A majority of students (92.8%) enjoyed the use of pop culture in the courses and
 283 thought it was attractive and helped capture their attention (86.4%). A majority (81.6 %)
 284 also agreed that the use of pop culture elements helped them make connections between the

285 theoretical aspects of the course and their application and helped improve their
286 understanding (69.6%). Fewer (64.8 %) students agreed that the pop culture helped them to
287 develop their critical thinking or made them think about aspects of the course (60%). It is
288 worth noting that a majority thought that pop culture helped them to connect with other
289 students (71.2%) and even more with educators (79.2%). Finally, a large majority (83.2%)
290 think that the use of pop culture is an excellent educational tool that can complement the
291 classical application of chemical engineering. In a free-response section of the
292 questionnaire, students were asked to provide comments on the activities. One of them was
293 "I will keep this exercise in mind all my life".

294 ■ SUGGESTIONS FOR ADDITIONAL OUTREACH ACTIVITIES

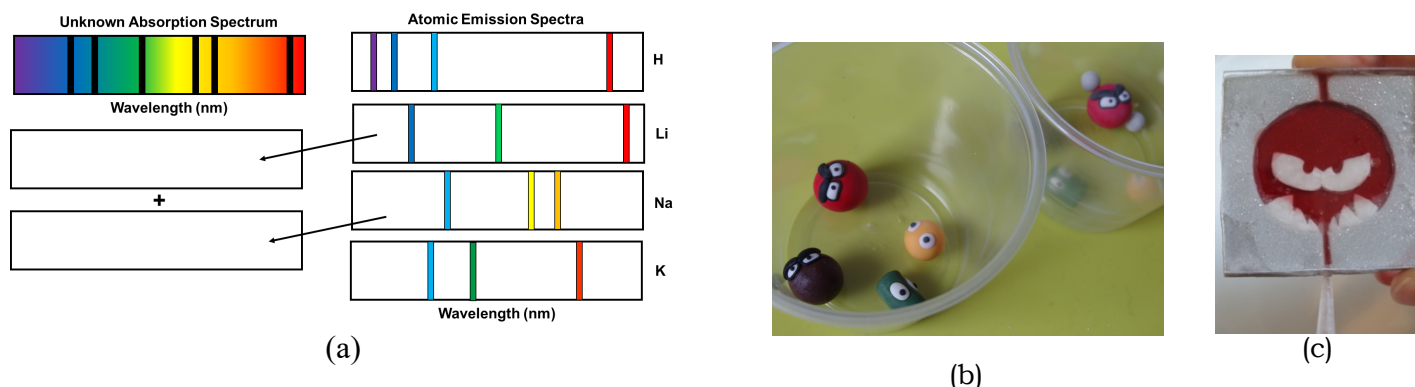
295

296 In this section, five supplementary activities based on recent pop-culture references are
297 proposed as a support for educative purpose ("Spiderman", "Angry birds", "Stranger
298 Things & Chernobyl", "Raving rabbids" and "Dragon Ball"). All of them were performed
299 with students' or visitors during open days or outreach forums. A specific evaluation is
300 proposed at the end of this section to discuss the benefits of such activities.

301 SPIDER-MAN

302 As pointed out in the movie *Into the Spider-Verse*, Peter Parker has a degree in chemical
303 engineering and teaching materials can be developed from one of the most popular
304 video games of 2018: Insomniac Games' *Spider-Man*. An important aspect of the game is
305 the completion of missions that involve collecting PAH (PolyAromatic Hydrocarbons)
306 samples, studying vehicle emissions, and determining the chemical composition of
307 atmospheric particulate matter¹³⁵. The video game directly simulates chemical analysis
308 of these samples by having the player solve simplified versions of absorption spectra.
309 Completion of the collection and analysis of these samples grant the players research
310 tokens that can be used to upgrade their suit and gadgets. Though a limited amount of
311 the underlying scientific content is conveyed to the player in analyzing these spectra, it
312 is very straightforward to create a puzzle game using a similar format that could be an

313 effective way to teach concepts in atomic spectroscopy. An example of such a puzzle
314 game is shown in Figure 4.a.



315 **Figure 4.** (a) Puzzle game to assign an unknown absorption spectrum using an inventory of atomic emission
316 spectra. (b) Particles made from modelling clay (FIMO®) are used to mimic heterogeneous particles present in
317 drinking water samples. Those with “angry” faces model waterborne pathogens that can be harmful to
318 humans and should be separated and detected to prevent outbreaks. (c) Macro-fluidic device made of
319 modelling clay, a Plexiglass layer and silicon for bonding¹³⁶.

320 In this puzzle, the player assigns the unknown absorption shown on the left as a
321 simple sum of the individual atomic spectra using the emission spectra inventory on
322 the right. Providing conceptual background about atomic absorption and emission
323 spectroscopy and using known line positions of hydrogen atom (Balmer Series) or alkali
324 atom spectra as shown in Figure 4.a conveys actual science to the player. In addition to
325 assigning spectra using a spectral line inventory, an exercise could be envisaged using
326 the Rydberg formula:

327
$$\frac{1}{\lambda} = RZ^2 \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right) \quad (3)$$

328 to predict the different electronic spectra by varying the nuclear charge and principal
329 quantum numbers of hydrogenic atoms.¹³⁷ The puzzle game could also be expanded to
330 other kinds of absorption spectroscopy such as infrared (IR) absorption.

331 This activity is recommended for middle school students' and high school
332 students' as a game or a discussion in the classroom with a video of the game. This
333 inventory-based video game puzzle may be well-suited for an electron impact mass
334 spectrometry-based game as well. Instead, consider that your fragment inventory
335 shown on the right is a molecular fragment inventory, and the player determines the

336 molecular structure of the parent ion based on the fragmentation pattern. An
337 interactive, video game puzzle could also include variables like varying the electron
338 impact energies to show how the mass spectrum changes as a function of hard vs. soft
339 ionization.

340 ANGRY BIRDS

341 Another famous video game is *Angry Birds*, a casual puzzle video game developed by
342 Rovio Entertainment in 2009¹³⁸. The gameplay revolves around players using a
343 slingshot to launch birds at pigs stationed in or around various structures, with the
344 goal of destroying all the pigs on the playing field. The *Angry Birds* series had a
345 combined tally of over 2 billion downloads across all platforms and has been adapted in
346 movies and television shows. In previous work, the franchise has been used as an
347 introduction to the separation of waterborne pathogens using microfluidics¹³⁶, channels
348 in the micrometer range allowing for a precise control of fluid and particles at the
349 micrometer scale¹³⁹. In this activity, the analogy with pop culture icons was used to
350 rapidly identify harmful pathogens in water samples. The wide range of particles that
351 would normally be present in water but not visible to the naked eye due to their
352 microscopic size are represented magnified using modelling clay. This activity is
353 recommended for middle school students' and high school students' as hands-on
354 activity. Some particles, representing pathogens that can cause a potential threat to
355 human health, have facial expressions mimicking those from the video game *Angry*
356 *Birds* for rapid identification (Figure 4.b). The overarching aim of the activity was then
357 to engineer a suite of devices that replicate ongoing research in the field to isolate those
358 “angry” pathogens and understand the chemistry associated with 1) the detection of
359 those pathogens (fluorescence), the manufacturing process (e.g. bonding) of microfluidic
360 devices (Figure 4.c) and how viscous liquids can be used to mimic at a macroscale a
361 microfluidic environment^{136,140}.

362

363 STRANGER THINGS & CHERNOBYL

364 Another TV shows that can be used for illustrating chemical reaction is *Stranger Things*,
365 an American science fiction horror web television series created by the Duffer Brothers

366 and released on Netflix in 2016. In the show a large tentacled monster named the Mind
367 Flayer terrorizes the citizens of Hawkins, and in season 3, it expresses a huge desire to
368 consume chemicals, most often poisonous (e.g. fertilizer and cleaning products). The
369 reason is that the monster wants to create caustic reactions associated with this
370 chemical consumption to cause violent explosive transformations into amorphous blobs
371 of human biomass. This example is a very good tool to discuss acid-base reactions and
372 pH. *Chernobyl* is a historical drama television miniseries created and written by Craig
373 Mazin and directed by Johan Renck for HBO in 2019. The series centers around the
374 Chernobyl nuclear disaster of April 1986 and the unprecedented cleanup efforts that
375 followed. *Chernobyl* received widespread critical acclaim and became the highest rated
376 TV show in history on some review platforms. The series is a very good example to
377 discuss the operating principle of a nuclear power station, nuclear reactions and the
378 principle of radioactivity¹⁴¹. Other major accidents can also be mentioned (Three Mile
379 Island and Fukushima) in order to discuss the danger of this type of energy. Beyond the
380 chemical aspect of the nuclear power plant, it is possible to encourage students to think
381 about the series. For example, during episode 3, the basement of the plant is
382 successfully drained, but a nuclear meltdown has begun, threatening to contaminate
383 the groundwater. Authorities decide that a heat exchanger is needed under the plant to
384 cool the reactor core and, according to the scientists, all the liquid nitrogen available in
385 the Soviet Union will be required. This can be solved from a chemical engineering point
386 of view, with a simple heat balance between the core of the plant and the nitrogen
387 flowing below the power station as described Equation (4):

388
$$Q = m_{core} \cdot C_{p,core} \cdot \frac{dT}{dt} = U_{heat\ exchanger} \cdot Surface_{Heat\ Exchanger} \cdot \Delta T_{ml} \quad (4)$$

389 From this balance, the students can estimate, with some hypotheses on the parameters
390 of the reactor core given in the supplementary material, the amount of nitrogen
391 necessary to cool the power station down, from Equation 5:

392
$$Q = W_{N_2} \cdot C_{p,N_2} \cdot (T_{N_2,outlet} - T_{N_2,inlet}) \quad (5)$$

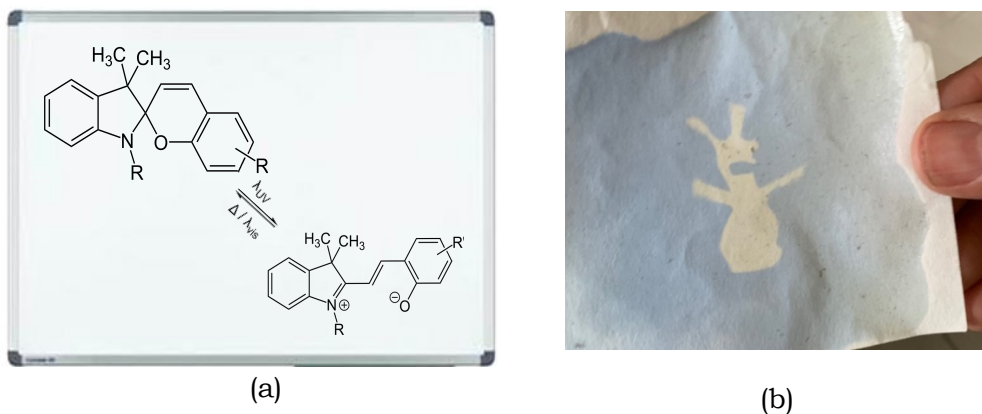
393 This show is thus a good example of the links between chemistry, chemical engineering,
394 reactor design and a recent pop-culture hit that could be used as project or a
395 discussion in the classroom for middle school students' and high school students'.

396

397 RABBIDS INVASION

398 *Rabbids Invasions* is an animated television series that premiered in 2013¹⁴². The show
399 is based on the *Raving Rabbids* video game series produced by Ubisoft and created in
400 2006¹⁴³. Among the hundreds of episodes of *Rabbids invasions*, developed by *TeamTO*
401 for *Ubisoft Motion Pictures*, some, e.g. episode 17 of season 1 ("Rabbit Dreams" by
402 Fabien Ouvrard & Mélanie Duval, 2014), involve scientific observations of those strange
403 creatures. Part of the action takes place in a lab comprising an experiment room
404 separated from a glass-walled observation office, where the scientists Gina and John try
405 to decipher the reaction of a sample rabbit. To make it more realistic, a library of
406 images has been compiled in which the cartoonist has selected the lab's etiquette.
407 Thus, along with the mandatory white lab coats, there is a board covered with scientific
408 formulas, some from physics and some from chemistry. The surprise is that the
409 chemistry ones are complex and related to a specific field of organic chemistry called
410 "photochromism" (reproduced in Figure 5a) and a chemical reaction describing the
411 light-induced coloration of a dye belonging to the spiropyran family is clearly visible¹⁴⁴.
412 Photochromic dyes are commonly used in sunglasses, to adapt the optical density of the
413 lenses to the surrounding luminosity. However, spiropyran dyes are rather unstable
414 and fade away readily when used intensively. Thus, these dyes are now used for
415 pedagogical or research purposes. A famous example is the commercially available
416 "NitroBIPS", the photochemistry of which can be tested in the teaching lab^{145,146}. The
417 one on display in the *Rabbit Invasion* is the "1',3'-dihydro-8-methoxy-1',3',3'-trimethyl-
418 6-nitrospiro[2H-1-benzopyran-2,2'-(2H)-indole]", which differs from NitroBIPS by the
419 presence of an extra methoxy group CH₃O on the ring carrying a nitro group NO₂, and
420 is thus more expensive. As *TeamTO* is a French company, it is probably inspired from
421 work of the CEA-Paris that was working on such dyes¹⁴⁷. The experiments could be

422 done with students, using a polystyrene film and a UV light as depicted in Figure 5.b.
423 This activity is recommended for middle school students', high school students' or even
424 for open days as the reaction is fast and visual. Materials and methods for this activity
425 are detailed in the supplementary information.

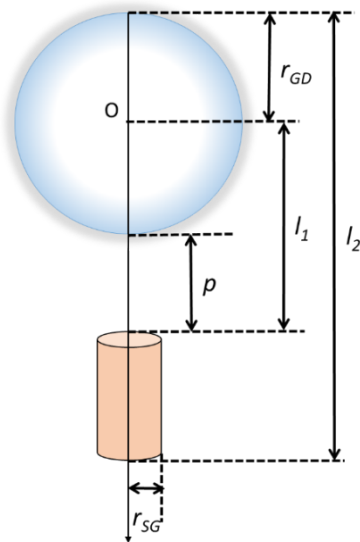


426 **Figure 5.** (a) Reproduction of the molecule presented in the Raving Rabbits (b) experiment to illustrate
427 the photochromism of the NitroBIPS molecule with a Raving Rabbit as a blank marker.
428

429 DRAGON BALL

430 *Dragon Ball* is a Japanese manga franchise written and illustrated by Akira Toriyama
431 originally serialized in Weekly Shōnen Jump magazine from 1984 to 1995¹⁴⁸. Since its
432 release, *Dragon Ball* has become one of the most successful manga and anime series of
433 all time, having generated more than \$20 billion in total franchise revenue as of 2018.
434 Genki dama (元気玉) is one of the most powerful attacks of Son Goku, the famous hero
435 of the anime (illustrated in Figure 6). It consists of a giant sphere of vital energy
436 provided by all the living cells surrounding Goku. Although similarities seem to exist
437 with the well-known Kamé Hamé Ha (かめかめ波), no real description of its energy
438 nature can be found. While this energy is indeed able to vaporize in some of the anime
439 episodes, this energy also appears as mostly mechanical in others (buildings
440 destruction, etc). One reasonable hypothesis is to assume that it behaves as a
441 blackbody, whose spectral irradiance distribution is given by the Planck distribution.
442 This activity is recommended for middle high school or university students' (Chemical
443 Engineering) as a project or a tutorial with professor.

444 Thus, let us consider that this sphere is a blackbody of temperature T_{GD} , with a radius
 445 $r_{GD} = 10$ m. Let also assume that the shortest distance between the sphere surface and
 446 Son Goku is $p = 20$ m (see Figure 6). It is also important to note that no value for the
 447 temperature T_G seems available but, regarding the visible emission (bright blue) of the
 448 Genki dama, a reasonable temperature would be around 6000 K. The radiative
 449 emission of Son Goku should also be neglected and Son Goku is assumed to be a
 450 cylinder of height $l_2 - l_1 - r_{GD} = 1.8$ m and radius $r_{SG} = 0.3$ m. In order to propose an
 451 original work to the student, we propose to calculate the net radiative flux from the
 452 Genki dama to Son Goku.



453 **Figure 6.** Scheme of the problem

454

455 The net radiative flux between two blackbodies is given by the Stefan-Boltzmann
 456 radiation law, assuming that both material emissivities are close to 1:

457
$$q_{GD-SG} = q_{GD \rightarrow SG} - q_{SG \rightarrow GD} \simeq A_{GD} F_{GD-SG} \sigma T_{GD}^4 \quad (6)$$

458 With A_{GD} (m^2) the total area of the Genki dama, F_{GD-SG} the view factor from the Genki-
 459 Dama sphere to Son Goku, assumed as the external surface of a coaxial cylinder (see
 460 Figure 6). $\sigma = 5.67 \times 10^{-8} \text{ W}/(\text{m}^2 \text{ K}^4)$ is the Stefan-Boltzmann constant. The resolution of
 461 the problem is given in the supplementary section.

462

463 As some of these suggested additional activities were not tested in situ with students,
464 they were presented to a panel of students' (N = 35 - Chemistry, Environment and
465 Chemical Engineering – Academic year 2019/2020) during a scientific discussion (2 h)
466 on the links between science and pop-culture in order to evaluate students'. The survey
467 was conducted as an anonymous paper exercise, with students required to strongly
468 agree, agree, neither/neutral, disagree or strongly disagree with a series of 10
469 statements. The majority of respondents were positive about educational benefits of pop
470 culture with 82% of the respondents agreeing that the use of pop culture was a useful
471 learning activity. More specifically, 75% of the students agreed (or strongly agreed) that
472 pop culture had helped them apply chemistry/chemical engineering in a useful way.
473 Having just discussed about these pop-culture activities, the majority of respondents
474 agreed (78%) that they would appreciate this approach in different subject areas of their
475 cursus. These findings support the high level of student engagement and interaction
476 observed by instructors when pop-culture is used. The data collected show that the
477 majority of students enjoyed discussing science with a pop culture approach, in the
478 open section of the survey some students' recommended to use it at a recreative
479 moment between students' or with educators.

480 ■ DISCUSSION

481 Pop-culture in classrooms can be beneficial as it creates engaging links between
482 chemical concepts and their applications, and between educators' and students'
483 interests. The objective is not to promote movies or video games but to connect and use
484 the interest of students for these pop culture elements towards learning science.
485 Connection with recent pop culture elements such as those proposed in the present
486 work could be used as support for demonstrating reactions, as side projects, analogies
487 to communicate concepts and/or as a platform to start discussions. Educators need to
488 be careful about inappropriate content depending on the student's age, to avoid spoiling
489 anything for someone reading or watching a show, movie or book, to make sure the
490 science involved is actually correct. It is also important to leave the students free to

491 search chemistry during project in all types of media, recent or not, according to their
492 interests to unleash their curiosity. Finally, pop-culture promotes critical thinking and
493 cultural literacy, which are important skills for students to develop.

494 **CONCLUSION**

495 The present work provides creative and original activities based on pop culture (*e.g.*
496 video games, movies and TV series) to engage chemistry and chemical engineering
497 students. The goal has been to show that chemistry and chemical engineering
498 phenomena are widely present and play an essential role in recent pop culture as
499 typified in the superhero movies, action video games or fantasy drama series.
500 Instructors can stimulate students' interest in these domains by discussing the
501 chemical content of such works during lectures, tutorials, by generating quizzes and
502 assignment items based on occurrences in these videogames and movies, or by creating
503 a stock of scientific trivia collected from popular culture sources. To conclude, pop-
504 culture offers a wide range of possibilities for involving students in classroom, from
505 hands-on activity to critical thinking, and from basic chemistry to chemical engineering.

506 **ASSOCIATED CONTENT**

507 **Supporting Information**

508 Fortnite: Making “slurp juice”; Game of Thrones and Harry Potter: Making green fire;
509 Breaking Bad: Synthesizing dexterine; The Black Panther movie: Proposing a process flow
510 diagram for fabrication of “vibranium steel”; Raving Rabbids: Making color-changing paper;
511 Dragon Ball: Calculating the net radiative flux from the Genki Dama to Son Goku (DOCX)

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