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# USING POP-CULTURE TO ENGAGE STUDENTS IN THE CLASSROOM

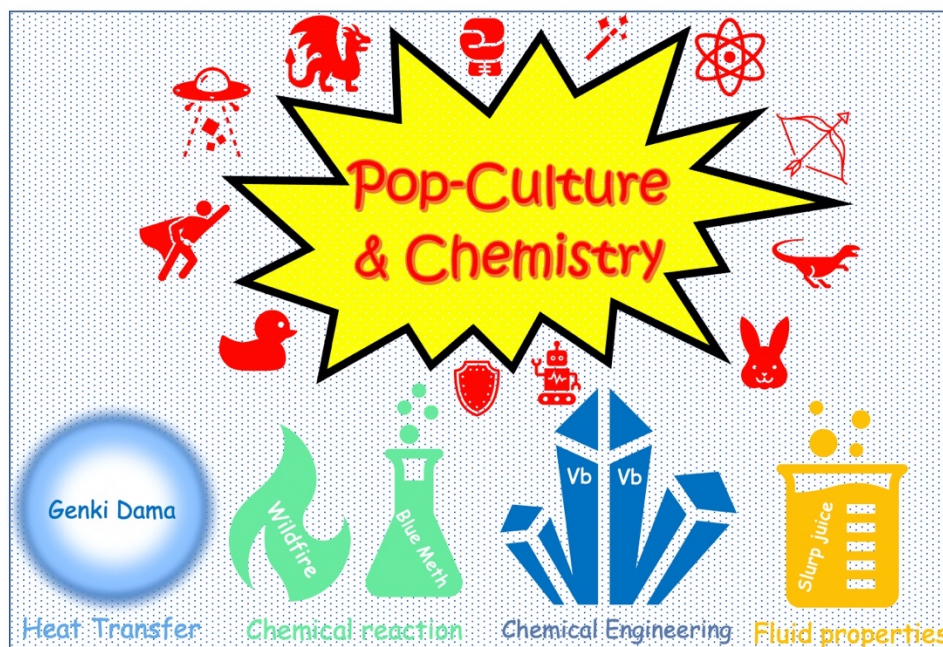
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## ■ ABSTRACT

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<sup>1,2</sup> and developing stimulating, alternative teaching methods is  
34 important for educators in all disciplines. In several articles, authors describe aspects  
35 of popular culture<sup>3</sup> 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 music<sup>4-7</sup> (including jazz<sup>8</sup> and opera<sup>9,10</sup>) and paintings<sup>11-13</sup>  
38 (including fashion art<sup>14</sup>), history<sup>15-18</sup>, archaeology<sup>19-21</sup>, or literature<sup>22-27</sup>. As examples,  
39 educators illustrated chemistry with a Shakespeare's play<sup>28</sup> while others found  
40 inspiration in detective cases where chemistry was used by the perpetrator of a crime or  
41 in their identification<sup>29,30</sup>. The chemical references from Ian Fleming's *James Bond*<sup>31</sup>  
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 experiments<sup>32</sup> 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 chemistry<sup>33-35</sup>, as has a murder novel of Agatha Christie<sup>36</sup>. Michael Crichton's novel  
48 *Jurassic Park*<sup>37</sup> has been an inspiring source of discussions on the chemical defense of  
49 plants or chemicals used by animals for communication. Cartoons<sup>38,39</sup> and comic  
50 books<sup>40</sup> can also illustrate chemical principles (*e.g.* microscale chemistry in *Archie's*  
51 comic book<sup>41</sup> or general chemistry in *Dick Tracy*<sup>42-45</sup>, *DC Comics*<sup>46</sup> or *Marvel comics*<sup>40</sup>).  
52 Recently, lab safety rules have been presented to students with comics<sup>47</sup>, graphic novels  
53 and mangas<sup>48</sup>. Beyond novels and comics, movies are currently one of the biggest  
54 providers of pop-culture<sup>49,50</sup>. The list of movies used to illustrate chemistry is  
55 impressive, including for example *Apollo 13*<sup>51</sup>, *October Sky*<sup>52</sup>, *Star Trek*<sup>53</sup> and many  
56 others<sup>54-58</sup>. The omnipresent *Marvel* franchises often invoke various areas of chemistry  
57 and chemical engineering such as nanotechnology in the suits of *Iron Man*<sup>40</sup>, properties  
58 of the fictional metal vibranium in *Black Panther*<sup>59</sup>, the quantum realm in *Ant-Man*<sup>60</sup>, or  
59 material sciences in *Spider-Man*<sup>61</sup>. Television is also a good way to illustrate chemistry<sup>62</sup>

60 and famous shows used for this purpose include *The Price is Right*<sup>63</sup>, *The Big Bang*  
61 *Theory*<sup>64</sup>, *CSI*<sup>65</sup>, *The Simpsons*<sup>66</sup>, *Bones*<sup>67</sup>, *ER* and *House*<sup>68</sup>. Trending games<sup>69-89</sup> are also  
62 an interesting pathway to involve students in general chemistry courses<sup>90-97</sup>. 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<sup>88,98</sup> 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 theme<sup>99</sup>. Video games<sup>100</sup> have become an increasingly important part of the  
70 entertainment industry, and they are also considered a form of art<sup>101</sup>; surprisingly the  
71 use of videogames to illustrate chemistry or chemical engineering<sup>102</sup> is relatively  
72 unexplored in the literature even though pedagogical videogames exist<sup>103-105</sup>. 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 resourcefulness<sup>106-</sup>  
76 <sup>108</sup>. 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 game<sup>109</sup>.  
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.

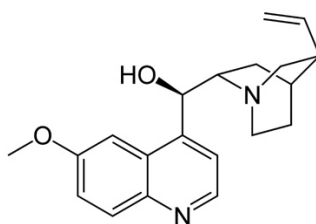
111 The videogame *Fornite* is more oriented toward physics than chemistry (*e.g.* bullet  
112 and rocket trajectories, amount of force per impact of projectiles, etc.). Nevertheless, in  
113 the game, once players have landed on the map, they must scavenge for weapons,  
114 resources and other items. 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 alcohol<sup>110</sup>. 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?



(a)



(b)



(c)



(d)

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 blue<sup>111-113</sup>, 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 <sup>114</sup>. 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 chemiluminescence<sup>115-117</sup>. The “*stink*  
146 *bomb*” can also illustrate chemical reaction and gas-liquid equilibrium as it is composed  
147 of ammonium hydrosulfide (NH<sub>4</sub>SH), 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

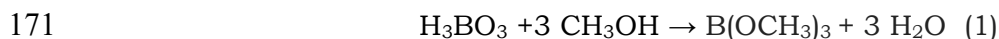
152 *Game of Thrones* is an American fantasy drama television series created by David  
153 Benioff and D. B. Weiss for HBO in 2011<sup>118</sup>. It is an adaptation of *A Song of Ice and Fire*,  
154 George R. R. Martin's series of fantasy novels, the first of which is *A Game of Thrones*,  
155 first published on August 1, 1996<sup>119</sup>. “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

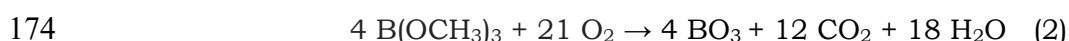
166 made in the lab only by the educator with screen protection and a safety disclaimer<sup>48,120</sup>  
167 (see hazard section).

168

169 When mixing boric acid with methanol; the reaction occurring is the synthesis of  
170 trimethyl borate, B(OCH<sub>3</sub>)<sub>3</sub> 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 color<sup>121</sup>, as done for the older pop culture reference *Harry*  
180 *Potter*<sup>32</sup>. More information about the experiment is given in the supplementary section.

181

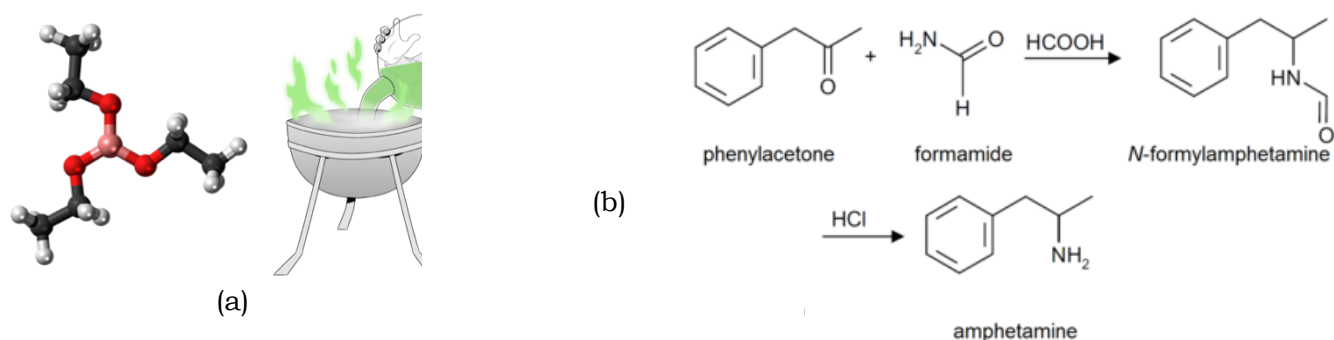
## 182 **BREAKING BAD**

183

184 *Breaking Bad*, a crime drama television series created by Vince Gilligan in 2008<sup>122</sup> 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 destabilization<sup>123</sup>. 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 narcolepsy<sup>124</sup>. 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<sup>125,126</sup>), explosives, and  
205 ricin poisons<sup>127</sup>. 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 Vibranium<sup>59</sup>. 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 title<sup>56</sup>. Many fictional elements are also present in the  
 225 movies<sup>128</sup> (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<sup>129,130</sup>. 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)<sup>131</sup>  
 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)<sup>132,133</sup>. 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

<i>Name</i>	<b>Assumed Symbol</b>	<b>Reference</b>
-------------	-----------------------	------------------

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

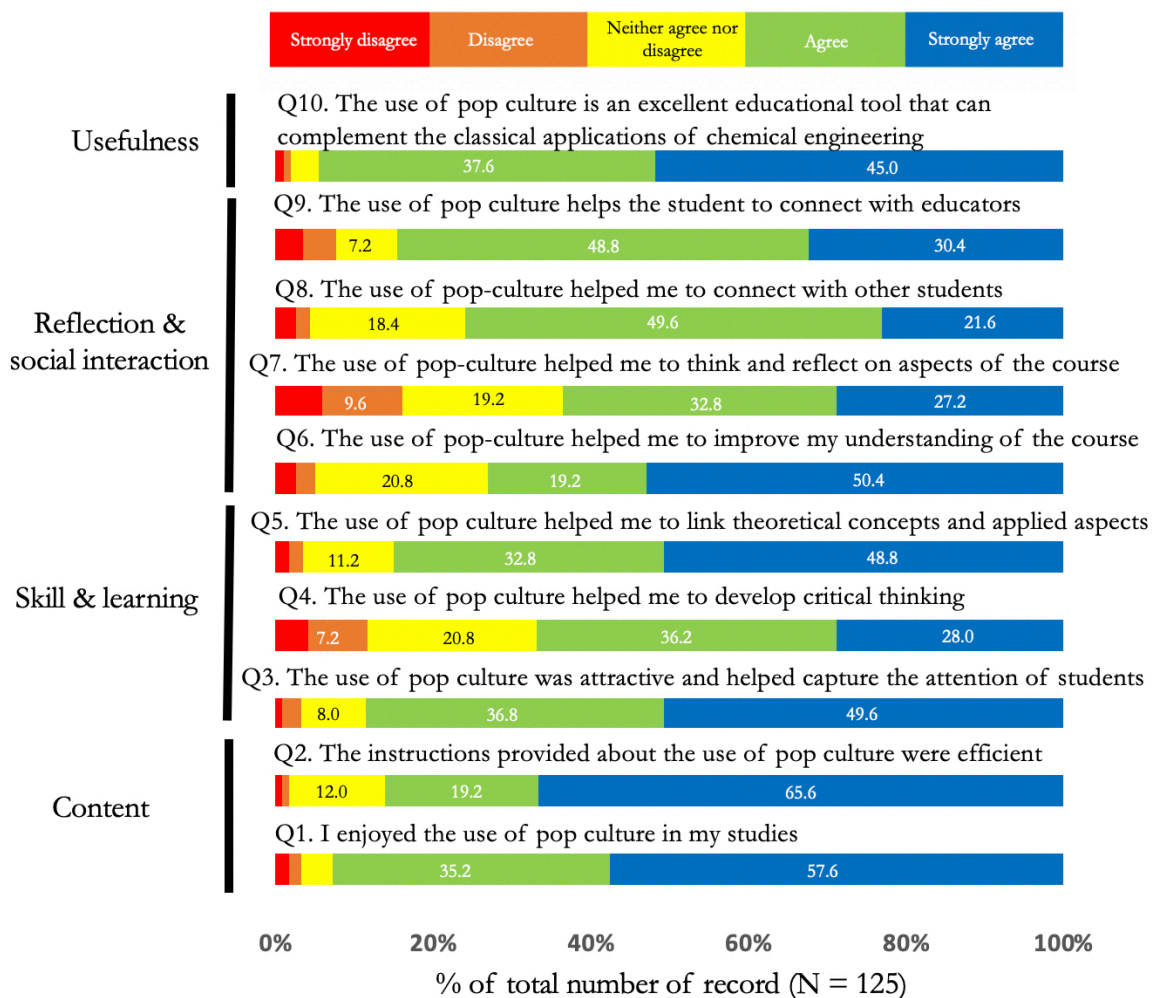
## 263 ■ STUDENT'S EVALUATION AND DISCUSSION

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 Likert<sup>134</sup>  
 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

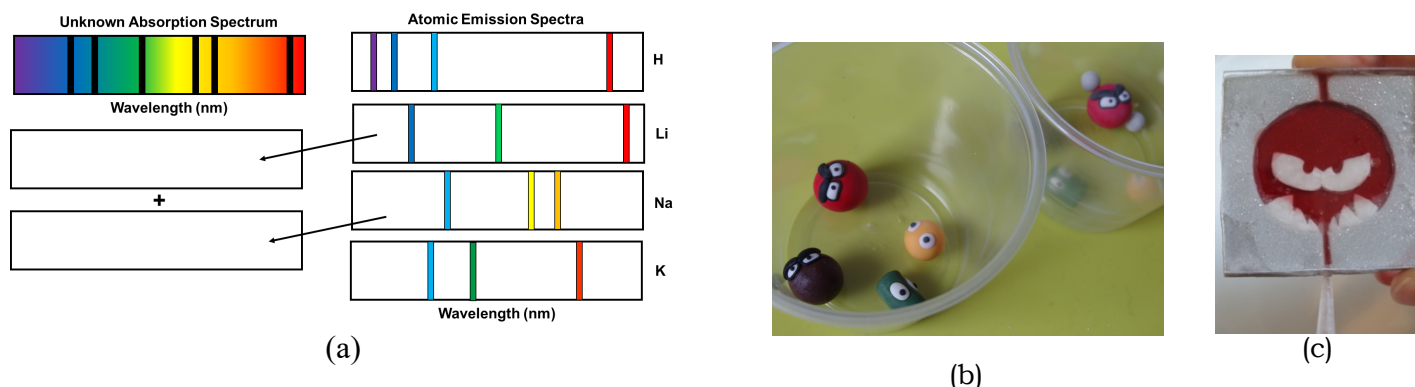
295

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 matter<sup>135</sup>. 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 bonding<sup>136</sup>.

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.<sup>137</sup> 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 2009<sup>138</sup>. 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 microfluidics<sup>136</sup>, channels  
348 in the micrometer range allowing for a precise control of fluid and particles at the  
349 micrometer scale<sup>139</sup>. 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<sup>136,140</sup>.

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 radioactivity<sup>141</sup>. 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 
$$Q = W_{N_2} \cdot C_{p,N_2} \cdot (T_{N_2,outlet} - T_{N_2,inlet}) \quad (5)$$



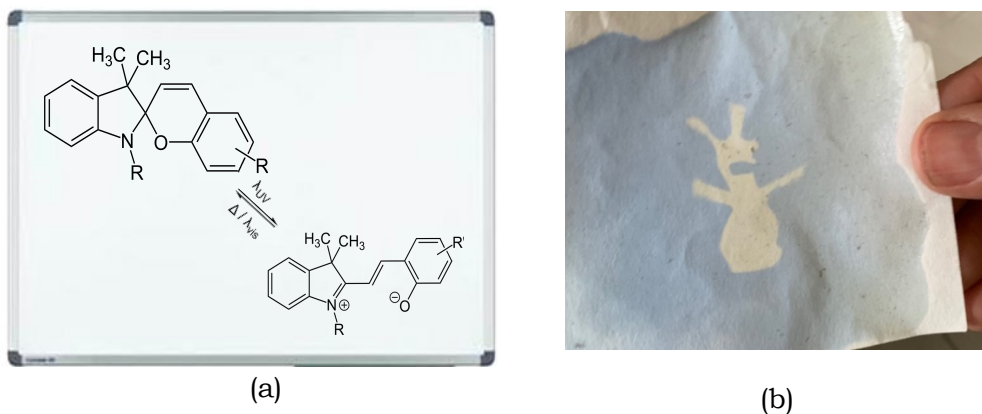
393 This show is thus a good example of the links between chemistry, chemical engineering,  
394 reactor design and a recent pop-culture hit that could be used as project or a  
395 discussion in the classroom for middle school students' and high school students'.

396

#### 397 RABBIDS INVASION

398 *Rabbids Invasions* is an animated television series that premiered in 2013<sup>142</sup>. The show  
399 is based on the *Raving Rabbids* video game series produced by Ubisoft and created in  
400 2006<sup>143</sup>. 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 visible<sup>144</sup>.  
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<sup>145,146</sup>. 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 CH<sub>3</sub>O on the ring carrying a nitro group NO<sub>2</sub>, 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 dyes<sup>147</sup>. 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.

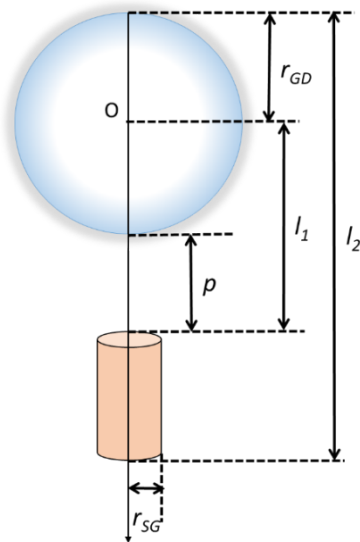


426 **Figure 5.** (a) Reproduction of the molecule presented in the Raving Rabbits (b) experiment to illustrate  
427 the photochromism of the NitroBIPS molecule with a Raving Rabbit as a blank marker.  
428

#### 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 1995<sup>148</sup>. 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  $A_{GD}$  ( $\text{m}^2$ ) 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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