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Fun with Flags and Chemistry

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1 Fun with Flags and Chemistry

2 Christophe Coudret* and Nicolas Dietrich*



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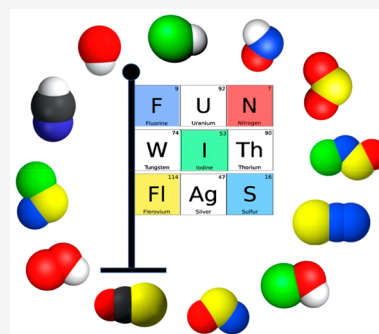
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Supporting Information

3 **ABSTRACT:** The purpose of this study is to present a learning
4 activity that combines the simultaneous practice of geography and
5 chemistry. It is a game activity based on the identification of
6 national flags and colored molecules (from the famous CPK
7 model), with an extension to the creation of imaginary flags from
8 real, useful molecules for middle school, high school, and university
9 classrooms. The goal of using a game is to motivate/involve
10 learners, to encourage them to work and develop adaptability and
11 responsiveness by practicing chemistry and geography components.
12 The feedback received from students who participated in this
13 exercise during the 2019–2020 academic year has been evaluated
14 and shows an increase of motivation and critical thinking. The
15 objective is to make students more aware of geopolitics, to engage
16 discussion on their awareness of the world, and to prepare them to play an active role in it.

17 **KEYWORDS:** *Humor/Puzzles/Games, Pedagogy, Interdisciplinary/Multidisciplinary, Domain, General Public, Audience,*
18 *History/Philosophy, Domain, Molecular Properties/Structure, Topics*



Fun with Flags
& Chemistry:

An educative
game for teaching
Geography and
Science
simultaneously

19 ■ INTRODUCTION

20 If we are to face the great challenges of the 21st century^{1,2} (clean
21 energy, sustainable cities, climate action, good health, etc.), a
22 new approach is required for education.^{3–5} The next generation
23 will have to solve important national or global problems to create
24 the industries and jobs of the future; expand the frontiers of
25 human knowledge about ourselves and the world around us; and
26 tackle important problems related to energy, health, education,
27 the environment, national security, and global development.
28 Interaction between social sciences and natural sciences is a
29 necessary condition for success in this endeavor and an
30 important part of the modernization of the educational process
31 in regard to these challenges. For example, the new technologies
32 and devices that enriched our lives in the 21st century require
33 rare earth metals.⁶ Future engineering should be sensitive to the
34 planet's natural resources,⁷ their location, the reserves available,
35 and possible substitute products. Therefore, teaching the next
36 generation will require a multidisciplinary approach:⁸ a
37 combination of natural science, technology, innovation, and
38 social science to help them face the challenge of managing the
39 world's resources. Some educators have already developed
40 innovative, multidisciplinary approaches⁹ to teaching geogra-
41 phy, chemistry, and ecology together,¹⁰ or combining
42 geography, math, and science to teach climate change and sea
43 level rise.¹¹ The results of this research suggest that most
44 students view such developments positively and recognize that
45 they bring many advantages, such as critical thinking and a
46 broadening of their knowledge horizons.¹² In the perspective of
47 developing a new educative activity in this direction, humanities

and chemistry could be associated, and this paper presents an
48 original, engaging activity to help students to connect chemistry
49 and geography. It was developed on a game based on 50
51 recognizing flags with simple chemical molecules and is
52 named “Fun with Flags” in reference to episode 14 of the fifth
53 season of *The Big Bang Theory*,¹³ an American television sitcom
54 created by Chuck Lorre and Bill Prady in 2007, where two of the
55 main characters present a YouTube podcast on the topic of
56 vexillology¹⁴ (term created by Whitney Smith in 1958 from the
57 Latin word vexillum/“flag” and the Greek suffix -logia/“study”)
58 named “Sheldon Cooper Presents: Fun With Flags”. In this
59 fictional video podcast, several “fun facts” about flags, such as the
60 shape, the presence of animals, or the origins of the flags, are
61 presented in an entertaining way. Using pop-culture refer-
62 ences^{15–18} is an interesting approach to improve students’
63 motivation,¹⁷ and several educators have developed educational
64 games^{19–22} to involve students in interactive, entertaining
65 activities.²³ Games are an excellent method of active learning in a
66 recreational environment,²⁴ and many methods have been
67 tested in the past decade:²⁵ a word game,²⁶ quiz games,^{27–35}
68 card games,^{36–38} dice games,^{39,40} board games,^{41–46} computer
69 games,^{47–49} memory/concentration games,^{50–52} and even 69

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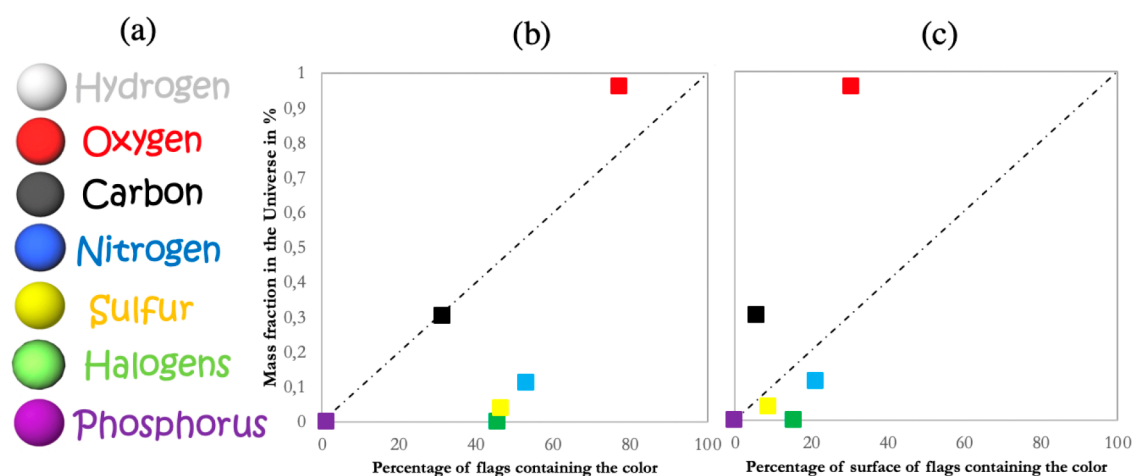


Figure 1. (a) CPK model. (b) Mass fraction in the universe in % plotted against the percentage of flags containing the color. (c) Representation of the atom fraction in parts per million in the universe plotted against the percentage of flags containing the color (refs 73 and 74). Hydrogen mass fraction in the universe is 70.57%, and white is present in 72.92% of flags and in 19.12% of the surface.

70 escape games.^{53–58,58–61} All of these educators have succeeded
71 in creating a recreative environment improving the student's
72 engagement and motivation for science.

73 The link between flags and chemistry has already been
74 attempted by educators, only on the basis of the chemistry
75 necessary to produce the colored dyes.⁶²

76 Some authors have tried to connect objects with molecules in
77 order to create a recreative environment, such as structural
78 chemical formulas with human forms (called NanoPutians),⁶³
79 monsters (NanGobelin),⁶⁴ or racing car shapes.^{65,66} The goal of
80 these studies was to educate children in the sciences in an
81 effective and enjoyable manner. They have made several videos
82 featuring the NanoPutians as anthropomorphic animated
83 characters. In order to relate vexillology with chemistry, and in
84 the following of these *chemistrymorphisms*, we propose to create
85 a game on the manipulation of colored atoms looking like the
86 real flags. In 1952, Corey and Pauling published a description of
87 space-filling models of proteins and other biomolecules that they
88 had been building at Caltech.⁶⁷ Their models represented atoms
89 by faceted hardwood balls, painted in different colors to indicate
90 the component chemical elements. Their color scheme included
91 the following: white for hydrogen, black for carbon, blue for
92 nitrogen, and red for oxygen (Figure 1a). In 1965, Koltun
93 patented⁶⁸ an improved version of the Corey and Pauling
94 modeling technique. In his patent, he added several colors:
95 yellow for sulfur, purple for phosphorus, green for the halogens
96 (F, Cl, Br, I), and silver for metals. This model is known as the
97 CPK model (for Corey, Pauling, and Koltun). Several of the
98 CPK colors refer mnemonically to colors of the pure elements or
99 notable compounds (hydrogen is a colorless gas; carbon, as
100 charcoal, graphite, or coke, is black; sulfur powder is yellow;
101 chlorine is a greenish gas; etc.). This molecular model is typically
102 used by students in introductory organic chemistry courses to
103 represent bonds and atoms with small plastic polygons or
104 spheres,^{69,70} and the models are helpful when students are
105 learning about molecular geometry and stereochemistry. This
106 paper describes an activity to link national flags to simple
107 chemical molecules of the same color (according to the CPK
108 code) in order to make students manipulate geography and
109 chemical concepts simultaneously. This activity can be done
110 remotely for distance learning^{7,54,60,71} from middle school to

university level (with an adaptation of the discussion, see the
Discussion section).

■ RELATIONSHIP BETWEEN FLAGS AND THE CPK MODEL

There are numerous flags in the world, representing the different
geographical, ethnic, religious, and national groups of human-
kind. A flag is more than an image or a scrap of fabric, it can be a
part of an individual's identity and a visual representation of a
collective. According to the United Nations, there is a total of
193 sovereign states in the world (and 2 observers states), and
each one has a recognizable national flag.⁷² The most frequent
type is the three-colored flag (40% of flags), followed by two-
and four-colored flags (20% each).⁷³ Red is the most widely used
color by percentage surface area and by number of flags (Figure
1b). The second color in the ranking is not the same by area and
by frequency (blue or white), as shown in Figure 1b,c. It is
noteworthy that the colors originally chosen for the CPK model
are very similar to the colors present in the flags of the world's
nations.

It is also worth noting that there is a similarity in value for
some colors/atoms between the presence in flags and presence
in the universe. For example, the hydrogen atom (white in the
CPK model) is present at 70.57% in the universe and appears in
72.92% of the flags while the phosphorus atom (purple) is
present at less than 0.1% in the universe or in national flags
(purple is used only in the flags of Spain, Nicaragua, and Sri
Lanka and in a small proportion). This demonstrates a good
probability of identifying flags and molecules with the same
colors. The only exception is for the color orange, which is not
included in the original CPK model but is present in 4.6% of
flags (1.2% of surface area), excluding flags of Ireland, India,
Côte d'Ivoire, and a few other countries from our analysis. In
vexillology there are many geometrical flag designs: *cantons* (a
flag divided in four equal quarters), *pales* (a flag divided into 2 or
3 vertical bands), *fesses* (a flag divided into three horizontal
bands), *saltire* (a flag with a diagonal cross), and *Scandinavian
cross* (a flag with a cross, the vertical arm of which is positioned
more toward the hoist). Two thirds of all national flags include
the use of symbols (sometimes even more than one) such as a
star (30%), emblem (14%), cross (9%), sun (8%), or crescent
(7%). Most flags are based on a simple formula of colors, 151

152 symbols, and layouts, and this results in as many differences as
 153 surprising similarities. 53% of all national flags are designed with
 154 a simple band layout, and the three-stripe design is by far the
 155 most popular, with over 80 national flags. The most widely used
 156 combinations are red–blue–white (30 flags), red and white (16
 157 flags), green–white–red (12 flags), red–yellow–white (11
 158 flags), and white–blue (10 flags).

159 ■ METHODOLOGY

160 Students from two separate courses used the game activity as a
 161 homework project after attending a series of lectures (10 h)
 162 covering an introduction to chemistry. The 87 students who
 163 participated came from either a Chemical Engineering course
 164 (class 1, 56 students, in 2020) or an Introduction to Chemistry
 165 master course (class 2, 31 students, in 2020). At the end of the
 166 activity, the teacher invited all students to evaluate the activities
 167 by completing an online form in French containing 10 questions
 168 with responses based on the Likert⁷⁵ scale. Participants were
 169 approached twice by email, and the response rate was 80%. The
 170 data from the online surveys were entered into a Microsoft Excel
 171 spreadsheet and were collated. All responses were analyzed, and
 172 the results are presented in the next section.

173 ■ ACTIVITY

174 The core of the activity is based on quizzes concerning the
 175 identification of the country from a simple molecule
 176 representing the associated flag. The objectives of the activity
 177 are to make student practice the CPK model (memorizing color
 178 and atoms), to manipulate the molecular geometry (VSEPR
 179 theory), and also to initiate discussions on resource localization
 180 and geopolitics and culture and history. We will first restrict the
 181 activity to band type flags with one to four colors in order to
 182 propose perfect matching or quasiperfect matching between the
 183 flags and chemical molecules of 1–4 atoms, and we will neglect
 184 all the symbols (emblem, cross, coat of arms, etc.) or differences
 185 in shape ratio to simplify the problem. After what was, to the best
 186 of our knowledge, a complete analysis of all national flags, we
 187 found only 10 “perfect matches” between existing flags and
 188 existing chemical compounds, with the right color, the right
 189 order of the colors, and the correct number of colors (4 for
 190 bicolor flags, and 6 for tricolor flags) and 20 quasiperfect
 191 matches (where the colors were correct but not the number of
 192 colors or the order of the colors). Figure 2 depicts the 10 “perfect
 193 matches”: from left to right, the flags are Gabon (Figure 2a, it
 194 could also work for Rwanda in the reverse order), Estonia
 195 (Figure 2b), Monaco/Indonesia/Singapore (Figure 2c; it could
 196 work for Poland in the reverse order), Algeria (Figure 2d; it
 197 could also work for Pakistan in the reverse order and Wales with
 198 a rotation), Russia/Slovakia/Slovenia (Figure 2e), Spain
 199 (Figure 2f), Romania/Moldavia/Chad (Figure 2g), Belize
 200 (Figure 2h), Nigeria (Figure 2i), and Portugal (Figure 2j; it
 201 could also work for Burkina Faso with a 90° rotation). The
 202 molecules used to recreate the flags are given in the legend of the
 203 figure.

204 This first series of flags is considered as easy due to the perfect
 205 match of color/order/number of colors between a flag and its
 206 CPK representation. It allows a total of 16 countries to be
 207 manipulated (depending on the orientation of the molecule).
 208 This series provides a good introduction to the activity and
 209 permits a focus on the similarity of certain flags in the world.

210 The second series concerns quasiperfect matching, where the
 211 number of atoms and their colors are identical to the number of

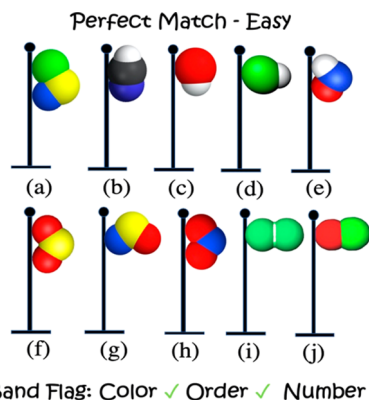


Figure 2. Molecular flags built with the CPK model for (a) Gabon/Rwanda—CINS thiazyl chloride; (b) Estonia—HCN hydrogen cyanide; (c) Monaco/Indonesia/Singapore—OH[−] hydroxide; (d) Algeria—HCL hydrochloric acid; (e) Russia/Slovakia/Slovenia—HNO nitroxyl; (f) Spain—OSO sulfur dioxide; (g) Romania/Chad/Moldavia/Andorra—OSN[−] sulfinylazanide; (h) Belize—NO₂[−] nitrite; (i) Nigeria—HF₂[−] bifluoride; (j) Portugal—ClO[−] hypochlorite.

bands and the colors of an existing flag, but not the order. The
 difficulty is thus greater than in the first series. Figure 3 depicts 5

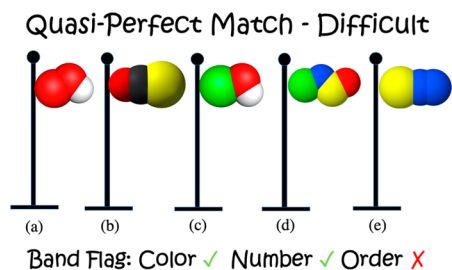


Figure 3. Molecular flags built with the CPK model for: (a) Austria/Peru—OHO hydroperoxyl; (b) Belgium/Germany—OCS carbonyl sulfide; (c) Bulgaria/Italy/Hungary/Iran/Mexico/Tajikistan—HClO hypochlorous acid; (d) Mauritius—ClNOS sulfinylamino chloride; (e) Barbados—N₂S dinitrogen-*N*-sulfide.

“quasiperfect matches”. From left to right, the flags are Austria/
 Peru (Figure 3a), Belgium/Germany (Figure 3b), Bulgaria/
 Italy/Hungary/Iran/Mexico/Tajikistan (Figure 3c), Mauritius
 (Figure 3d), and Barbados (Figure 3e). The molecules used to
 recreate the flags are given in the legend of the figure.

Note that “perfect match” flags could also be used for
 “quasiperfect” matching: Figure 2e could be used in that context
 for the flags of France/Netherlands/Luxemburg/Croatia/
 Czech Republic, and Figure 2e could be used for the flags of
 Colombia/Ecuador/Armenia/Venezuela. This second series of
 flags allows a total of 20 supplementary countries to be
 manipulated. The difficulty is higher due to the fact that colors
 are not in the right order, but as there is often more than one
 solution for each molecule, the possibility of success is good. The
 third series proposed concerns the “imperfect matches” where
 the color of the flags and the molecules are the same, but the
 order or the number of colors are not correct, making this
 category the hardest one. Figure 4 depicts the 17 “imperfect
 matches”. Starting with the band flag, at the top, from left to
 right: Somalia (Figure 4a), Argentina/Salvador/Guatemala/
 Honduras/Israel (Figure 4b), Vatican (Figure 4c), Bolivia/
 Lithuania/Cameroon/Republic of the Congo/Guinea/Mali/
 Senegal/Ethiopia/Myanmar (Figure 4d), Sierra Leone/Uzbeki-

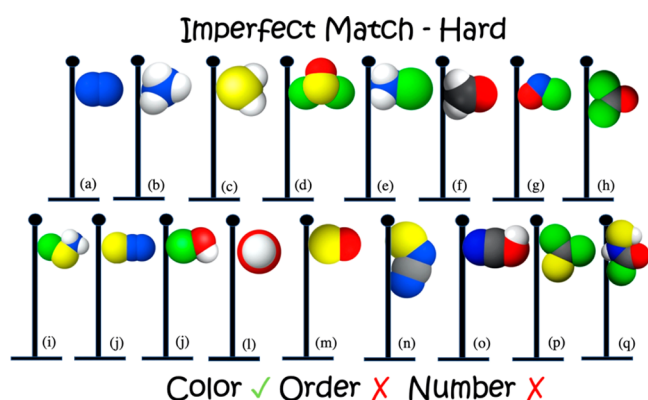


Figure 4. Molecular flags built with the CPK model for (a) Somalia— N_2 nitrogen; (b) Argentina/Salvador/Guatemala/Honduras/Israel— NH_3 ammonia; (c) Vatican— H_2S hydrogen sulfide; (d) Bolivia/Lithuania/Cameroon/Republic of the Congo/Guinea/Mali/Senegal/Ethiopia/Myanmar— Cl_2OS thionyl chloride; (e) Sierra Leone/Uzbekistan/Lesotho— NH_2Cl chloramine; (f) Yemen/Egypt/Syria/Iraq— CH_2O formaldehyde; (g) Azerbaijan— $CINO$ nitrosyl chloride; (h) Malawi/Afghanistan/Libya— CCl_2O phosgene; (i) Brazil— H_2ClNS amino thiohypochlorite; (j) Ukraine/Congo/European Union/Kazakhstan/Sweden— N_2S dinitrogen-*N*-sulfide; (k) Oman— $HClO$ hypochlorous acid; (l) Turkey/Tonga/Switzerland/Tunisia/Japan/Denmark/Canada/Bahrain— OH^- hydroxide; (m) China/Kyrgyzstan/North Macedonia/Vietnam— SO sulfur monoxide; (n) Bahamas— CN_2S thiocyanamide; (o) South Korea— $CHNO$ cyanic acid; (p) Jamaica— CCl_2S thiophosgene; (q) South Africa/Olympic Flag— CH_2ClNOS *N*-sulfanylcabamoyl chloride.

stan/Lesotho (Figure 4e), Yemen/Egypt/Syria/Iraq (Figure 4f), Azerbaijan (Figure 4g), and Malawi/Afghanistan/Libya (Figure 4h, which also works for the Pan-African flag). This series adds more than 27 countries, to give a total of 64 (triband flags that can be linked to a simple chemical molecule with several levels of difficulty).

In order to complete the analysis with nonband flags, including all the elements present in the flag this time, some other shapes are presented in Figure 4: at the bottom, from left to right, Brazil (Figure 4i), Ukraine/Congo/Kazakhstan/Sweden (Figure 4j, which also works for the European Union flag), Oman (Figure 4k), Turkey/Tonga/Switzerland/Tunisia/Japan/Denmark/Canada/Bahrain (Figure 4l), China/Kyrgyzstan/North Macedonia/Vietnam (Figure 4m), Bahamas (Figure 4n), South Korea (Figure 4o), Jamaica (Figure 4p), and South Africa (Figure 4q, which also works for the Olympic flag). This last series, which adds 23 extra countries, is more complicated to solve due to the complexity of certain flags such as those of Brazil or South Africa. A full table is proposed in the Supporting Information in order to list all the combinations of color possible with simple molecules for the 186 states of the United Nations. Another series of flags is also proposed. It is the most difficult one, based on flags that no longer exist. For this section, special attention has been paid to unicolor flags, which is open to discussion for specific molecules. This category implies matching the flag with a homonuclear molecule (molecule composed of only one type of element). The most familiar homonuclear molecules are diatomic (they consist of two atoms): hydrogen (H_2), oxygen (O_2), nitrogen (N_2), and all the halogens (an easy-to-remember mnemonic for the diatomic elements is “Have No Fear Of Ice Cold Beer” for hydrogen, nitrogen, fluorine, oxygen, iodine, chlorine and bromine). Ozone (O_3) is a triatomic homonuclear molecule and

phosphorus (P_4) a tetratomic molecule. Allotropes are different chemical forms of the same element (not containing any other element) that are homonuclear: sulfur forms several allotropes containing different numbers of sulfur atom (S_2 , S_3 , S_6 , S_8) forms. The element carbon is known to have several homonuclear molecules, including diamond and graphite. With these particular molecules, it is possible to establish single-color flags. Although no monocolour flags exist at the present time, there have been several in the past, as presented with the last series of flags in Figure 5.

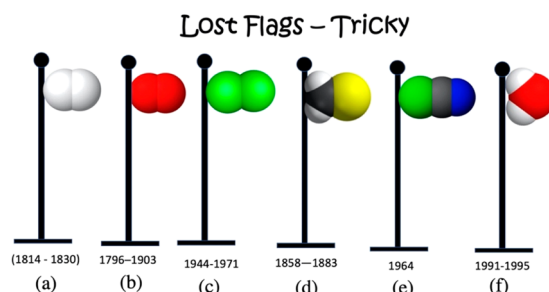


Figure 5. Molecular flags built with the CPK model for: (a) Kingdom of France (1814–1830)— H_2 hydrogen; (b) Maldives (1796–1903)— O_2 oxygen; (c) Libya (1944–1971)— Cl_2 chlorine; (d) Russian Empire (1858–1883)— CH_2S thioformaldehyde; (e) Zanzibar (January–April 1964)— $CCIN$ cyanogen chloride; (f) Belarus (1991–1995)— H_2O water.

Figure 5 depicts the 5 “lost flags”, starting with the monocolour flags: from left to right, the flag of the former Kingdom of France (1814–1830) in Figure 5a (it could also work for the peace or surrender), the former flag of the Maldives (1796–1903) in Figure 5b (this flag could also be used as an imperfect match for Morocco), the former flag of Libya (1944–1971) in Figure 5c, the band flag of the former Russian Empire (1858–1883) in Figure 5d, the former flag of Zanzibar (January–April 1964) in Figure 5e, and the former flag of Belarus (1991–1995), the last two of which are also perfect matches. This last series enables the student to manipulate specific homonuclear molecules and may also lead on to a discussion on the effect of political events and regime changes (royalty to democracy) that could lead to a change of the national flag. This last series also provides the opportunity to manipulate well-known molecules such as water (H_2O), which is one of the most famous molecules in the world. In order to encompass as many of the known molecules as possible, a last series is proposed. In this series, it is not the molecule that is represented but a fictional flag created on the basis of an existing well-known molecule. The 8 imaginary flags that can be found are depicted in Figure 6 and complete the list of famous molecules already used in the previous series (HCl, HCN, HClO, etc.).

These molecules can lead to a specific discussion on the complex shapes of flags and specific elements of vexillology (stripes, triangle, circle) and introduce the rare color purple. Discussion of the production of each molecule and the production locations in real countries is also possible. CPK colors are concentrated in the nonmetal part of the periodic table. To achieve brightly colored edifices, one should then imagine combinations with this restricted group of elements. This can lead to an interesting exploration of chemical literature: are such combinations stable? When have they been prepared? What for? What are their properties?

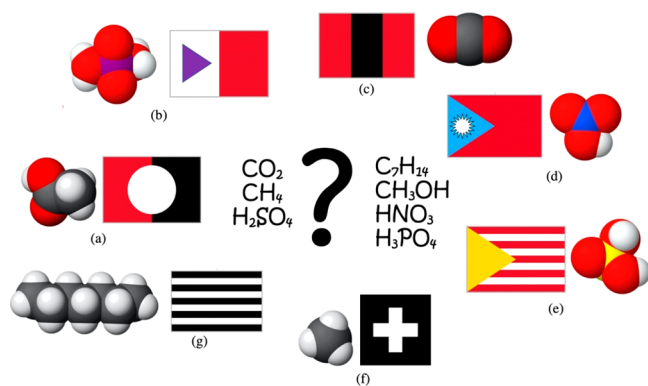


Figure 6. Imaginary flags built with the CPK model from real molecules: (a) CH₃OH—methanol; (b) H₂PO₄—phosphoric acid; (c) CO₂—carbon dioxide; (d) HNO₃—nitric acid; (e) H₂SO₄—sulfuric acid; (f) CH₄—methane (g); C₇H₁₄—heptane.

314 ■ DISCUSSION

315 From all of these series of flags, simple quizzes could be
 316 organized with the students, where the objective is to find what
 317 molecule and what country (or countries) is (are) represented
 318 by each molecular flag. Some variations could be done to adapt
 319 the level of the activity from middle school to university such as
 320 letting (or not) the students have access to a database of flags in
 321 order to find the most difficult ones and even to an encyclopedia
 322 to identify flags from earlier times (see the [Supporting](#)
 323 [Information](#)). Teachers can let each student draw a molecule
 324 at random and let them find the corresponding flag, and the
 325 different characteristics of the country, and of the molecule.
 326 After the game, questions can be raised, based on the
 327 identification of capitals, continents, and the molar weight or
 328 the applications of the chemical compounds. It is also an
 329 opportunity to address the question of resources and its
 330 localization and about the gross domestic product (GDP) of
 331 each country. Moreover, combined questions can be elaborated
 332 such as “In which continent is Thiophosgene?” (Thiosphosgene
 333 is Jamaica; answer is “america”), “What is the most Belgian
 334 molecule?” (answer is “carbonyl sulfide”), “Propose an existing
 335 molecule with the most common color combination (and name
 336 the country)” (there are 30 countries with the red–blue–white
 337 combination; see the list in the [Supporting Information](#) section),
 338 “What is the most populated molecule?” (sulfur monoxide
 339 corresponding to the Chinese flag) or “What is the molecule
 340 with the higher GDP?”. According to the level targeted, and as a
 341 variation for the postgame discussion, a list of some of the
 342 countries/capitals/molecules can be proposed in front of
 343 molecular flags to create a matching game. Whatever the results
 344 of the game, the objective remains to practice basic knowledge of
 345 world flags and manipulation of the CPK model representation.
 346 Students from two separate courses used the game activity and
 347 were surveyed after the activity with responses based on the
 348 Likert⁷⁵ scale (Figure 7). The response rate was 95%. In general,
 349 all statements showed high levels of agreement (“agree” and
 350 “strongly agree”), ranging from 62.1% to 93.1% of those
 351 surveyed.

352 A majority of students (89.7%) enjoyed the use of “Fun with
 353 Flags” in the courses and thought it was attractive and helped
 354 capture their attention (86.2%) while 81.6% also agreed that
 355 using this game helped them make connections between the
 356 theoretical aspects of courses in geography (69%), chemistry
 357 (90.8%), and geopolitics (69.0%). Fewer students (66.7%)

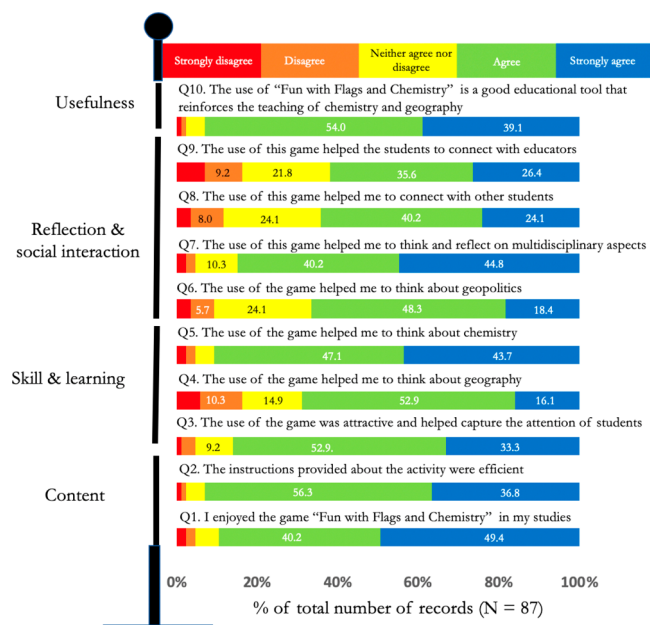


Figure 7. Student responses relating to the use of “Fun with Flags and Chemistry”. Total number of respondents = 87 (academic year 2019/2020).

358 agreed that this activity helped them to develop a multi-
 359 disciplinary outlook.

360 It is worth noting that a majority thought that this activity
 361 helped them to connect with other students (64.4%) and also
 362 with educators (62.1%). Finally, a large majority (93.1%) think
 363 that “Fun with Flags and Chemistry” is an excellent educational
 364 tool that can be used to practice chemistry and geography
 365 simultaneously. Using “Fun with Flags and Chemistry” is thus
 366 beneficial for the classroom because it creates engaging links
 367 between chemical concepts and geography, and between
 368 educators’ and students’ interests. The objective is to connect
 369 the student’s knowledge in the two disciplines and to initiate
 370 discussions/debate on geopolitical aspects of both. Geography
 371 education research has worked hard to remove itself from the
 372 common misconception of geography education relating to
 373 memorizing (countries, capitals, and state/national flags). Here,
 374 the flag identification is not the end of the activity, it is a pretext
 375 to practice and manipulate CPK code and to discuss on
 376 geopolitics in a recreative environment; it is then an original
 377 approach for more discussion on advanced and modern topics.

378 Work can then be extended after the activity to think more
 379 deeply about where resources are located, independence of
 380 resources, global politics concerning resources, and the future
 381 societal challenge linked with the abundance of chemical
 382 compounds.

383 Educators need to be careful to open the boundaries of this
 384 activity so as to unleash the students’ curiosity to think about
 385 facing these future problems. It is also important to leave the
 386 students free to search for information on chemistry, geography,
 387 or even history during projects/activities using all types of
 388 media, recent or not. Finally, combining geography and
 389 chemistry promotes critical thinking and develops skills in
 390 humanities, which will be important throughout the students’
 391 lives.

392 ■ CONCLUSION

393 The objective of this paper is to present an original way to
394 practice chemistry and geography simultaneously. The activity is
395 based on the similarities of color observed in world national flags
396 and in simple molecular models. With some simplifying
397 hypotheses (band flags, approximation of colors, and neglect
398 of coats of arms and symbols), and after a precise analysis of
399 almost 200 national flags, several series of molecular flags have
400 been proposed with several levels of difficulty, from perfect
401 matching of colors, their number, and their order, to imperfect
402 matching considering color matches only. These series were
403 used as a base for a quiz game where the objective was to identify
404 the country corresponding to the molecular flag. The feedback
405 received from students that participated in this exercise has been
406 evaluated and indicates an increase in motivation through such
407 activities and their acceptance as a good multidisciplinary tool.
408 The game was seen as a good exercise for practicing chemistry
409 and geography, breaking down frontiers between disciplines,
410 engaging students, and raising their awareness of the world's
411 challenges. Such a combination of disciplines made it possible to
412 start discussions about locations of resources and geopolitical or
413 societal challenges of the future. The activity helped students to
414 connect together, and to develop their own curiosity and
415 creativity. It could be adapted to regional flags or those of
416 province/state. To conclude, "Fun with Flags and Chemistry",
417 the first ever attempt of chemo-vexillology, offers a wide range of
418 possibilities for involving students in the classroom, from games
419 to critical thinking, and from basic chemistry to human sciences.

420 ■ ASSOCIATED CONTENT

421 **SI** Supporting Information

422 The Supporting Information is available at <https://pubs.acs.org/doi/10.1021/acs.jchemed.0c00514>.

424 List of combination for the representation of the 195 UN
425 nations flags (PDF, DOCX)

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438 Notes

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