

PARTNERING ETHICS AND CHEMISTRY IN SECONDARY AND UNIVERSITY STEM EDUCATION VIA AN INNOVATIVELY DESIGNED PERIODIC TABLE OF CHEMICAL ELEMENTS

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Abstract: As declared by the United Nations, 2019 is the International Year of the Periodic Table of Chemical Elements. Accordingly, an innovative new **Periodic Table of Chemical Elements and Ethics [PETE]** has been developed as an educational tool for secondary and university STEM (Science, Technology, Engineering and Mathematics) education. The tool is designed to be used in a case-based approach that is feasible to both individual and small group learners. Specifically, with the new periodic table, STEM becomes aligned with STSE (Science and Technology on Society and Environment), laying a curricular pathway for integrating discussions of ethics into the teaching of chemistry. Presented is the table, as well as sources for pairable ethics cases, and guidance for teachers to create curriculum which facilitates connections between ethics, chemistry, and society.

Keywords chemistry; education; ethics; science/education; educational technology

Ética y química asociadas en la educación secundaria y universitaria STEM, a través de una tabla periódica de elementos químicos de diseño innovador

Resumen: Según lo declarado por las Naciones Unidas, 2019 es el Año Internacional de la Tabla Periódica de Elementos Químicos. En consecuencia, se ha desarrollado una nueva tabla periódica innovadora de elementos químicos y ética [PETE] como una herramienta educativa para la educación secundaria y universitaria STEM (Ciencia, Tecnología, Ingeniería y Matemáticas). La herramienta está diseñada para usarse en un enfoque basado en casos que sea factible tanto para estudiantes individuales como para grupos pequeños. Específicamente, con la nueva tabla periódica, STEM se alinea con STSE (Ciencia y Tecnología en Sociedad y Medio Ambiente), estableciendo una vía curricular para integrar las discusiones de ética en la enseñanza de la química. Se presenta la tabla, así como las fuentes de casos éticos deseables y orientación para que los maestros creen un plan de estudios que facilite las conexiones entre la ética, la química y la sociedad.

Palabras clave: química; educación; ética; enseñanza de las ciencias; tecnología Educativa

Associando ética e química na educação stem secundária e universitária via uma tabela periódica de elementos químicos desenvolvida de forma inovadora

Resumo: Como declarado pelas Nações Unidas, 2019 é o Ano Internacional da Tabela Periódica de Elementos Químicos. Portanto, uma inovadora e nova Tabela Periódica de Elementos Químicos e Ética (PETE, sigla em inglês) foi desenvolvida como uma ferramenta educacional para educação STEM (sigla em inglês para Ciência, Tecnologia, Engenharia e Matemática) secundária e universitária. A ferramenta é elaborada para ser usada em uma abordagem baseada em casos, viável tanto para aprendizagem individual como de pequenos grupos. Especificamente, com a nova tabela periódica, STEM se alinha com STSE (sigla em inglês para Ciência e Tecnologia na Sociedade e Ambiente), estabelecendo uma via curricular para integrar discussões de ética no ensino de química. Apresenta-se a tabela, bem como fontes de casos éticos pareados, e orientação para professores criarem um currículo que facilite conexões entre ética, química e sociedade.

Palavras chave: química, educação, ética, ciência/educação, tecnologia educacional

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Introduction

In 2016, Dr Astrid Steele argued in *The Journal of Science Teacher Education* that there was the “need for a moral component for science education”(1:357). She further stated that an ethical framework would “inform decisions and directions of [STEM] teachers, and teacher educators”(1:359). Concurring, an innovative new design of the Periodic Table of Chemical Elements has been created which facilitates both ethics and chemistry education in secondary schools as well as universities (Figure 1). Specifically, with the new periodic table, STEM content aligns with STSE (Science and Technology on Society and Environment) content, facilitating a curricular pathway to integrate discussions of ethics into the teaching of chemistry. 2019 was declared the International Year of the Periodic Table of Chemical Elements by the United Nations(2), thus the timely creation of this new table for STEM is fitting [See next page].

The Evolution of the Periodic Table of Chemical Elements

What is known today as the Periodic Table of Chemical Elements had its origination in the mid-1800s by several scientists, including chemist Dmitri Ivanovich Mendeleev and physician Julius Lothar Meyer. Even the contributions and ultimate authorship credit of the table is an ethical issue worthy of debate(3). Due to the table’s unique ability to be a visual teaching tool, many variations have been created. These variations are notably different from the original in that they do not aim to also teach chemistry concurrently, but rather the Periodic Table of Chemical Elements becomes only a geometric template with the chemistry content removed. Such examples include the Periodic Table of the Presidents (<https://periodicpresidents.com/product/ptotp/>), Periodic Table of Figures of Speech (<https://visual.ly/community/infographic/education/periodic-table-figures-speech>), and the Periodic Table of Musical Instruments (<https://www.kickstarter.com/projects/1913274728/periodic-table-of-musical-instruments>).

Meet PETE

Presented here is a newly designed Periodic Table

of Chemical Elements termed the **Periodic Table of Chemical Elements and Ethics [PETE.]** PETE retains the standard features of the Periodic Table of Chemical Elements(4) (i.e., atomic number, element symbol, element name, atomic mass) while pairing one word relating to ethics or research ethics along with the chemical element. The word pairing aligns to the letters of the element symbol (118 unique pairs). In this way, the geometric layout and scientific content of the Periodic Table of Chemical Elements are retained and visually intact, and the ethics content is added.

Some of the word-element pairs have an immediate ethical connection. For example, potassium (element 19, symbol K) is paired with the ethics word “kind”. In this context, students could explore the case of three authors who unkindly plagiarized the work of others who had also researched potassium(5). With regard to element 98 (Californium, symbol Cf), this is paired with the ethics word “confidentiality” and students could explore the National Aeronautics and Space Administration’s Aviation Safety Reporting System(6) in the context of Californium’s use in the detection of aircraft metal fatigue. Copper (element 29, symbol Cu) is paired with the ethics word “culture” and this can be explored in the context of mining harms to indigenous peoples(7). For the word-element pairings that do not [currently] have direct ethical connections, analysis of the pairings in the context of element groups and historical cases is proposed.

Teaching chemistry involves exploring the chemical elements according to their group (vertical column of elements that generally have similar physical and chemical properties), period (horizontal row of elements that have the same number of atomic orbitals), and blocks (table segments relating to electrons). Table 1 collates the ethics words according to element group to facilitate a potential curricular package that can further pair with a chemistry-related ethics case(8) that either the teacher presents for analysis, or that the students search for using the Internet as part of an individual or small group project. Reflective writing could also be added in addition to case discussions(9). Online sources for case studies are presented in Table 2.

Periodic Table of Chemical Elements and Ethics (PETE)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H Hydrogen 1.00794	2 He Helium 4.002602	3 Li Lithium 6.941	4 Be Beryllium 9.0122	5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180	11 Na Sodium 22.990	12 Mg Magnesium 24.305	13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.63	33 As Arsenic 74.922	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.94	43 Tc Technetium 98	44 Ru Ruthenium 101.07	45 Rh Rhodium 101.07	46 Pd Palladium 106.36	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.757	52 Te Tellurium 127.6	53 I Iodine 126.905	54 Xe Xenon 131.29
55 Cs Cesium 132.905	56 Ba Barium 137.33	57 La Lanthanum 138.905	58 Ce Cerium 140.12	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.242	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.5	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.967	
87 Fr Francium 223	88 Ra Radium 226	89 Ac Actinium 227	90 Th Thorium 232.0377	91 Pa Protactinium 231.03688	92 U Uranium 238.02891	93 Np Neptunium 237.04817	94 Pu Plutonium 244.06422	95 Am Americium 243.06138	96 Cm Curium 247.07035	97 Bk Berkelium 247.07035	98 Cf Californium 251.0825	99 Es Einsteinium 252.0832	100 Fm Fermium 257	101 Md Mendelevium 258	102 No Nobelium 259	103 Lr Lawrencium 262	

Radioactive element

Table 1. Element Groups and the Ethics Terms/
Atomic Number

Group #	Ethics Terms
1	Hypothesis/1; Listen/3; Nature/11; Kind/19; Robust/37; Codes/55; Fair/87
2	Benefit/4; Mitigate/12; Careful/20; Scruples/38; Balance/56; Rapport/88
3	Secure/21; Yielding/39; Lawful/57; Cerebral/58; Proper/59; Need/60; Permission/61; Smile/62; Equipoise/63; Good/64; Timber/65; Duty/66; Honest/67; Earnest/68; Teamwork/69; Verifiability/70; Luminant/71; Accurate/89; Thank/90; Pauseful/91; Utility/92; Non-Partisan/93; Purpose/94; Amiable/95; Circumspect/96; Benchmark/97; Confidentiality/98; Ethos/99; Fathom/100; Methodical/101; Novel/102; Liberty/103
4	Timely/22; Zoiatrics/40; Helpful/72; Reference/104
5	Veracity/23; Noble/41; Tactful/73; Debrief/105
6	Credible/24; Moral/42; Worthy/74; Sporting/106
7	Manners/25; Toxicity/43; Reliable/75; Bioethics/107
8	Feedback/26; Rule/44; Onus/76; Humans/108
9	Collegial/27; Rights/45; Irenic/77; Mentored/109
10	Nice/28; Prudent/26; Patience/78; Disclose/110
11	Culture/29; Agile/47; Authorized/79; Regulated/111
12	(Grey) Zone/30; Credit/48; High Road/80; Consent/112
13	Bona Fide/5; Altruism/13; Gatekeeper/31; Insight/49; Truthful/81; Neighborly/113
14	Courage/6; Sincere/14; Genuine/32; Sound/50; Publish/82; Fly Right/114
15	Norm/7; Professional/15; Ask/33; Stable/51; Biosafety/83; Meticulous/115
16	Objective/8; Sharing/16; Search/34; Temperate/52; Polite/84; Level-headed/116
17	Futility/9; Clear/17; Belmont Report/35; Inclusion/53; Attentive/85; Trust/117
18	Humane/2; Neutral/10; Archive/18; Kindred/36; Xenial/54; Randomization/86; Obligation/118

 Table 2. Online Sources for Chemistry-Ethics
Case Studies

Source	Location
News stories	Google search (e.g., search terms chemist/chemistry, ethics/misconduct, lab/laboratory, poison)
Full journal articles discussing chemistry-ethics cases	http://www.hyle.org/journal/issues/special/ethical-cases.html
Fictional chemistry-ethics cases created by the American Chemical Society	https://www.acs.org/content/acs/en/about/governance/committees/ethics/ethics-case-studies.html
Fictional cases in e-book, chapter 7, <i>The Ethical Chemist</i>	https://global.oup.com/academic/product/the-ethical-chemist-9780190668648?cc=lu&lang=en&
Catalogue of chemistry-related retracted journal articles	https://retractionwatch.com/category/by-subject/physical-sciences-retractions/chemistry-retractions/
Misconduct cases from the US Office of Research Integrity	https://ori.hhs.gov/content/case-summary-endo-matthew https://ori.hhs.gov/content/case-summary-baughman-brandi-m https://ori.hhs.gov/content/case-summary-ramadugu-venkata-sudheer-kumar
Online chemistry magazine with news content which includes ethics cases	https://www.chemistryworld.com/

Examples for connecting elements to cases include the following: Strontium (element 39, group 2) could be discussed along with concepts in ethics and nuclear chemistry, specifically, balancing benefits and risks in various settings (medicine, war) and the careful use of mitigation to minimize harm(10). Carbon (element 6, group 14) could be discussed in the context of the ethics of the Pheramor dating app (<https://www.pheramor.com/>), specifically exploring how the concepts of sincerity, genuineness, soundness and evidenced-based science thread among marketing of “health” and social apps. Silver (element 47, group 11) could be discussed in the context of the ethical complexity of silver nanoparticles, raising concerns about regulations and authorized use (medical use in hospitals vs personal use in socks)(11). Manganese (element 25, group 7) could be discussed in the context of the improperly formulated metal storage vats of the 1919 catastrophic molasses flood, along with the concepts of reliability and professionalism (a synonym for *manners*)(12). The level of complexity of cases and concepts should be steered by the teacher during curriculum development so as to match the learning environment (secondary vs higher education).

Why Bring Ethics to Chemistry?

The European Chemical Society established the Working Party on Ethics in Chemistry(13) with objectives that include increasing the awareness of the moral complexity of chemistry activities(14). More specifically, they view the ethical issues as crossing several domains, including good scientific practice, publishing, chemical safety (inside and outside the laboratory), chemical synthesis, education, mentoring, and sustainability(14). Other issues in chemistry include professionalism(15,16) and dual use technologies(11).

The ALL European Academies Permanent Working Group on Science and Ethics argued in their statement on *Ethics Education in Science*(17), that ethics education should include the ethical aspects of how society interconnects with science. Education about the ethical connections in chemistry has also been promoted by others(18). Yet while the Working Group’s focus is the university setting, it seems appropriate to begin these discussions prior to university, where early learners are

forming their attitudes, values, and behaviors.

Indeed, the many examples of ethics cases illustrate there are frequent possibilities for ethical dilemmas in the field of chemistry. Memorization of element symbols, atomic numbers and atomic mass, are devoid of the innate contextual connection of chemistry to society, and the ethical matters therein. The use of the PETE in chemistry education is a potential tool for luminating the connection and facilitating discussion and deconstruction. When students make links to real world cases, this can help chemistry seem real and alive, and there is support for this ethics teaching method among chemistry educators(19). For the students who become scientists, “[they] have an obligation to further the conversation about the implications of their work, because they possess more information about the advances that create these ethical questions”(20:59).

A potential limitation of this work is that the ethics words chosen for the PETE table are generally positive or neutral, rather than negative. For example, element 87 (francium, Fr) was assigned the ethics word “FAIR” rather than “FRAUD”. Similarly, element 27 (cobalt, Co) was assigned “COLLEGIAL” rather than “CONFLICT OF INTEREST”. The PETE table is intentionally created with a positive tone to show the beneficent aspects of ethics; however, through case discussions, the negative aspects of ethical dilemmas will also emerge. For example, when discussing element 82 (lead, Pb, group 14, ethics word “publish”) chemistry teachers can include the concept of plagiarism. This notably links to other ethics words in group 14, such as “COURAGE” and “GENUINE”. Another potential limitation of this work is that it has not been formally studied as a curriculum tool. It is hoped that the publication of PETE in open-access form will encourage teachers to use it and assess its value with empirical research methods.

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