Making Inorganic Chemistry Interesting*

Analogy Based Pragmatic Approach to Learning

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The undergraduate student perception of inorganic chemistry as routine and unimaginative was transformed by adopting few innovative approaches in the pedagogy. This is primarily a reflection of my experiences in classroom teaching that is presented in this commentary. Fun-oriented, analogy based and pragmatic approach was used to explain simple concepts in inorganic chemistry. Laboratory demonstrations and exposure to understand research articles made the course more interesting. Selective examples of defining classroom moments are presented in this reflective commentary. Framing questions in an animated, imaginative and unconventional style made students feel quite challenged and also experience the joy in learning. The introduction of group discussion as an evaluative component enhanced the soft skills of the students. The creative instinct in learning changed students' perception of inorganic chemistry from an insipid to a highly engaging and captivating subject.

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Traditionally, chemistry is classified under the umbrella of three sacrosanct divisions— Inorganic, Organic, and Physical. Undergraduate students perceive inorganic chemistry as an insipid and run of the mill subject. I teach Inorganic Chemistry I(ChemF214) course at the second-year level for the five year integrated M.Sc (Hons) Chemistry program. This introductory level course essentially is structured for 42 lectures in the semester encompassing topics such as electronegativity, basic electrochemistry, the chemistry of main group elements, acid-base concepts and solid-state chemistry. After a brief mutual introduction in the first lecture class, I asked the students about their perspective of inorganic chemistry. The typical responses that I received were: (a) conven-

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tional (b) remembering metallurgical terms (c) balancing ionic equations, and (d) boring. I had to shed these misconceptions, and it was really a challenge to make the students realize that inorganic chemistry is equally exciting, conceptual, and above all, engaging.

Over the years, there has been a resurgence in inorganic chemistry extending from its diverse applications, curriculum development, and devising innovative pedagogical methods [1–7]. Nennig et al., [8] compared the impact of online learning against the traditional methodology of teaching inorganic chemistry courses at the sophomore level and students who major in chemistry. Crafting assignments as per the learning outcomes is an effective way to augment student learning as well as enhance their performance [9]

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Classroom learning should be fun, analogy based, and also arouse curiosity [10] in the minds of the students. By projecting images of multicolored chemicals in the first lecture class, I instilled confidence in students that this subject will be equally vibrant. I floated the first question, "What is special about the year 2019 and inorganic chemistry?" I got the reply from one chemistry buff as "International Year of the Periodic Table", which set the ball rolling. I projected slides emphasizing the importance of bonding, metal ion interactions in biology, medicine, inorganic-organic hybrid materials, and the utility in electronics, computers, and other diverse fields. The job opportunities and interdisciplinary research prospects were also highlighted in these slides, and now to an extent, I could see a glow in the faces of the students. The next ice-breaking question with a 30-second quiz clock timer was to write down a few terminologies fairly common to inorganic chemistry. The response was overwhelming, and one prominent term that emerged was *electronegativity*. Students were now requested to assemble in groups of ten, and by giving a rope each group was made to play tug of war inside the classroom. Students were excited, and then I put forth the question, "How do you link the concept of electronegativity to this game?" With a quiz clock timer on the screen, I gave the students thirty seconds to think. When the time elapsed, the concept of electronegativity was presented through a more in-depth interactive approach by discussing its periodic trends and other intricacies. The students slowly started realizing that learning inorganic chemistry would be fun and enjoyable. Furthermore, in this context, deliberations on the outstanding contributions of Noble Laureate Linus Pauling was interesting to the students and made them appreciate the concept of electronegativity. In a fifty-minute monologue lecture class, I observed that typically a student could be engrossed for approximately twenty-five minutes. Instead of a classic one-sided lecture, learning inorganic concepts through an interactive and pragmatic approach was preferred by the students for the entire 50 minutes duration. The year 2019 continued in our discussion and students were asked to relate the Nobel Prize in Chemistry and a light metallic element used to power cell phones. Students were permitted to use their smartphone and get further information through Google Search. Students were excited to get more details about this element (lithium) and its huge technological impact, thereby, resulting in a dynamic classroom chat. The intercalation of lithium in the layered graphite [11] structure and the increase in interlayer spacing of graphite was explained using the analogy of a burger and vegetable sandwich. Taking a cue from our institute logo *Innovate, Achieve, Lead* students were made to guess a heavy metal from the pun on the last word in the quotation. This was quite straightforward and the involvement was obvious even from an otherwise indifferent student. The toxicity of lead and its biogeochemical cycle was discussed subsequently. Sensing the excitement level in the class, I flashed the classic quote *To Be or Not to Be* from the Shakespearean play *Hamlet* [12], and students were asked to spot a chemical element hidden in the quote. By now, the interest level of the students had increased and everyone echoed in unison that the answer is *Beryllium*. I realized that the tone was now set for deeper learning. Present generation students are computer savvy, and I checked their awareness about a critical material being used in computer chips. The whole class chorused the response *Silicon*, and one student came with a query, "Why human beings do

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not have silicon-based life?" This triggered a fine debate and an animated classroom atmosphere when I correlated an episode of popular science fiction television series *Star Trek* [13] and silicon-based life. Playing with words is an attention-grabbing method to arouse curiosity in young minds. Realizing this, the biological concept of color transformation in chameleon was used as an analogy to explain the phenomenon of *chemical chameleon* in a time-tested classic reaction involving the color changes in varying oxidation states of manganese [14]. The stability of manganese in these states was also explained through the Frost diagram [1] in electrochemistry. Linking movies with science also make the subject exhilarating. When I asked students about their awareness about an award-winning movie *Erin Brokovich* [15], I saw a few hands rising. A home assignment was given to study the correlation between this movie and inorganic chemistry. In the next class, there was a lively debate on chromium chemistry and its link to the central theme of this movie. Subsequently, students could appreciate the speciation of chromium at varying pH and its influence in designing methods for the sequestration of chromium from wastewater. The color change of hexavalent chromium from yellow in alkaline medium to orange in highly acidic medium was demonstrated in the class in order to explain the isopolyanion [1] chemistry.

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Going forward, I ensured that every class is a revelation about the practical applications of inorganic chemistry. Inorganic chemistry is best appreciated when it is coupled to laboratory experiments or demonstrations as well as analytical characterization techniques [16, 17]. Periodic visits to inorganic and analytical chemistry research laboratories augmented these features. Technology is an offshoot of science, and students were shown how a lab prototype can be engineered to adsorb metals and other contaminants from water. This concept was exemplified by discussing the hard-soft acid-base (HSAB) principle [1] involving the interaction of soft acids such as mercury, cadmium, etc., with soft base ligands containing sulfur and iodide. The discussion of research articles through active student participation is an effective way to emphasize the practical concepts in science subjects [18]. Likewise, the interaction of hard acid aluminium with the hard base fluoride and the adsorption onto a carbon-based material [19] was discussed to showcase the defluoridation of water. In this context, surface analytical characterization techniques such as scanning electron microscopy (SEM), energy dispersive X-Ray analysis (EDAX), and X-ray powder diffraction (XRD) were also introduced. Students were sensitized to the relevance of recovering valuable metals from electronic waste. The concept of donor-acceptor charge transfer interactions [20] was demonstrated by illustrating the affinity of iodine with different solvents such as carbon tetrachloride, hexane, etc. The solvent extraction of iodine into CCl_4 and the subsequent determination of its concentration in aqueous and organic layers were described through the standard iodimetric titration procedure.

Spectacular colorful experiments in inorganic chemistry are very well illustrated by Roesky [21]. The concept of solvation of electrons by liquid ammonia and the resulting blue color due to the interaction with sodium was highlighted through YouTube video demonstration. Indeed, YouTube demonstrations during the lecture classes were in alignment with the topics discussed in the course. The explosive nature of fulminate of mercury, the high reactivity of fluorine, the use of LiOH canister in the Apollo 13 spacecraft to sequester carbon dioxide as lithium carbonate, preparation of interhalogen compounds such as iodine monochloride, etc., were illustrated through the available YouTube videos.

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Likewise, while discussing few preliminary aspects of metal-ligand interaction, the color change of cobalt (II) from pink in an aqueous medium to a deep blue in a highly acidic hydrochloric medium was demonstrated in the laboratory by explaining the transformation from octahedral ($Co(H_2O)_6^{2+}$) to tetrahedral ($CoCl_4^{2-}$) geometry. The chapter on solid-state chemistry was introduced through multifarious applications of materials. While discussing the structure of titanium dioxide, students were delighted to know about the concept of catalytic clothing [22] in air purifying jeans, and also the utility of this compound as a photocatalyst to degrade dyes. Since the M.Sc students in the first year have learned the basic concepts of spectroscopic identification of organic compounds, they were also introduced to the art of interpreting the infrared spectrum in this inorganic chemistry course by recognizing the characteristic M-O, M-N, and M-halogen (M denotes metal) stretching frequencies. In this regard, they also knew the working and operational features of an infrared spectrometer. The concept of NMR and its application in inorganic chemistry was also discussed by taking the example of phosphorous pentafluoride and the fluxional behavior in this compound [1].

Evaluation Components and Representative Exam Questions

Making the assessment questions more appealing is also equally challenging for a teacher. I frame questions in an *imaginative and animated* storytelling mode with cryptic clues, and this would make the students feel challenged as well as experience the joy of answering to the point. Few representative assessment questions are given below:

(i) An outstanding chemist who was awarded the Nobel Prize twice introduced a scale involving an important concept in inorganic chemistry. Predict the name of this chemist and briefly give the principle behind the development of this concept.

Xenon went to Café and asked for a Cappuccino. The attendant refused stating that they do not serve noble gases. Xenon was cool and did not react. Do you agree that Xenon could be totally unreactive? Give a historical (scientific) evidence to elucidate the reactivity of xenon.

(ii) Xenon went to Café and asked for a Cappuccino. The attendant refused stating that they do not serve noble gases. Xenon was cool and did not react. Do you agree that Xenon could be totally unreactive? Give a historical (scientific) evidence to elucidate the reactivity of xenon.

(iii) “This element has proved beyond doubt that it is good enough to charge the electronic world”. Looking at this sentence, guess the element and the name of an iconic Nobel Laureate in Chemistry for 2019, and comment on the interaction of this element with graphite.

(iv) BITSMAX–a new multiplex theatre is planning to premiere a movie entitled “Relativistic Conclusion”. The plot of this movie revolves around the electronegativity concept of a highly precious metallic element that finds colossal utility in jewelry. (a) Explain this concept associated with the precious element. (b) The precious metal can associate with sodium cyanide to give a complex anion which is used in the extractive metallurgy of the metal. What is this complex anion, and account for its formation? (c) Explain the chemistry as to how would you recover the precious metal?

(v) "Care should be taken to prevent eye strain while sitting in front of computer monitor for long hours". Use this analogy to explain the F-strain involved in Lewis acid-base interaction between a bulky amine and a boron compound.

Another interesting evaluation component that was introduced in this course was Group Discussion (GD) with 10% weightage. Typically, students were informed before to form a group of five according to their choice of team members. The topic was also left to their comfort level. Representative topics chosen by students were (a) Silicon-based life—fallacy or reality?, (b) Aurophilicity, (c) Depletion of xenon from Earth's atmosphere, (d) Zeolites and its applications, (e) Si=Si versus C=C bond, and (f) Lithium chemistry and its applications. The traits that were evaluated in each student were their ability to moderate the discussion in a logical flow, their level of participation, eye contact, and relevance to the topic. Students enjoyed the GD component as it improved their articulation, teamwork, and above all raising their confidence levels while discussing a scientific topic in an informal and affable ambiance.

Concluding Remarks

Reversing the perception of young minds about this traditional science subject was indeed a great experience. At the end of the semester as a teacher, it was gratifying that I have attempted to make a difference in approach by changing the views which the students had at the beginning of the semester. At the undergraduate level, students were aware of diverse journals in chemical education and inorganic chemistry. In addition, they also learned the art of literature search and interpreting a scientific article from a research journal. Lo and behold, classroom attendance and student participation improved significantly, and this was also reflected in the overall comments about this course—fun, lively exam questions, interactive. My enthusiasm also increased towards adopting new methods in teaching this subject. Some students also evinced interest in doing lab oriented projects in the area of inorganic analytical chemistry. Indeed, from my classroom experience, inorganic chemistry is not insipid and it has certainly carved a niche as an interesting application-oriented subject for the undergraduates who also do a dual degree in engineering. I cherish this classroom experience as truly enriching and rewarding.

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