INFORMAL LEARNING ENVIRONMENT TO COMMUNICATE SCIENCE: AN *OPEN DAY* EVENT AT THE INDIAN INSTITUTE OF SCIENCE, BANGALORE

Surabhi Kulkarni[1], Athavan Alias Anand Selvam[2]*, Vinay Bapu Ramesh[3] and Hotha Srinivas[4]
[1,2,3]Prayoga Education Research Centre (PERC),
[4]Indian Institute of Science Education and Research, Pune
[2]athavan@prayoga.org.in

In the present work, we have discussed the hands-on activities and games performed in an "Open Day" event at the Indian Institute of Science, Bangalore. The participants are students from various academic institutions and the general public. The volunteers are chemistry teachers and educators from various organizations and institutions. In the view of celebrating the international year of the periodic table (IYPT-2019), participants were exposed to three different games which were designed based on the periodic table and Bohr's atomic model. During this event, the volunteers explained the history of the periodic table, the importance of IYPT-2019 and the game rules to the participants. Both the card and board games entertained the players with active participation and also resulted in effortless learning. In order to extend the knowledge about IYPT-2019, all the participants and winners were rewarded with pocket-size cards, charts, and books related to the modern periodic table.

INTRODUCTION

Science communication is emerging as a favored approach for communicating science both in a formal and informal way to the audiences/participants. Effective science communication is crucial to spread scientific thoughts and to develop an interest in science learning especially among young students (Burns, O'Connor, & Stocklmayer, 2003). It has also helped the general public familiarize with the basic principles of science and appreciate the contribution of science to everyday life. During the sixteenth and seventeenth centuries, science communication aimed mainly to engage the audience in wonderment and surprises (Knight, 2002). In late 1700, the Royal Institution was founded, which became the center for spectacular scientific lectures and was very popular among the upper classes of the community. Most popular lectures were delivered by experts like Humphry Davy, Michael Faraday, John Tyndall, and Henry Huxley. Even today, evening lectures and Christmas lectures are delivered to communicate science at the Royal Institution, London. (James, 2002; Austin and Sullivan, 2018). By the twentieth century, science demonstrations moved from learned class to include people from all the strata of society by introducing planetariums, exhibitions, science workshops, and museums to disseminate the ideas of science.

The environment of science learning is broadly classified into two ways, formal and informal learning. The formal learning environment is a traditional lecturing format which is largely present in schools, colleges, and universities. The informal learning environment is non-structural learning which includes a broad array of settings like museums, exhibitions, science shows/demonstrations, theatres, media programs, botanical gardens and other activities to transmit knowledge. A growing literature shows that students learning in a formal setup find science to be a difficult subject (Johnstone, 1991; Reid, 2008). Among the various scientific disciplines, chemistry is largely considered as a tough subject due to the nature of the subject itself. (Taber, 2001; Tumay, 2016; Alsop and Watts, 2003). Certain topics like atomic structure, the periodic table, mole concept, chemical bonding, and chemical equilibrium are considered as threshold concepts for high school students (Johnstone, 2010; Johnstone and Kellett, 1980). A plethora of research shows that using educational games will be fun, interesting, motivating and captures students' attention for a longer duration (Franco-Mariscal, Martínez, & Maìrquez, 2012; Franco-Mariscal, Martinez & Mairquez 2016; Martí-Centelles and Rubio-Magnieto, 2014; Tan and Chee, 2014).

In this paper, we discuss the activities performed in an informal learning environment known as '*Open Day*' event which is organized by the Indian Institute of Science (IISc), Bangalore every year (https://www.iisc.ac.in/events/iisc-open-day-2019/). IISc, a premier research institute opens its doors for the public every year on an open day event and this tradition has been followed since 1956 till date. The aim of this event is to showcase the research undertaken in the institute and to communicate important scientific concepts to the general audience. The year 2019 being the international year of the periodic table (https://www.iypt2019.org/), we had a stall during the open day event (March 23, 2019) to engage students/participants with some chemistry games. These games engage students in an interactive, enjoyable learning environment and also foster conceptual understanding. The activities included card games, board game, and a crossword puzzle which helped participants to realize that the invention of the periodic table is one of the most significant achievements in science. The students from various schools and colleges actively participated in our designed games. In an effort to encourage learning about the periodic table and atomic structure, all the participants and winners were rewarded with different prizes.

METHODS

Understanding the structure of the periodic table gives the ability to make predictions concerning atomic size, ionization energy, electron affinity, electronegativity, melting point, *etc.* about different elements (Rouvray, 2004). About four optimized games based on the periodic table and Bohr's atomic model were introduced to the participants during IISc open day event (Figure 1). The objectives of those games were as follows:

- To recognize the name, symbol, group and period of the elements in the periodic table.
- To recall the chronology of various periodic tables till the modern periodic table.
- To understand the electronic configuration and distribution of electrons in an atom.
- To correlate electronic configuration and the periodic table classification.

Figure 1: Game materials for the participants (a) *ChemDom* - card game (b) *ChemUno* - card game (c) *ChemUdo* - board game and (d) Elements name searching puzzle game

Games rules

The card games such as *ChemDom, ChemUno* were designed based on the periodic table and the board game *ChemUdo* was developed to explain Bohr's atomic model. Both the card and board games were designed to enhance students' engagement and motivation towards the learning goals and not by following any pedagogy. The rules and methods for each game are given below.

(i) *ChemDom:* *ChemDom* is a card game for 2-10 players. There are 118 cards in a deck that corresponds to the elements of the Periodic table. Each card is printed with the symbol, name, electronic configuration, block that it belongs to the periodic table, atomic number, period and group of an element with a *hypothetical* rank. Hypothetical rank is a random number given to each card. It is an independent variable and there is no correlation between other variables mentioned. The objective of this game is to recognize the name of the element, its symbol, electronic configuration, period, group and atomic number. The game begins by equally distributing cards among all the players. The player on the right side of the person who has distributed cards will start the game. The players will look at the above first card and declare one of the five variables (atomic number, period, group, block, and rank) in that round of the game. Subsequently, all the players will be showing their cards. The person with the highest value will be winning that round. However, if the variable is rank, then the participant with the lowest value will be winning that round. The order for blocks is $s<p<d<f$. All the cards that were displayed will be taken by the winner. The process goes on until one player remains with a maximum number of cards.

(ii) *ChemUdo*: *ChemUdo* is a board game that can be played by a maximum of four players. The Game set includes the mainboard, 36 small display cards, dice, 16 e-cones (pawns) of red, blue, green, and yellow colors. The objective of this game is to understand the Aufbau principle and Pauli's Exclusion Principle. Each player will pick and display a card, which has the name, atomic number and electronic configuration of an element. The participants will choose four e-cones of identical color and the game begins with a person who gets the highest atomic number by rolling dice. Players are required to get either six or one to enter the home (center) for each e-cone. Eventually, the game continues the anti-clockwise direction. E-cone degeneracy will not be allowed in any orbital except s orbital. Each player will be commencing the game to complete the electronic configuration of the chosen element. The player who completes the electronic configuration of all the chosen elements of all participants will be considered as a winner.

(iii) *ChemUno:* *ChemUno* is a card game that is very similar to *the UNO* game for 2-10 players. The objective of this game is to recognize element symbol, atomic number, group, period and general properties of elements. There are 103 cards in the deck. Cards are of four different colors red, blue, green and yellow. There are two types of cards: number cards and action cards. Number card consists of the element name, symbol, atomic number, group and period of an element. Besides the Number cards, there are several other cards that help mix up the game. These are called action cards with five different actions and the descriptions of action cards are given below.

(a) ***Reverse*** – When a player gets a Hg or Br card, the clockwise direction game switches to counterclockwise or vice versa. This is to convey to participants that only Hg and Br elements are in the liquid state at standard temperature. (b) ***Skip*** – When a player places inert gas cards (He, Ne, Ar, Kr, Xe, Rn), the next player has to skip their turn. This will make participants understand that these gases do not react with any other elements. (c) ***Draw Two*** – When a participant discards a semi-precious element (like Ag & Cu) the next person will have to pick up two cards and forfeit his/her turn. From this, the students come to know that these elements are costly but not exorbitant. (d) ***Wild*** – This card represents all four colors, and can be placed on any card. The player has to state which color the card represents for the next player. This rule followed to convey to students that these elements are versatile and they react with most of the elements known. (e) ***Wild Draw Four*** – This acts just like the wild card except that the next player also has to draw four cards as well as forfeit his/her turn. This is to convey to students that these elements are very exorbitant in cost.

After shuffling, 7 cards are distributed to each player and they are dealt face down. The rest of the cards are placed in a draw pile face down. The top card should be placed in the discard pile, and the game begins! The game usually follows an anti-clockwise direction and all the players should try to match the card either by period, group or block (color) in the discard pile. Besides the card and board games, a crossword puzzle (element names) game was created to engage participants who are not familiar with the atomic structure and periodic table properties.

RESULT AND DISCUSSION

Students, parents, and teachers from various schools and colleges attended the "Open Day". Approximately

25,000 - 30,000 people visited the event at IISc. We designed our stall in association with the chemistry department of IISc to engage 40-50 participants in a batch. In the stall, 3 sets of each game were facilitated by 10 volunteers to participants aged above 12 (Figure 2). The role of volunteers is to undertake two major tasks - one of them is to facilitate games, and another is to provide logistics for distributing prizes and participatory gifts to the players. The volunteers introduced all the games to the participants by describing the theme of IYPT-2019, followed by questions pertaining to the periodic table and the atomic structure. The students were allowed to choose games randomly with their peers and also others.

As described in the introduction, game-based learning is a technique to motivate students to learn and understand concepts in an interesting way. The designed card and board games showed positive impact on the students' perceptions towards learning chemistry. Many students expressed their interest to learn all the chemistry concepts through a game-based approach. The participants enjoyed all the activities and some of the students showed competitive behavior while playing games. In comparison to the general public, school students quickly developed an interest in all the games. Initially, the volunteers asked a few basic questions to examine the acquaintance of the participants with the periodic table, periodic properties of elements and its electronic configuration. The common questions asked to all the students during the activities are given below.

- What is the periodic table?
- Are you familiar with IYPT-2019?
- Can you write the electronic configuration of any element?
- What do you know about subatomic particles?
- Do you know how the elements differ in properties?
- Do you know the shapes of s, p, d, and f orbitals?

Figure 2: IISc Open Day activities (a) Participants actively engaged with games, (b) & (c) Volunteers explaining card and board games, (d) Young participants deeply involved in the word puzzle game, (e) pocket size and chart periodic table for the participants, (f) The periodic table handbook for winners

Specific questions were asked to identify the alternate conceptions of the students who enrolled in pre-university and undergraduate courses. The volunteers collected data to test our hypothesis that the majority of the students lack knowledge on certain key facts and/or do not possess conceptual understanding of periodic table and atomic structure. A few example questions are - *"How are the elements arranged (in terms of atomic properties) in the periodic table? Which is the smallest element by size? What is the physical state of bromine at room temperature?"* and so on. For the first question, we observed an erroneous thought among a lot of students that *"elements are arranged in the increasing order of atomic size"* which was rectified by the volunteers. We also observed there exist a confusion between atomic mass and atomic size among students. Therefore some of them are wrongly relating the number of electrons to the atomic radius: *"Hydrogen has the smallest radius because it has only one electron"*. For the second question, some of the students answered wrongly that *"Hydrogen is the smallest element by size"*. Most of the students answered correctly as helium but without any explanation indicating the answer might have been memorized or guessed. Later during the gaming sessions, the facilitators explained the nuclear charge differences between hydrogen and helium to improve their understanding. The common misconception for the third question was, *"Bromine is a gas at room temperature like fluorine and chlorine"*. Playing with '*reverse*' active cards in *ChemUno* game, the players came to know that bromine and mercury are in liquid state at room temperature. It came to our notice that some students erroneously thought, *"there is no relation between the number of electrons and the chemical behavior of an atom"*. Later by the descriptions of active cards in *ChemUno* game, volunteers made clear the relationship between the outermost electrons and the chemical properties of some elements. By playing *ChemDom* card game, the students got familiar with the Greek names of the elements. From the students' response which were collected after the gaming sessions, we imply that the constant playing of both *ChemUno* and *ChemDom* card games will help in identifying group, period, atomic number and properties of most of the elements. The *ChemUdo* was identified as the most interesting game among students. Many students expressed that they could identify most of the modern atomic theory concepts in the board game. With *ChemUdo* game, the volunteers explained the application of electronic configuration in determining the period and group of the element without looking at the periodic table. The students asked some significant questions like: "*What is the difference between orbit and orbital?, What is the importance of electronic configuration?, How to write electronic configuration for cations and anions?, What is an unpaired electron?*", and so on. Based on the questions asked by the students, the volunteers explained Pauli's exclusion principle, Hund's rule and Aufbau principle to enable them to play the game. Furthermore, the anomalous electronic configurations of some transition elements such as molybdenum, copper, palladium were also informed during the board game session. It was observed that *ChemUdo* board game aid students to write electronic configuration of elements and improves conceptual understanding of atomic structure. The common students' misconceptions about the periodic table and atomic structure are listed in Table 1.

The main instrument used to evaluate the effectiveness of the games was a survey. After completion of each game, the volunteers interacted with the participants to get feedback about the games and effectiveness in learning concepts. Survey statements from the students were categorized based on their perceptions: the benefits of playing games for learning chemistry, the difficulty or simplicity of the game rules, and their motivation level in participation. Most of the students reflected with positive statements like: *"It is useful to learn effortlessly"*, *"These games support me to learn about less familiar elements"*, *"I like to learn all*

No.	Questions asked	Sample Responses (Verbatim)
1	How the elements are arranged in the periodic table? (in terms of atomic properties)	- *Based on its atomic size.* - *Arranged by atomic weight.* - *Based on its chemical behaviour.*
2	Which is the smallest element by size?	- *Hydrogen atom is the smallest because it has only one electron.*
3	What is the physical state of bromine at room temperature?	- *Bromine is a gas.* - *Gas like fluorine and chlorine.*
4	Is there is any element which don't follow Aufbau principle?	- *All elements follow Aufbau principle.* - *Yes. Radioactive elements don't follow.*
5	What is the correct electronic configuration for Na^{2+} (Z=11)?	- $1s^2 2s^2 2p^6 3s^1$ - $1s^2 2s^2 2p^4 3s^1$
6	Do all the elements have electrons, protons and neutrons?	- *Yes. All elements are made up of three sub-atomic particles.*

Table 1: Students' misconceptions about periodic table and atomic structure

the chemistry concepts through games", "I would like to purchase the game kits to play at home" etc. Some students felt difficulty in following the rules of *ChemUdo* game due to lack of coherent understanding of Aufbau principle, Pauli's exclusion principle, Hund's rule and the difference between orbit and orbitals. Later it was resolved by clarifying all the doubts during the gaming sessions. We observed that the designed games helped the students to overcome their misconceptions. To encourage more participation, pocket-size cards/ posters of the periodic table were issued to all the players (Figure 2). The winners of each game were appreciated with "*The Periodic Table Handbook*" written by Prof. C.N.R. Rao and Indumati Rao. Many teachers and parents responded positively about the gaming sessions and also inquired the availability of game sets to purchase. Some teachers commented that this was their first experience of using games to teach chemistry concepts. By viewing the responses from the parents and the teachers, we suggested that similar educational games can be used in a formal learning environment. However, the teacher needs to understand the objective of the games thoroughly and be able to achieve the required learning goals. We emphasize that there is a strong need for creative educational games like *ChemDom*, *ChemUno*, and *ChemUdo* in formal learning environment because it can be used to monitor the learning process of the students constantly. We also recommend that these games can be used in similar informal learning environments like science exhibitions, workshops, and other science community gatherings with appropriate audience.

CONCLUSION

Informal learning is a great approach to motivate students towards the learning process. All the participants enjoyed the autonomy associated with the IISc-open day event. The activities conducted by us as a part of the Open Day event helped school students to gather knowledge about IYPT-2019 and its importance. Many curious individuals showed deep involvement in solving puzzles, playing games and engaged in constructive interaction with the volunteers. The games and interactions allowed the facilitators to clarify certain common misconceptions in chemistry. This informal learning environment using games facilitates engagement in science learning and also enhances the academic performance of students. The entire program was successfully carried out to communicate science to all learners. There is a plenty of scope to conduct research on informal learning approaches and also incorporating game based pedagogies for various chemistry concepts.

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