# ChemicAble: Tangible Interaction Approach for learning Chemical Bonding

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### ABSTRACT
In this paper we present ChemicAble, a Tangible User Interface (TUI) for teaching ionic bonding to students of grade 8 to 10. ChemicAble acts as an exercise tool for students to understand better the concepts of ionic bonding by letting them explore and learn. We discuss the instructional content of the system along with its prototyping details. Usability testing conducted with students has been discussed. The system realizes its aim of learning collaboratively with fun.

### Author Keywords
Education, Chemical Bonding, Tangible User Interface, Tabletop Interaction

### ACM Classification Keywords
H5.2. User Interfaces, K.3.1. Computer Uses in Education: Collaborative learning

### General Terms
Design

### INTRODUCTION
Learning through exploration, trials and failures is one of the most effective and fun ways to understand new concepts and to foster the learning process. [35] ChemicAble aims to achieve this effectiveness and fun in teaching transfer of electrons in simple ionic compounds by using concepts of tangible interaction.

Two or more elements combined in a definite proportion result in the formation of a chemical compound. However, as the number of atoms in a compound increase, it becomes difficult to visualize the compound formation. Various attempts have been made to make this concept understandable using Augmented Reality (for example 15, 16, 17) and interactive tabletop technologies (for example 8, 21, 22, 23). We chose to use interactive table-top medium for this task because of its ability to enhance collaboration [25].



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To implement ChemicAble, we used the rear-DI technology [10, 12]. The next section of the paper describes tangible user interfaces in learning and further highlights the ones employed in chemistry education. We also discuss the instructional content of the system along with an elucidation of the usability testing.

### TANGIBLE USER INTERFACE IN LEARNING
The educational research conducted in the past has emphasized on the importance of a child interacting with physical objects around him for the overall development of his mind. There are ample evidences to strongly support the fact that through touching, manipulating, exploring and testing, children find out and learn about the world around them and grasp things in a much faster way than when it is presented to them in textual format [1, 2, 3]. Developmental psychologists around the globe have emphasized the importance of using physical objects for young children's cognitive development [4, 5, 6]. According to Piaget’s developmental theory, manipulating physical objects supports and develops thinking in children and hence tangible user interfaces might bring about expedited and natural learning [5, 29]. Paul Marshall talks about how tangible interfaces enhance learning. He describes the present research in cognitive science and education and also provides a set of perspectives that can guide research and development in the area of tangible user interfaces [27]. Rogers et. al. showed how mixed reality environments with novel mixes of physical and digital worlds engender enormous exploration and reflection among children[26].

Few projects that use Augmented Reality based technologies for educational purposes are Origami Desk, Construct3D (a 3D geometric construction tool based on the collaborative Studierstube), Participatory Simulations Interactive Textbooks and MagicBook [7, 15, 16, 17, 18, 19]. Some augmented reality system have also been developed to facilitate learning like a 3D molecular model pop-up embedded in the book using Matrix [20]. In Computer Human Interaction. Projects using Interactive Tabletop technologies for education are G-nome Surfer (learning of genomics), Involv (for exploring biodiversity and the relationships among organisms), NIMIS (in elementary schools for reading instruction), Envisionment and Discovery Collaboratory (EDC), table tops used in SynergyNet project, and Tangram Tabletop System [21, 22, 23, 24, 32, 33]. Schneider et. al.,[31] through their study of Phylo-Genie, a tabletop interface, state that table top interface fosters collaborative learning which was based on the socio-constructivist theory which is a coalescence of theories of Piaget[29] and Vygotsky[30].

## TANGIBLE INTERFACE IN CHEMISTRY EDUCATION

Petrucci et al. in their research ponder upon the question whether visuals can be used to help make abstract chemistry more tangible, and further substantiate the importance of use of TUIs in education [14]. Yu-Chien Chen compares the use of physical objects and augmented reality for chemistry education. He posits that AR creates an alternative way to see chemistry [28]. If designed well, it enhances learning by creating a constructivist learning environment and by grabbing user's attention. Augmented Chemistry [36] is a tangible user interface aimed at organic chemistry education with a focus on concepts like the octet rule and tetrahedrons. Analysis has also been made of learning effectiveness and user acceptance of AC versus the more traditional ball-and-stick model (BSM). CheMO is another mixed reality interface for performing chemistry experiments [34]. Chemieraum is another tabletop interface for chemistry education. [35].

The hasn't been any significant work done in this direction specifically for the indian context. The primary school education system in India stresses on the Lewis dot structure and it plays a major role in understanding of chemical bonding by indian students. We tries to leverage this concept and build upon that to develop a system particularly relevant for the Indian education system.

## INSTRUCTIONAL CONTENT

Generally schematic or computer-based molecular models are used for representing a physical concept or a mathematical formula, but they are mostly synthetic and highly abstract [9]. Such models represent ideas, helping us to understand the underlying structures and dynamics of organic and inorganic chemistry. There are a large number of models and concepts in chemistry and each one is meant to show a different aspect of chemistry and must be chosen depending on the educational purpose and the target audience. There is no one single kind of model which is best suited for chemistry education. Rather, different models and concepts must be blended in a way serving educational levels and needs.

Lewis structure forms the base for understanding the concept of electron transfer for students of grade 8 and 9 in India. { As stated in the NCERT book on Science for class X, chapter 3, 4, the electrons present in the outermost shell of an atom are known as the valence electrons. The outermost shell of an atom can accommodate a maximum of 8 electrons. Atoms of elements, having a completely filled outermost shell show little chemical activity. Of these inert elements, the helium atom has two electrons in its outermost shell and all other elements have atoms with eight electrons in the outermost shell. The combining capacity of the atoms of other elements is explained as an attempt to attain a fully-filled outermost shell (8 electrons forming an octet).The number of electrons gained, lost or shared so as to make the octet of electrons in the outermost shell, gives us directly the combining capacity of the element called the valency. An ion is a charged particle and can be negatively or positively charged. A negatively charged ion is called an 'anion' and the positively charged ion, a 'cation'. Metals generally form cations and non-metals generally form anions. Atoms have tendency to complete their octet by this give and take of electron forming compounds. Compounds that are formed by electron transfer from metals to non-metals are called ionic compounds.}

The task of understanding the Lewis model and the electron transfer with the help of just text and figures is a really herculean one for kids. Considering the scripting limitations, graphics, and educational scope, we employed the Lewis structure model in our project.

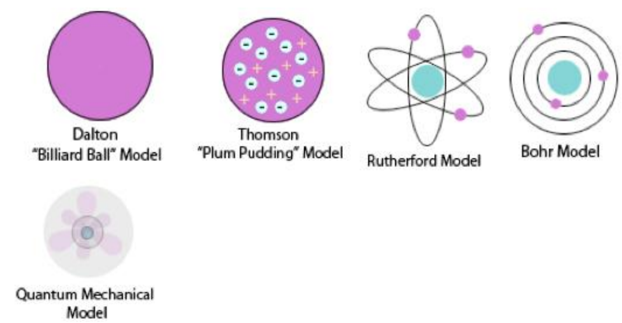


**Figure 1. Various atomic models [13]**

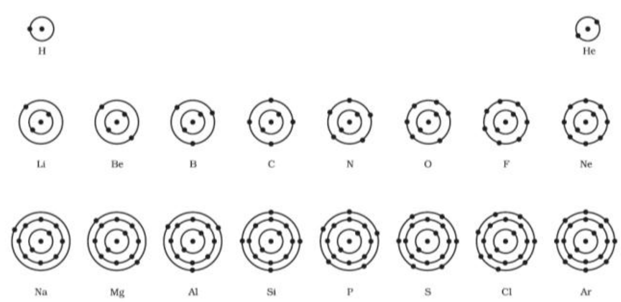


**Figure 2. Bohr model of first 18 elements of the periodic table [11]**

## SYSTEM OVERVIEW

ChemicAble is an interactive tabletop interface that helps children understand ionic compound formation. The system has an in-built exploratory nature and promotes collaborative learning with fun. First 20 elements of the periodic table are represented by 20 tokens. Figure 3 shows the task flow of the system. For example, when a token representing sodium atom is placed on the table top, its valence shell (outermost shell) with 1 revolving valence electron is displayed around the token. When the student places a chlorine atom on the table, its valence shell along with 7 revolving valence electrons is displayed.

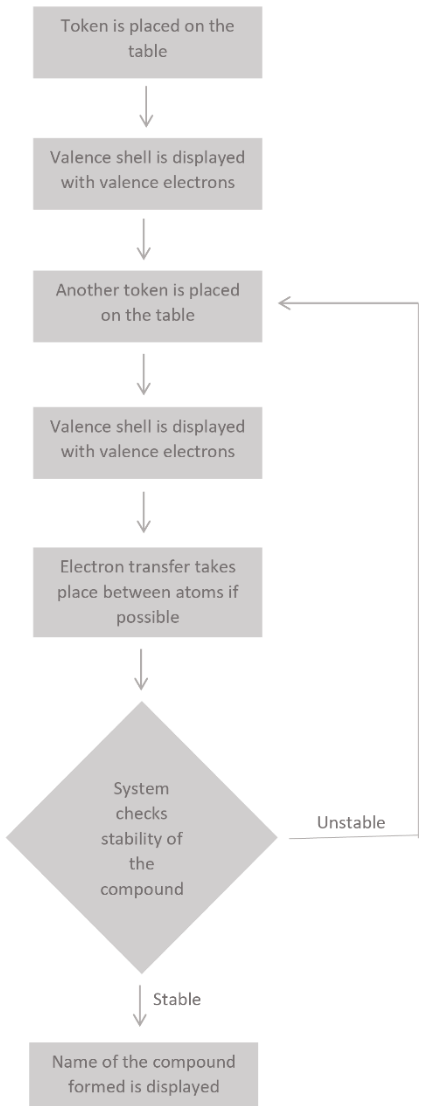


**Figure 3. System Taskflow**

The electron from the sodium atom gets transferred to the chlorine atom. +1 charge appears on the sodium atom due to loss of electron and -1 charge appears on the chlorine atom due to gain of electron. Both form a stable compound. The top bar on the user interface turns green to show success and displays the name of the stable compound so formed (sodium chloride, in this case). The valence shell of the atoms also turns green to show a stable compound.

The child is encouraged to explore with different atoms and see how the transfer takes place. Feedback (visual and auditory) is given at every step (whenever an atom is unstable, an atom is placed/ removed from the table, electron transfer happens and a stable compound is formed).

**Figure 4. ChemicAble working prototype**

## PROTOTYPING

The system (figure 5) consists of a table, a projector, a camera and a sheet of glass. The projector and camera were placed beneath the table. Atoms were represented by hemispherical tokens and were tagged with fiducial markers underneath. They also had the name of the atom along with the mass and atomic number written on the top. These tokens, when placed on the table, are detected by the camera. Programming was done using Processing and Reactivision was used for identification of the fiducial markers.

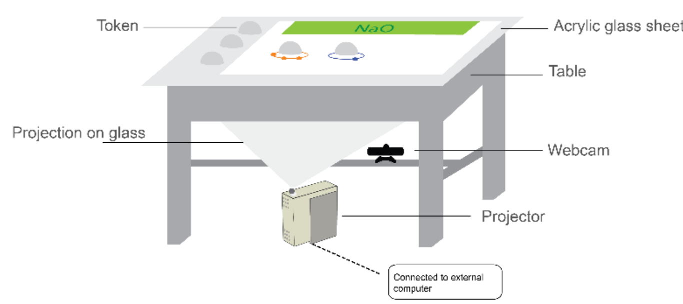


**Figure 5. Basic Setup of ChemicAble**

## USABILITY TESTING

The aim of user testing was to observe and measure ease, engagement and understanding of the system for students of grade 8-10. Quantitative approach of user testing was taken by using Likert Scale. Simultaneously, detailed observations were made of the interaction between students and ChemicAble.

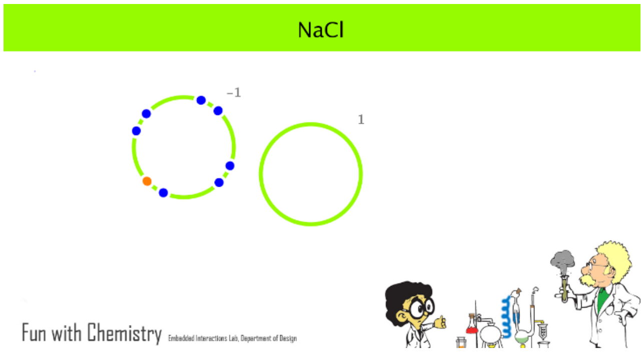


**Figure 6. Screenshot of the graphical user interface**

After the experiment, students were asked to evaluate ChemicAble through a questionnaire that consisted of a 4-point likert scale with markings ranging from strongly disagree to strongly agree without the neutral option. We chose "forced choice" survey scale to avoid neutral response from the users.

| | | Positive Response (%) | Negative Response (%) |
|---|---|---|---|
| Q1 | ChemicAble helped me in learning about the chemical compound formation | 90.91 | 9.09 |
| Q2 | I enjoyed using ChemicAble to make chemical compounds. | 90.91 | 9.09 |
| Q3 | The action required for making the compound were easy to understand. | 63.64 | 36.36 |
| Q4 | It was easy to perform chemical compound formation using ChemicAble | 90.91 | 9.09 |
| Q5 | The info. displayed on the table was clear and eay to understand. | 72.73 | 27.27 |
| Q6 | Overall, I liked the use of ChemicAble to learn about making chemical compounds. | 90.91 | 9.09 |

**Figure 7. User Testing with Students**

As shown by figure 7, students perceived that they learnt about the chemical compound formation (as evident from question 1). They found compound formation easy using ChemicAble (as evident from question 4).

Results also show that students were doubtful about the procedure for making the compounds (as evident from question 3).Overall students liked the table and found it to be fun. The table also had certain level of engagement (as evident from question 6).

The results tabulated in figure 7 show that there was an overall likeness among children for the experience. However due to a small sample size, extensive analysis could not be performed and the results so obtained from the quantitative study are of not much significance. However, the observations from the qualitative study mentioned in the next section show a very strong liking for ChemicAble.

**Figure 8. User Testing with Students**

## OBSERVATION AND DISCUSSION

### Collaborative Learning

Students enjoyed exploration and they grasped the method of interacting with the table better when in groups than when alone. For example, when a student was interacting with the table alone he took some time in deciding which atom to bring next after first one. However, when in group, different students brought different atoms and saw simultaneous feedback leading to a more natural interaction. Children showed excitement and interacted with each other while interacting with the table. For example in one case, one student tried to explain the concept of electron transfer to another student while demonstrating the system.

### Exercise Tool

Students used their prior knowledge of chemical bonding taught in class to figure out which atom to bring next. For example - a student didn't remember that oxygen requires two electrons in its valence shell to complete its octet. This lack of knowledge hampered his interaction with the table.

### Feedback

Children enjoyed playing around with the physical atoms. The concept of transfer of electrons was pretty clear to them after the experiment. However, some students construed the completely empty outermost shells of metals after they let go off electrons as being unstable. Fully-filled penultimate sub-shell needs to be shown in case of metals.

### Display penultimate shell in metals

Another shortcoming which was found during user testing was the confusion amongst students in deciding whether a metal has become stable or not. The cause for this was that only the valence shell of the atoms is displayed on the table. So when a metal loses electrons its valence shell becomes empty and the octet stability of its penultimate shell is not visible. This can be countered by displaying both the valence as well as the penultimate shells of each atom.

### Interaction with Dr. LN Gupta

ChemicAble was also presented to Dr L.N. Gupta, the chemistry teacher at Kendriya Vidyalaya who found it very useful for students of grades 8-10 and suggested addition of covalent and co-ordination compound formation to the system. Also, he suggested showing a real ionic compound formation visually as opposed to showing that just through text and color based feedback.

**Figure 9. Interaction with Dr. LN Gupta**

## CONCLUSION

ChemicAble so produced can prove to be an effective learning tool for students of grade 8-10. The didactical aim of teaching valencies and ionic bond formation is achieved. It realizes the aim of learning collaboratively with fun and reinforces their concepts of ionic bonding. A few shortcomings have been observed in the system. After a few changes, the system's usefulness and usability can increase manifold.

## FUTURE WORK

Although the present version of ChemicAble gave us satisfactory results, there are a few aspects of it which have scope for further improvement. Firstly, the present version only shows the formation of ionic compounds between a metal and non-metal. The formation of covalent and coordinate compounds can also be depicted which gives the students a better idea of the three types of chemical bonds and the differences between them. The present interface has minimal interactive elements. An animation which clearly shows the transfer of electron from one atom to another will be very helpful for students. Better ways of interaction like haptic feedback, when there is an electron transfer or when a compound is formed, is also a good idea. Bringing forth a wrong atom could be accompanied by a voice based feedback saying that it is unstable and another atom should be tried. The concept of proximity sensing can also be applied for the atoms on the table. Further shortcomings will become evident when the table starts getting used more often and by an even larger audience.


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