Studies in Application of Augmented Reality in E-Learning Courses

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Abstract Previous Studies have indicated that specific concepts in chemistry education require visuospatial skills by students. This paper presents an attempt to extend Augmented Reality technology to school textbooks—particularly Chemistry. A qualitative study conducted with five high school chemistry teachers in India with the aim to identify existing pedagogical patterns related to Solid State Chemistry taught in high schools in India and attempt to design a device based application that will aid students' learning. The results were found to be concurring with existing literature in chemistry learning. On the basis of this study, design suggestions to be considered while designing AR based solutions in the field of solid state chemistry are proposed. Incorporating these suggestions, we then conceptualized and developed an AR application for mobile and tablet devices based on a popular platform. This application uses standard XII NCERT textbook images as markers/reference to augment dynamic 3-dimensional content. User testing of the application indicated its acceptance.

Keywords Augmented reality · E-Learning · Solid-state chemistry models

1 Introduction

One of the challenges of modern chemistry education is that while learning one has to address multiple levels of representation which requires interdependent, networked thinking of the students [1, 2] and establishing relationships between these multiple levels can be challenging for novice learners [2]. In our study, we aimed at addressing learning difficulties of Solid State chemistry and similar concept followed by proposing an Augmented Reality application design.

Solid State chemistry which is taught as the first topic in the 12th year of school (standard XII in high school chemistry in India) involves several concepts with

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A. Chakrabarti (ed.), *ICoRD'15 – Research into Design Across Boundaries Volume 2*,
Smart Innovation, Systems and Technologies 35, DOI 10.1007/978-81-322-2229-3_32

3-dimensional visualization of atoms and molecules. Other than spatial visualization skill, students also require to constantly switch between micro and symbolic levels to understand the concepts. Educational research of Potter et al. [3] concluded that spatial ability influences academic performance in engineering. Every student in the classroom doesn't necessarily have a good spatial visualizing ability. Previous studies have shown that students with lower visuospatial abilities are unable to perform well in solving spatial and non-spatial chemistry problems [4, 5].

Augmented Reality (AR) is defined as any system which combines real and virtual, is interactive in real time and is registered in three dimensions [6]. Literature [7] suggests that such immersive Augmented Reality tools increase motivation, contributes to better learning, and enhances the educational experience for students. AR offers an alternative way to see the abstract chemistry world and allows students to interact with the system and discover knowledge by themselves through "sensorimotor feedback" [8]. Overall, AR as an educational medium provides a great alternative environment for students to learn. There have been research projects like Studierstube and Construct 3d etc. [9, 10] towards application of AR in education. Chen [11] investigated student perceptions while using AR based tool and physical models to learn about amino acids. In contrast with these, we followed a user centric design process in the development of this e learning tool, by taking inputs from teachers and students before and after building the prototype respectively. We aimed at development of AR based e-learning tool for Solid State chemistry whose features, interactions, topics were chosen based on user expectations and needs, making our tool more useful and usable.

2 Application Design Methodology

2.1 *Topic Chosen*

We chose Solid States, which is the first chapter in Chemistry book of class 12th according to NCERT [12] course curriculum. This chapter deals with 3d arrangement of atoms of crystalline metallic, non-metallic elements and ionic and covalent compounds which need the students to understand the concepts sub-micro and symbolic level at the same time. More importantly, it requires students to visualize the atomic arrangement in 3d space which deals with Visio-spatial thinking capability of the students.

2.2 *User Need Analysis*

The primary user of our application is the student of 12th class studying Solid state chemistry. The secondary user was identified as the Teacher who teaches the chapter. With the aim to identify the problem points and additional needs of

Fig. 1 Teachers under interview in their respective school environment

teachers and students in terms of their learning/teaching and understanding the underlying concepts, a user survey was conducted (Fig. 1). Semi-structured in-depth interviews with five higher secondary class chemistry teachers currently involved in teaching 12th class students, were conducted. Out of these five teachers, 3 were interviewed in person and remaining two were interviewed through email dialogue as they were located in a distant place.

The interview questionnaire had six questions which are reported below under each question heading. In the semi structured interview having terms such as "what is the difference …" or "Do you feel there is difference ….." was adopted.

2.3 Questions Categorized and Insights from Interviews

(a) Difference between Solid States and other chapters:
Responses to this question were found to be quite consistent for all five interviewed teachers. They describe Solid States chapter as more demanding in terms of 3 dimensional visualization and imagination for students. One teacher said, "As solid state involves 3d concepts, it requires more visualization and imagination skills of the students". According to another teacher: "It gives help to understand 3-D structures of metals and Ionic Compounds. Visualization in 3-D is required." These feedback gives support to our assumption that there is need of 3d visualization aiding for students in Solid States and nurture our motivation to design a Augmented Reality based tool for the same.

(b) Division of chapters into different modules and sub-topics:
Based on the dialogues and discussions that were recorded and analyzed the following insight emerges.
As some teachers are more focused towards teaching school syllabus whereas other are focused towards teaching entrance exam syllabus, there are slight differences across teachers in the content and the modules in which the content is divided. Even though, there is similarity in terms in terms of teaching core

concepts of the chapter: different layer wise 3 dimensional arrangement of atoms, unit cells of Face Centered Cubic (FCC) and Hexagonal Closed Packing (HCP) and tetragonal and octahedral voids. We also asked from some of the teacher's most important points of emphasis during teaching the chapter. These insights helped us to choose spatial arrangement of atoms in unit cells and voids formed inside them as content for AR based pedagogical tool to start with.

(c) Relatively difficult topics to teach and learn:
Teachers find it difficult to make student visualize and understand the spatial arrangement of particles in 3d space in his/her imagination. One teacher informed, "For students it is difficult to understand 3d crystalline structure and where and how different voids are present inside the structures." From different structures couple of teachers found Hexagonal cubic packing relatively difficult to visualize and so to teach.
Solid States chapter contains other concepts as well e.g. Voids, Cation-Anion Ratio, Coordination number. There are numerical problems in these concepts. These concepts are associated with and extension of basic concepts of 3d structure arrangement and unit cells. According to one teacher, "Once 3d arrangement of atoms is clearly understood by the student, everything else falls into place and becomes easier." This resulting insight motivated us to start conceptualizing an AR application with spatial arrangement of atoms in unit cells and voids as instructional content to be resolved.

(d) Text book alone is insufficient:
Most of the teachers admire prescribed text books (NCERT) because of the content and instruction design. Though It helps students understand the crystalline structure with the help of colorful 2d figures. Students do not find it sufficient in terms of depth of content and its effectiveness in providing a clear 3d visualization of structures and lattices inside the void. One teacher stated, "Text books are good and there are some diagrams and explanations for 3d concepts but these are not clearly not sufficient." Teachers often search and refer to multiple books that have rich illustrations. The student however does not have access to such resources when studying on their own.

(e) Use of additional tools:
Although few teachers used to take help from physical ball and stick models, they expressed the shortcomings of such tools when probed further. 3d physical models could be difficult to make, store or carry and demonstrate. According to one teacher, "It is time consuming to make slides or use 3d models. There is non-availability of 3d models in market." Also, these models are just static 3d representation of one state of lattices. The models are not dynamically changing which is required for a student to understand the concepts. Animations are often relied upon but a teacher shared his views, "Unfortunately the videos and models are not very useful and user friendly so they also do not provide much help for teachers." Insight regarding use of animations that emerged is as follows: Rewinding and replaying the

animations is not of much help if the student fails to grasp the underlying concept the first time itself. Instead, we hypothesized that if we can have the visualization of the 3-D structure illustrate how a structure is formed step wise, it will help. It should be handy and simple to use." It was interesting to note that most teachers mentioned the analogy of classroom space to teach arrangement of atom in cubic unit cell and sharing among different unit cells.

3 Design Suggestions

In [13], authors have suggested five principles for designing chemistry visualization tools that help students understand concepts and develop representational skills through supporting their visuospatial thinking. On the basis of these principles and insights form teachers' interviews, we propose following suggestions to be considered while designing AR application for chemistry learning:

(i) Step wise instruction: One of the teacher told that visualization of 3d molecular structure formation should be step wise to make it clearer. In his fifth principle [13] also suggested to reduce cognitive load by making information explicit and integrated. Hence, rather than one 3d model for one concept multiple models arranged in appropriate flow through which student can step wise navigate, are advisable. We implemented this navigation using two on-screen GUI buttons, next and previous.

(ii) Content delivery style: Most of the previous works in AR based e-learning tools are solely relies on visual 3d content [9–11] whereas according to [14], animation and narration should also be presented in a coordinated way to ameliorate the learning of low spatial ability students. We incorporated background audio instruction and animated 3d models in our tool.

(iii) Touch based interaction: As the marker based detection technique requires image always to be present in front of the camera, it is not possible to see bottommost surface of the 3d model just by tilt interaction. Also, part of image can come out of the camera view during device tilting, causing disappearance of the 3d model. With the increasing popularity of touch based devices, users have become well versed with touch interactions and it should be used consistently in AR applications as well [15]. We added touch interaction to rotate 3d models along with tilt.

(iv) Direct interaction with content: Wu and Shah [13] proposed that there should be visible referential link among representations provided by the visualization tool. One of the biggest advantages of AR based e-learning tool is that there is direct connection between content in the tool and content in the textbook. Following this, we included virtual button feature in the tool which allows students to switch to a particular subpart of the content by moving the finger over image related to that subtopic in textbook page.

4 Development and Design

4.1 Development Platforms

Initially, D'Fusion studio [16], a GUI based cross platform SDK for building AR applications was explored. Scenario intelligence programming is done using Lua script. 3D rendered objects can be directly imported from Autodesk 3ds Max and Maya using exporters provided in its developer package. We were successful in augmenting 3d molecular structure over a black and white pattern marker. We also tried adding interactivity to it by changing the rendered supplement when two markers are brought nearby. However, during the course of our exploration with D'Fusion studio, we found certain technical issues such as flickering of 3D models and adding interactive elements etc. which compelled us to look for alternatives such as another tool named as Vuforia.

Vuforia [17] by Qualcomm is an Augmented Reality Software Development Kit (SDK) for mobile devices that enables the creation of Augmented Reality applications. Tracking in Vuforia is quite more stable in comparison with D'fusion. AR application can be developed by importing Vuforia SDK into Unity 3d [18] which is a cross-platform game engine with a built-in IDE and used to develop video games for web plugins, desktop platforms, consoles and mobile devices. Apart from providing Image tracking capabilities, Vuforia also gives developers the flexibility to add interactions through buttons, gestures, animation, sound etc. in the mobile application by programming in C sharp and Java script in Unity 3d. For generating 3D models, we used SketchUp [19] which can be easily imported in Unity 3d.

4.2 Application Features and GUI of Developed Solution

Virtual buttons in AR interfaces are developer-defined rectangular regions on image targets that trigger an event when touched or occluded in the camera view. Such buttons provide an intuitive means of interaction since the users are directly using the content (on paper/surface) to navigate/as a button rather than on screen buttons.

The graphical user interface of Augmented Reality Apps is primarily simple because a major chunk of screen space is dedicated to the camera for easy viewing. Any additional content that needs to be shown to the user is subsequently placed on layers above the camera layer. In this application, we have used two GUI buttons to allow users to navigate/toggle between different views of the same 3D model (Fig. 2). The models are placed in a chronological order—i.e. the next view of the model is obtained from the previous view.

To assist learning and provide instruction, audio feedback was added into the application to guide users through the flow of the application as well as help in instruction. A pause button to turn off these instructions has also been provided on the GUI in our design. We also incorporated animation in 3D models in cases where

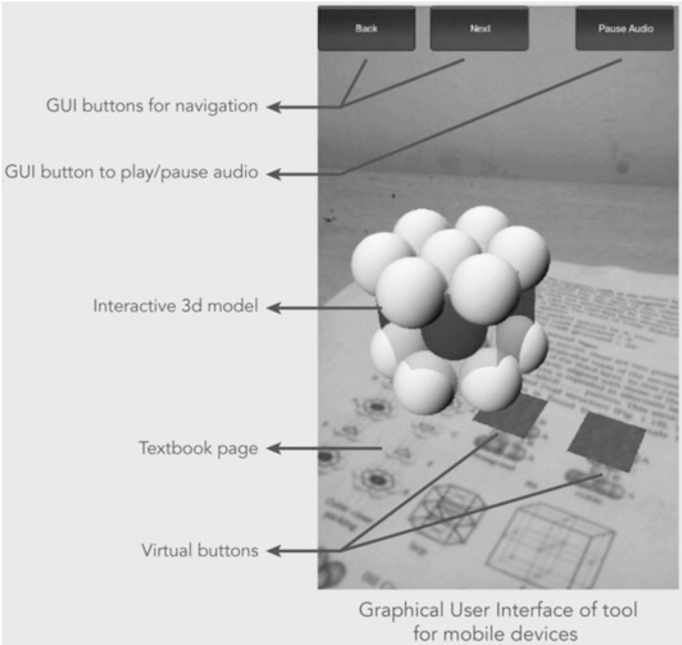

Fig. 2 Labeled GUI of AR application for mobile devices

we needed to portray positioning of one layer of atoms over another. We showed through animation how one layer fits over another and forms a complete lattice. This was based on insights gained from Teacher's interviews.

Another key feature of our application was on screen interactions. Users could rotate the models as per their convenience by swiping on the screen, in the direction of rotation. The swipe rotation also included inertia so that the rotation looked more natural i.e. upon swiping in a particular direction, the model rotated for a particular angle and then came to a smooth stop based on the speed of the swipe. A single tap on the rotating model also brought it to a halt.

We divided our teaching content into two modules, based on the content finalized through feedback from our qualitative research. Both these modules were on separate pages on the NCERT textbook, and thus, had separate image trackers. Content related to these modules was displayed on the tablet/mobile device upon successful tracking of the respective text book page (image tracker) by the camera of the tablet/mobile device.

The developed modules are:

(a) Understanding 3D Closed Packing Structure:

   (i) Hexagonal Close Packing
   (ii) Cubic Close Packing

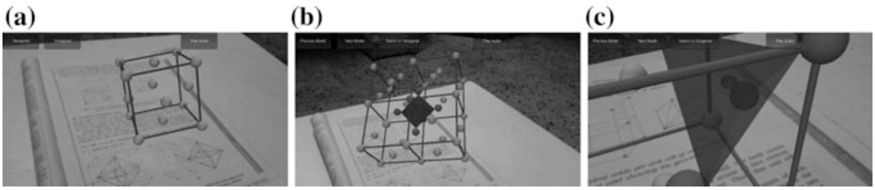

Fig. 3 (**a**, **b**, **c**) Different GUI screens of AR application for tablet devices. **a** First 3d model: face centered cubic; **b** Octahedral void (OV) selected and navigated to edge centered OV; **c** Switched to tetrahedral void and zoomed by moving device closer to marker

(b) Understanding Voids:

  (i) Tetragonal voids
  (ii) Octahedral voids

Both these modules have similar information architecture. The difference is only in terms of content—i.e. 3D models and related audio feedback. The working of the application can be understood through the following steps with reference to Fig. 3.

(a) User is reading the NCERT textbook and comes across the concept of 3 dimensional closed packing.
(b) User turns on the application on his mobile/tablet.
(c) The home screen of the application is essentially live feed from the camera of the device. The user points the device to that particular page of the NCERT book.
(d) A 3D model is augmented on the device with audio feedback. Virtual buttons to toggle between hexagonal close packing and cubic close packing are also augmented on the device. This 3D model, consists of two layers of atoms in which placement of second layer, is shown through animation. The first layer is white in color while the second is in green. Different colors are used to differentiate between orientation of layers and easy understanding.
(e) The user points/touches the desired concept to be explored on the NCERT book.
(f) The virtual button triggers the animation and placement of third layer which is augmented on the textbook.
(g) User can also toggle between different 3D models of the selected concept (hexagonal close packing or cubic close packing in case of module 1 and tetragonal void or octahedral void in case of module 2) using on screen GUI buttons (back and next).

5 Testing

The prototype developed was subjected to a limited pilot testing involving high school students (Fig. 4). Qualitative testing by heuristics and response gathering was done. Five students of class 12 were involved in this qualitative testing. Some key insights from the testing are as follows:

Fig. 4 School students using the developed prototype on a mobile device

- All 5 Students were happy to see such a learning content. They wanted similar 3D explanations to all the examples in the chemistry textbook.
- Wow factor and non-familiarity with technology was found to be the major driving force behind initial feedback which was very positive.
- One student wanted content to be broken down to even smaller steps (atom joining atom instead of layer joining layer).
- When students were provided with prototype not having touch interactions, they pointed that rotation and movement of 3d models should be accessible through touch gestures as well.

6 Discussions and Conclusion

The initial intent of exploring the potential of new emerging technologies such as Augmented Reality in learning applications was achieved. From the Teachers' as well as students' responses in the limited Qualitative survey and study it can be inferred that A R holds tremendous potential to aid understanding and learning especially of concepts involving spatial characters and features. In our study, we aimed at addressing learning difficulties of Solid State chemistry and similar concept followed by proposing an Augmented Reality application design.

We submit that in the context of non-availability of online internet access widely in the hinterland of a country like India, AR can become a very economical tool to bring three dimensional learning experience to the student on a device such as a mobile or tablet independent of the net connectivity and based on simply pointing out the device towards a text book.

Acknowledgments We would like to thank all the teachers and students of Kendriaya Vidalaya, IIT Guwahati Campus for their help in agreeing to the survey and discussing the prototype solution. We would like to extend our sincere thanks to our teachers at Kendriya Vidyalaya, Oriental Tutorials and Concept Education, Guwahati; FIITJEE and Vidyamandir Classes, New Delhi for their valuable insights and support throughout the project. We would like to thank the participants for their informed consent to use their pictures. We acknowledge respective IPR of platforms and products which we used for academic research purposes on terms of fair use: (a) Unity 3d, (b) Total Immersion D' Fusion, (c) Qualcomm Vuforia, (d) Trimble Sketch Up.

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