Collaborative Augmented Reality for Inorganic Chemistry Education

MANUELA NÚÑEZ, RICARDO QUIRÓS
Departmento de Lenguajes y Sistemas Informáticos
Universitat Jaume I, 12071 Castellón
SPAIN

INMA NÚÑEZ, JUAN B. CARDA
Departmento de Química Inorgánica y Orgánica
Universitat Jaume I, 12071 Castellón
SPAIN

EMILIO CAMAHORT
Departmento de Sistemas Informaticos y Computacion
Universidad Politecnica de Valencia
Camino de Vera s/n, 46022 Valencia
SPAIN

Abstract: - Augmented Reality (AR) is a computer related research area that allows users to see views of the real world enhanced with text and virtual information. AR with 3D models can be used as an educational aid to help students gain spatial intuition. This intuition is very useful in many disciplines like, for example, Inorganic Chemistry. We present in this paper an AR system for teaching spatial relationships and chemical problem solving skills to university-level students. Our system is based on inexpensive webcams and open-source software. Our students quickly gained visual cues and 3D intuition when the system was implemented. A survey we conducted after the experience shows great acceptance of the system as well as better results when solving Inorganic Chemistry problems related to 3D crystal structures.

Key-Words: - Inorganic Chemistry, Augmented Reality, classroom aids, 3D material modeling, collaborative environments, crystal structures, silicates

1 Introduction

Recent advances in Computer Graphics and Computer Hardware have introduced the Information Technologies into the classroom. PowerPoint presentations, for example, are being used pervasively in classrooms around the world. The problem of this technology is that the student remains a passive element of the learning process. Information Technologies must be targeted at better and more actively involving the students in their own education.

Augmented Reality (AR) is a fairly new area of Computer Graphics that also relies on other computer-related disciplines like hardware, computer vision, and sensing and tracking. It allows the user to view the real world with superimposed computer generated annotations and graphics. AR systems may be used by multiple users at the same time. This provides the opportunity for collaborative applications, like engineering design, architecture, multi-user games, and education, among others.

AR can be used in education to show models to the students that cannot be seen in the real world. Two examples are planets and galaxies that are too big, and atoms and molecules that are too small. Another example is certain types of chemical, physical and engineering processes like reactions, explosions, computational fluid dynamics, motion simulation, and many more.

We are interested in applying AR to Inorganic Chemistry education at the university level. Specifically, we want to show the students different material and compound structures. We want to show them in 3D, and we want to allow the students to move and manipulate them. The goal is for them to gain a spatial intuition of the structures, a key skill for the students to understand and solve Inorganic Chemistry problems.

We present in this paper an AR system for teaching university-level Inorganic Chemistry. Our system renders material and compound structures for better understanding by students. The system allows multiple users and different 3D models of chemical structures. The system is used to teach both theory classes and classes where problems are solved that require the students to develop a good 3D spatial understanding. Our experiments demonstrate that the students like the system. They even want to take it home and improve it by adding stereo.

Although the system has been developed for Inorganic Chemistry, other disciplines may benefit from our system. For example, it can be applied to mathematics, organic chemistry, theoretical physics, astronomy, applied physics and engineering. Its simplicity and ease of use make it suitable for University students and younger students, like secondary, junior high and high school students. It can also be used for demonstrations at fairs and trade shows, allowing prospective customers to interact with a certain product in a collaborative way.

Our paper is organized as follows. In the next section we summarize the advantages of using AR in education and we survey previous AR systems applied to teaching. Section 3 describes our goals and presents our system. It includes images of the system being run in our classrooms. Section 4 describes the results of using our system in the form of a survey done by a random set of students. Finally, Section 5 presents our conclusions and directions for future work.

2 Augmented Reality

Augmented Reality systems are an extension of the concept of Virtual Environment (VE). These systems present the user with an enhanced view of the real world. This view contains virtual elements. The visual augmentation may be accompanied by sound, tactile (haptic) and other types of augmentation. Visual augmentation requires that the user’s movements be tracked. Tacking computes the position and orientation of his head so that the virtual elements can be correctly rendered and displayed.

Rendered elements are displayed on the user’s view of the real world. Mixing both this view and the virtual graphics and text can be done in either of two ways. See-through devices let the user see the real world directly. They display the graphics in a transparent screen located between the real world and the user’s eyes. The display may be an LED or an OLED like those used in projectors. Alternatively, a camera mounted on the user’s head may capture the views of the real world. These may then be combined with the virtual graphics and displayed on a head mounted display (HMD). The main advantage of AR systems over regular VE systems is that they combine virtual and real world thus providing a much richer experience.

AR systems can be single- or multi-user collaborative. Single-user systems have been applied to science, engineering, training and entertainment, among others. Collaborative systems have been applied to the same areas with much more valuable results. For example, Schmalstieg et al. developed the StudierStube system to view scientific data [1]. They use see-through HMDs to allow multiple users to view the same data superimposed on the real world.

Today AR is a matured technology. Early surveys date back more than one decade [2]. Books have also been published entirely devoted to its study [3] [4]. Despite its maturity, it has barely been applied to education.

Many processes, ideas and concepts can be better illustrated using both images of the real world and graphics. Think for example of a future architect looking at a building. We may let the student look at the floor plans at the same time. A different but much better approach uses AR to superimpose the internal structure on the building so that she can understand why it does not collapse. In this Section we present the benefits of using AR in education. We also survey previous work in this same area.

2.1 Why Apply AR to Education.

University teaching methodologies have not evolved much for centuries. The method of attending lectures, taking notes and taking a final exam dates back to the 15th and 16th centuries. Recently, new technologies have appeared in the classroom. For example, it is common to see PowerPoint presentations and use networked platforms like Moodle [5]. Using these new technologies does not imply an increased interaction between students and the professor. In fact, many times information keeps on flowing in just one direction, from the professor to the students.

For students to learn more and better, education has to be both experimental and interactive. We learn more from hands-on experiences than from traditional lectures. Also, collaboration and discussions between students helps their education by teaching them opinions and methods proposed by their peers. This is more interesting for science and engineering students. But other disciplines like law may benefit from new technologies, like teleconferencing to attend or participate in remote trials. AR is mature enough to be applied to many every-day activities. Education is one of them, especially for the following reasons [6]:

- AR supports seamless interaction between real and virtual environments.
- AR allows using a tangible interface metaphor for object manipulation.
- Finally, AR provides the ability to transition smoothly between reality and virtuality.

AR can also be used for online education. Project MARIE (*Multimedia Augmented Reality Interface for E-Learning*) uses AR to present 3D information to the students [7]. The authors argue that AR is more effective than VEs in terms of price, realism and interactivity. They also predict that in ten years AR will be used in many every-day applications.

2.2 Example Applications

AR has been around for more than a decade. However, only a few systems have been applied to education. Project MagicBook was presented at the SIGGRAPH conference in 2000 [8]. A MagicBook includes text and images like any other book. But it also uses special markers that can be viewed with an HMD that superimposes 3D animated scenes on the book's pages. This interesting approach is considered to be the first application of AR to education. It was followed up by the implementation of *ARToolkit*, an open-source AR library widely used for writing AR applications.

Project MARIE was presented in 2002 [7]. It supports multiple students interacting with various virtual objects. It also provides a framework for writing AR-based educational applications. For example, it has been used to browse Web3D worlds for engineering education [9].

Researchers at the Technical University of Vienna started working on AR-based education with the StudierStube project. More recently, they built another system called Construct3D [10]. Construct3D has been successfully applied to geometry and mathematics teaching [11].

All of the above applications were based on AR technology that was too expensive and complex for every-day use. With the advent of ARToolkit and Personal Data Assistants (PDAs) AR systems became smaller and less expensive. Such systems are not immersive, but they are better suited for education applications where the students may be young and a bit careless. The "Education Arcade" group of MIT has collaborated with the Boston Museum of Sciences to develop the project "Mystery at the Museum" [12]. In the project a child and an adult are paired up. They are given a PDA with a camera and they are asked to solve an enigma by looking for clues in the Museum. The clues are markers and the enigma is related to a relevant historic event. The children involved in the project enjoyed the experience and learned a lot of history. Our idea is somehow similar.

3 Chemistry and Augmented Reality

We want to use AR to help teach three different classes of Inorganic Chemistry: Material Sciences, Advanced Chemistry Laboratory and Ceramics and Inorganic Chemistry. The classes are part of the Chemistry program of the Universitat Jaume I of Castellón (Spain). These classes are well suited for this purpose because:

- They are closely related.
- All of them are based on the knowledge of the structure of compounds and materials, especially ceramic materials.
- Materials' structures are much better understood using 3D models and rendering and tangible interfaces.

In this Section we describe the implementation and results of our experience with AR and Inorganic Chemistry. We explain the expected benefits of using AR in the classroom. We describe our goals, our classroom setup, and the results obtained. Specifically, we present the outcome of a satisfaction survey filled out by the student subjects of the experience.

3.1 Justification and Expected Benefits

Not every student has the same 3D spatial perception abilities. Some students have difficulties envisioning 3D objects drawn or displayed in 2D. This is relevant in Chemistry where students must analyze the 3D structures in order to devise correct answers to the class problems. 2D produces optical illusions that usually stem from the ambiguity of 2D renderings. Fig.1 and 2 show two examples: the Necker cube and an M.C.Escher drawing, respectively.

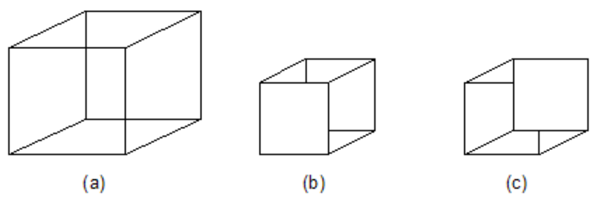


Fig.1. Necker cube: (a) where two edges of the cube cross, the image does not tell which one is in the front and which one in the back: the drawing is ambiguous; (b) and (c) are the two possible interpretations.

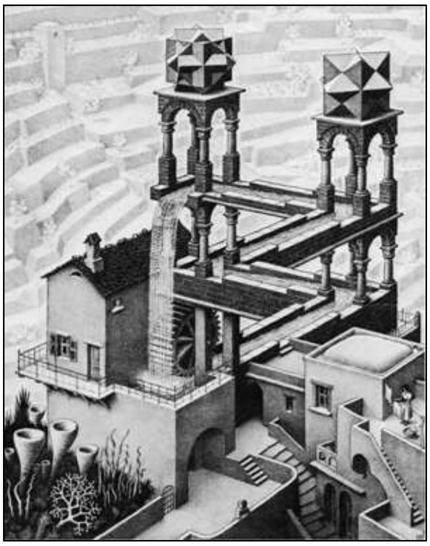


Fig.2. A 1961 etching of M.C.Escher showing a 2D image that is impossible to represent in 3D: the paradox is in the constant water flow.

Ambiguity of 2D models together with the difficulties of 3D analysis and perception imply that:

- Very often important concepts are not assimilated.
- Problems that can be easily solved by rotating a structure and analyzing its symmetry properties are almost unsolvable, even for competent students.
- Many students end up memorizing structures and problem solutions before the exam. A few days afterwards the students have forgotten most of them. Instead, structures should be derived from much simpler concepts. This would help the knowledge settle in their minds.

To improve our students' comprehension of compound and material structures we introduce an AR system. It allows tangible interaction with the virtual compounds and structures, thus simplifying their 3D analysis. The main two benefits of applying AR techniques to our classes are:

- Students have a much better comprehension and understanding of the fundamental concepts and structures presented in the classes.
- A powerful and flexible AR tool simplifies the professors' task of explaining the basic concepts related to materials structure.

3.2 Goals

Overall we have two goals: (i) improve the students' understanding of materials structures using AR, and (ii) provide the professor with a tool to better explain those structures that require a good 3D spatial intuition. Additionally, we have the following specific goals, including computer related goals.

With respect to the students of Inorganic Chemistry we want to achieve the following goals.

- We want them to get actively involved by introducing a novel technology like AR.
- We want to provide them with a tool to view different 3D material structures in an intuitive way.
- We want to increase their 3D analysis and perception skills.
- During class we want them to manipulate the structures independently or in groups; we also want them to do so during class, with the professor, and on their own, while working on problem solving.
- We want them to develop aptitudes such as initiative and class participation by manipulating the structures; we also want them to collaborate in groups.
- We also want to bring new computer technologies to the students, increasing their knowledge, their abilities and their communication skills; these skills are critical for the students to later be able to successfully join multi-disciplinary teams with experts from other areas.

With respect to the professors of Inorganic Chemistry we want to achieve the following goals.

- We want to provide them with a tool that will catch students' attention by attracting and surprising them; student attention and participation will then be maximized.
- Increase the professors' options to efficiently teach concepts where a good spatial intuition is critical for the students' understanding.

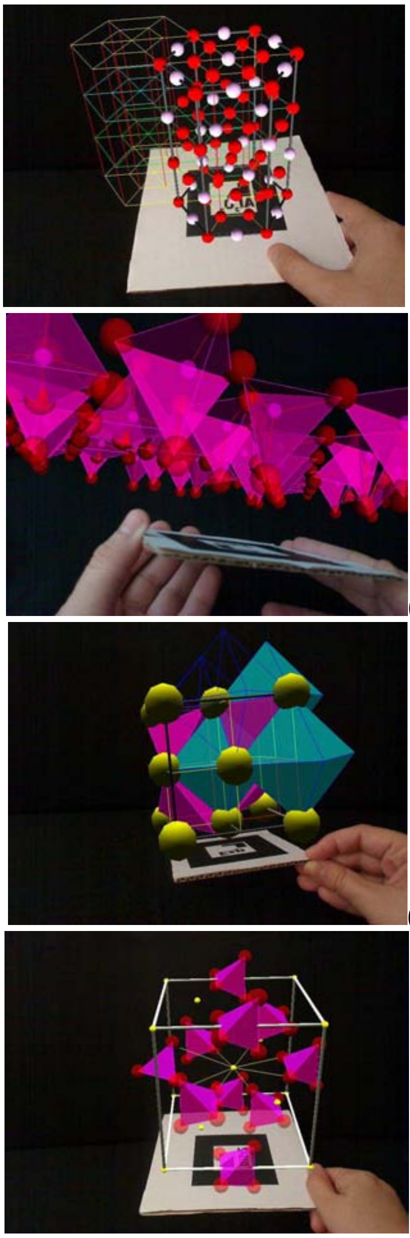
Finally, our computer related goals are the following.

- We want to compile a database of 3D models of chemical structures.
- We want to use it in a collaborative AR system with markers and cameras.
- We want to implement our software system with open-source libraries.
- We want to promote free software usage.

3.3 Classroom Implementation

To apply AR technology to our classes we first take into account our current methodology. We do not want to introduce substantial changes. Instead our goal is to naturally improve our current methodology using the AR system. To do so we add AR sessions to our current theory, problem, practice and laboratory classes. That is, we alternate between using the blackboard, PowerPoint presentations and other teaching resources, and using structure analysis using the AR system.

The system allows students to inspect a set of material structures by moving a maker. The marker is recognized by ARToolkit an open-source library for AR application development. The 3D models of the material structures are superimposed on the markers when these are recognized. The models have been built using the VRML modeling language. Fig.3 shows some of the structure models with their associated markers. Note that the makers easily identify the structures.



(a) (b) (c) (d)

Fig.3. Some of the structures implemented and their associated markers: (a) the student holds a marker with a corumdum α-Al_2O_3 structure, where the sub-cells made of Al atoms are drawn with red spheres and the holes are drawn as white spheres; (b) as the student moves the maker, the AR system displays SiO_4 tetrahedrons connected to form more complex structures – each tetrahedron is made of four O atoms (red spheres) located at its vertices and an Si atom (pink sphere) located at its center; (c) an AB_2O_4 spinel structure with octahedral and tetrahedral holes; and (d) a zircon structure made of isolated SiO_4 tetrahedrons and Zr atoms with a dodecahedral organization (yellow spheres).

Our system uses a personal computer and six webcams connected with USB cables and a concentrator. We organize the students in groups of two. We give each group a set of markers. The images received by the cameras are projected onto a large screen located in the classroom. That way, each student can observe and manipulate the structure of the marker s/he is holding in his/her hand. Students can also view their classmates' structures as well as the professor's lecture. Figure 4 contains a diagram of the classroom's AR setup. Figure 5 has some pictures taken in our classroom during a class taught using our AR system.

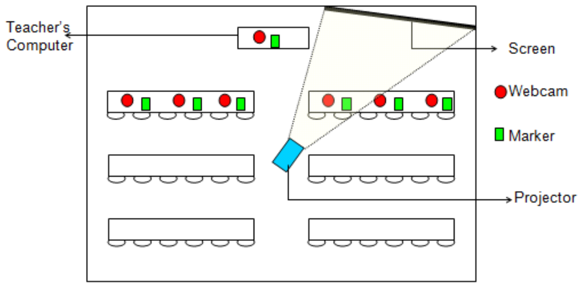


Fig.4. Multimedia classroom setup with webcams and markers for the professor and twelve students organized in six groups of two.

(a)

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(b)


(c)

Fig.5. Conducting an Inorganic Chemistry lecture using our AR system: (a) physical setup of the classroom for four groups of two students, each group with its webcam and set of makers; (b) students manipulating the $MgAl_2O_4$ spinel structure shown in Fig.3(c); and (c) students interacting with the zircon $ZrSiO_4$ crystal structure shown in Fig.3(d).

Our installation allows twelve students to interact with our AR system. In larger classes we can use higher resolution cameras or cameras mounted on tripods to capture more than one marker. That way several students can interact at the same time with different virtual structures. We have use this system to improve our theory classes and to help with problem solving classes. Problems where geometry is important to find a solution are best suited for using our AR system. One class of such problems is finding geometric elements in a crystal structure.

4 Results

In order to know the students' opinion about this project, a survey was carried out in the Inorganic Chemistry classes. The main objective of this survey was to collect their opinions about the advantages and disadvantages of the project. We also wanted to know whether it was useful from the point of view of the students as users of this methodology.

The survey group was made of fifteen students randomly chosen from the different classes where our system was used. Note that some of them were in more than one of these classes. The general opinion among them was that using AR to understand crystalline structures was very useful. All of the surveyed students considered that AR was a powerful tool that helped them to comprehend the 3D arrangement of these structures. Furthermore, most of them (70%) wanted to use it at home on their personal laptop or desktop computers.

40% of the students agreed that the main advantage of using AR in Inorganic Chemistry was the possibility of interacting with a 3D world (moving and rotating physical markers) instead of imagining the final structure through two-dimensional figures and pictures. Another 40% answered that the main advantage was the option of easily analyzing the crystalline structures from different angles and directions. Finally, the remaining 20% said that this methodology was very valuable in helping them improve their visual and spatial skills.

As for the disadvantages, 50% of the students complained of not having a physical system permanently installed in the classroom. They want a system to enable the use of more webcams and reduce the time of connecting the system for starting the class. Another 15% thought that the main disadvantage was the size of the images in the board. And the remaining 35% of the students did not see any disadvantage or thought that it would be good to continue the project and have it further improved.

Finally, when asked about adding stereo to this project, 95% of the students agreed with the idea, saying that it could be very interesting.

5 Conclusion and Future Work

We have introduced an AR system for teaching Inorganic Chemistry at theuniversity-level. Our system uses inexpensive cameras and open-source software to set up a collaborative environment that supports several groups of students interacting with material and compound structures. The structures are modeled in 3D using VRML. Interaction is handled using hand-held markers and ARToolkit a public domain AR software library. Our experience with the system shows that the students enjoy it and learn more Inorganic Chemistry. In fact, they ask whether they can take one home. We have also observed that they substantially improve their spatial intuition and learn to better understand visual cues.

We want to apply this system to other areas of Inorganic Chemistry, as well as disciplines like mathematics (vector and linear algebra), physics (vector physics) and engineering (applications). We also want to improve the tracking and rendering capabilities of the system. We want to support more students and we want to have a classroom permanently outfitted for collaborative AR education.

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References:

[1] D. Schmalstieg, A. Fuhrmann, G. Hesina, Z. Szalavári, L. M. Encarnaçäo, M. Gervautz, W. Purgathofer, The studierstube augmented reality project, *Presence: Teleoperators and Virtual Environments*, Vol.11, No.1, 2002, pp. 33-54

[2] R.T. Azuma, A Survey of Augmented Reality, *Presence: Teleoperators and Virtual Environments*, Vol.6, No.4, 1997, pp. 355-385.

[3] O. Bimber, R. Raskar, *Spatial Augmented Reality: Merging Real and Virtual Worlds*, A K Peters, Ltd., 2005

[4] S. Cawood, M. Fiala, *Augmented Reality: A Practical Guide*, The Pragmatic Bookshelf, 2008

[5] J. Cole, H. Foster, *Using Moodle: Teaching with the Popular Open Source Course Management System,* 2nd edition, O'Reilly Media, Inc., 2007

[6] M. Billinghurst, *Augmented Reality in Education*, New Horizons for Learning, 2002, http://www.newhorizons.org/strategies/technology/billinghurst.htm

[7] F. Liarokapis, P. Petridis, P.F. Lister, M. White, Multimedia Augmented Reality Interface for E-Learning (MARIE), *World Transactions on Engineering and Technology Education*, Vol.1, No.2, 2002, pp. 173-176

[8] M. Billinghurst, H. Kato, I. Poupyrev, The MagicBook - moving seamlessly between reality and virtuality, *IEEE Computer Graphics and Applications*, Vol.21, No.3, 2001, pp. 6-8

[9] F. Liarokapis, N. Mourkoussis, M. White, J. Darcy, M. Sifniotis, P. Petridis, A. Basu, P.F. Lister, Web3D and augmented reality to support engineering education, *World Transactions on Engineering and Technology Education*, Vol.3, No.1, 2004, pp. 11-14

[10] H. Kaufmann, D. Schmalstieg and M. Wagner, Construct3D: A Virtual Reality Application for Mathematics and Geometry Education, *Education and Information Technologies,* Vol.5, No.4, 2000, pp. 263-276

[11] H. Kaufmann, D. Schmalstieg, Mathematics and geometry education with collaborative augmented reality, *International Conference on Computer Graphics and Interactive Techniques, ACM SIGGRAPH 2002 conference abstracts and applications*, ACM New York, 2002, pp. 37-41

[12] E. Klopfer, J. Perry, K. Squire, Ming-Fong Jan, C. Steinkuehler, Mystery at the museum: a collaborative game for museum education, *Proceedings of the 2005 conference on Computer support for collaborative learning: learning 2005: the next 10 years!*, International Society of the Learning Sciences, 2005, pp. 316-320