

Cloud technologies of augmented reality as a means of supporting educational and research activities in chemistry for 11th grade students

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Abstract. Chemistry educational and research activities must be planned in a way that makes extensive use of experimentation. The implementation of chemistry experiments in the classroom is fraught with organizational and logistical challenges, and more recently, the necessity for online learning has been added. The article explains the current state of augmented reality (AR) technology use in contemporary chemical education and the potential for using augmented reality technology to enhance students' chemistry research projects. To complete the research tasks, augmented reality cloud technologies (A-Frame and AR.js) were used. The developed tool is a virtual chemical laboratory that incorporates augmented reality technologies (AR-based virtual chemical laboratory): individual markers correspond to reagents, and a pair of marker combinations activates the playback of a video showing the chemical interaction between the associated pair of reagents. The article describes the development of augmented reality software to support the research activities of 11th grade chemistry students in the form of an AR-based virtual chemical laboratory, as well as its implementation in the teaching and learning process.

Keywords: augmented reality, cloud resources, A-Frame, markers, virtual chemistry laboratories, chemistry education

1. Introduction

According to Law of Ukraine "On Education" [17], specialized secondary education of a scientific direction, which includes studies in the 11th grades of lyceums (high schools), is based on research-oriented education, aimed at in-depth study of specialized subjects and acquisition of necessary competencies for subsequent research-experimental, design, and inventive activity. By participating in conferences, Olympiads, exhibitions, contests, etc., students can demonstrate their mastery of competencies in experimental, design, innovative, and rationalization activities.

Because a graduate of a specialized school is a potential entrant into higher education institutions in the corresponding scientific direction, the main tasks of specialized training are the formation of students' aspirations and opportunities for self-realization, the development

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of skills for independent and conscious search for knowledge, and the creation of a system required for further professional development of knowledge and competences.

An aphorism attributed to Confucius says: “Tell me and I will forget, show me and I may remember; involve me and I will understand” [25]. This old wisdom – the independent creation of an educational trajectory – is, in our opinion, the primary benefit of educational and research work. Subjectively, when there is a chance to learn anything new on one’s own, via one’s own efforts, it is much more solidly internalized.

Following Kniazian [16], we define student educational and research activity as a sort of creative educational and cognitive activity aiming at discovering, researching, and explaining facts and phenomena of reality in order to acquire and systematize subjectively new knowledge about them.

One of the key aspects of the school chemistry curriculum is the domination of the principles of differentiation, research-based teaching, and the integration of theory and practice. This is particularly evident in the extensive use of laboratory experiments in chemistry courses and student experiments (including home and applied) [22, 23].

The chemical experiment is an important part of the chemistry education process. One of the primary components of students’ educational and research activities in chemistry classrooms and extracurricular time is the chemical experiment. The content of the key competences that a graduate should master when studying chemistry is explicitly defined in the chemistry curriculum for general secondary education institutions for grades 10-11 [12]. Among these are the abilities to discuss research findings and develop conclusions; to study natural things; to arrange self-education in chemistry: to establish the aim, plan, and select the appropriate means; to observe chemical transformations in objects and to organize a chemical experiment.

As a result, even at the standard level, chemistry instruction demands that students develop the necessary research skills.

The integration and deepening of students’ understanding of inorganic and general chemistry constitutes the content of 11th grade chemistry curriculum. Practical and laboratory work, demonstration experiments, and other activities go hand in hand with the study of the relevant theme blocks.

In specifically, 15 demonstration experiments, 26 laboratory experiments, and 19 practical tasks are planned to be completed in accordance with the profile level curriculum for the 11th grade [6]. There are actually no quantitative chemical experiments among these forms of student research and instructional activities; instead, they tend to be qualitative in nature.

Such a large amount of actual work necessitates a massive amount of time, organizational, and material resources. In fact, we are only discussing student educational and research activities that are coordinated and managed by the teacher. The costs outlined above multiply many times over when establishing an independent educational and research activities.

Students’ educational and research activities are frequently constrained by their study conditions:

- lack of reagents and equipment;
- the need to perform, first of all, the experiments planned by the curriculum;
- lack of time to perform extracurricular experiments;
- issues of safety equipment, etc.

Any of these circumstances (or a combination of a few or all of them) severely restrict students' ability to independently and creatively research solutions to the issues they have when learning a specific topic.

The instructional approach for performing laboratory work of a quantitative nature in chemistry uses virtual chemical laboratories actively. They can be used to reproduce a large number of experimental studies, but only in the situations where measurements and calculations need the use of specialized chemical equipment and utensils [21].

2. Using augmented reality to teach chemistry in the classroom

Virtual and augmented reality technology, which was first developed in the 1960s, is now seen as a very promising, potent, and practical tool, particularly for addressing educational issues. According to a definition given by Syrovatskyi et al. [29], augmented reality is the integration of real-world association objects and digital environments in semantically connected situations. In contrast to virtual reality, augmented reality merges virtual aspects with the real world rather than producing a wholly new virtual experience. The user is in a real world with virtual things that have been added to it and are responsive to his actions.

An augmented reality software displays an object in a real physical environment using the image recognition technology. The object of the virtual world is attached to the marker with a special program code. The marker can be turned, detached from the surface it is attached to, and moved in space. By doing so, you can watch changes to the virtual object as it appears on the digital device's screen [7].

The use of augmented reality technology in the teaching of chemistry is not only a nod to current trends and a way to attract students' interest, but it is also an effective way to illustrate the complex phenomena and concepts that make the chemistry. Additionally, the range of augmented reality technologies' applications in chemistry instruction is growing every year. Particularly, a sizable number of instructional software applications have previously been developed and ought to be utilized in the school-based instruction of chemistry:

- *Augmented Chemical Reactions* provides 3D visualization of the structure of molecules, their spatial dynamics and interaction, the possibility of forming molecules from individual fragments [18].
- *Study Marvel - Chemistry AR* provides 3D illustrations and models in specialized printed chemistry textbooks. An application designed specifically for classroom use with realistically reproduced real-time interactive objects for advanced and hands-on learning [28].
- *AR VR Molecules Editor Free* allows 3D visualization of molecules of organic and inorganic compounds in various forms (rod, ball-rod models, etc.) [30].
- *Dáskalos Chemistry* provides the visualization of the atomic structure of all chemical elements with the possibility of viewing additional data [13].
- *HTMoL - AR plugin* allows to make a 3D models of molecular structures with the possibility of using computational characteristics of molecules and semi-automatic animation of reactions by means of linear atom interpolation are coordinated between successive computational stages of reactions [27].

- *Arloon Chemistry*, which has theoretical and practical sections, provides an opportunity to construct and study molecules in 3D format, contains informative blocks, as well as test tasks and exercises from the material covered [4].
- *Elements4D* by DAQRI allows users to examine the periodic table of chemical elements and, through interaction with unique cubes, construct connections between those elements. Involvement of the game element in the learning process will make it possible to master such complex disciplines as chemistry with great interest and ease [11].
- *LiCo.Organic* is a mobile application created as a software accompaniment to the tutorial “Organic compounds. Atlas-handbook”. For a better understanding of the structure of molecules and the properties of organic substances, which are discussed in the textbook, their 3D visualization of ball-and-rod models of molecules in the mode of augmented reality is used [15].
- *QuimicAR - Chemistry AR* is an application created on the basis of the Vuforia SDK, which visually models how chemical bonds are created [10].
- *Chemistry* by MEL Science is an application that implements 3D modeling and molecular animation, crystal lattice structures, detection of substances by special markers in the form of interactive lessons. Each lesson lasts from 3 to 7 minutes, is easily integrated into the course of a real school lesson and helps to visualize the topic being studied in detail [19].

The majority of the programs in the list have interfaces in either English or Russian and primarily serve to illustrate matter structure. There are actually no applications that could be adapted to consider other topics of the school chemistry curriculum. Only a part of applications listed above are implemented without the use of special software, but on the basis of cloud technologies. The usage of cloud technologies is advised because some apps can consume a lot of memory.

Furthermore, the use of cloud technologies allows devices to be independent of the platform, allowing the operation of devices with multiple operating systems. This technique results in the unification of software development processes for client devices, which reduces the time required for testing and finishing software products on various technical devices and operating systems. We selected to employ the features of cloud services such as A-Frame and AR.js after doing a thorough evaluation of several web services for developing augmented reality [26].

A-Frame was developed by the Mozilla VR team in the second half of 2015 [20]. The Mozilla VR team was one of the first to develop the WebVR platform and specifications, but needed an easier way to create content. A-Frame was created to allow web developers and designers to create 3D and VR content from HTML without having to know WebGL [1]. The advantages of working with A-Frame are [26]:

- 3D and VR content is created using HTML.
- Compatibility with most web libraries and frameworks that exist today.
- Entity-Component-System architecture makes it easy to inherit complex 3D objects with components that can be reused many times.
- An extensible ecosystem of object component plugins.
- A visual inspector that can be called in the browser from any A-Frame scene.

- Support for developers contributing to the library is provided through GitHub, while support for developers building applications and web pages is provided through Stack-Overflow.
- Real-time support via Slack.

AR.js is a lightweight augmented reality (AR) library created by Jerome Etienne and maintained by Nicolò Carpignoli and AR.js community. AR.js uses jsartoolkit5 for tracking, but can display augmented content with either three.js or A-Frame. Markers are used here so that the camera can detect and display an AR object. This way of creating augmented reality is very essential because it is entirely based on Web technology, runs on even the most antiquated mobile devices, and is completely open source.

3. Implementation of augmented reality support for 11th grade chemistry students' educational and research activities

All you need to get started is an AR compatible browser, such as Firefox or Chrome, and a text editor (such as Sublime). JavaScript, HTML, and CSS fundamentals are required, and experience with GitHub and Web APIs is a plus. The main idea of AR is to display a computer model in real time and real space for the purpose of interaction between the user in real space and the 3D model in virtual.

A-Frame is similar to HTML in that all commands are specified by tags, which, unlike HTML tags, are not processed in a client-side web browser, but instead are a method to access JavaScript executed on the server side. It is a robust AR API that, when used with AR.js, hides the implementation details in JavaScript.

The virtual laboratory work we created is a collection of markers, each of which has a certain substance connected, and when you hover over a marker, you can see the substance's image (figure 1). However, in order to do the experiment, you must take two markers, position them side by side, and observe the experiment as it is being recorded on video (figure 2). We provide a list of required experiments for implementation, but we leave the student's creativity unrestricted: "If you want to play and combine not what the teacher said – please experiment!".

The formation of the concept of the ionic nature of interactions in qualitative chemical reactions is one of the serious methodological issues in chemistry in the 11th grade; even students who are good at creating complete and reduced ionic equations may not connect the form of the reduced equation with the essence of conducting qualitative reaction to a certain ion. It is quite simple to convey the essence of performing such high-quality reactions to the general public of students – it is necessary to perform the reaction $I^- + Ag^+ = AgI\downarrow$ with different combinations of reagents ($NH_4I + AgNO_3$; $NaI + AgNO_3$; $KI + AgNO_3$, etc.) – the same analytical effect will prove the truth of the statement that for carrying out a qualitative reaction, only those ions included in the reduced ionic equation are important. Giving the students the chance to reach this conclusion independently, based on a variety of conducted qualitative response variants and observation of the related analytical effect, is even preferable. In any case, there isn't enough time or material to use such a strategy. The expense and unavailability of some reagents, the lack of necessary equipment, and the distance learning format, which in recent

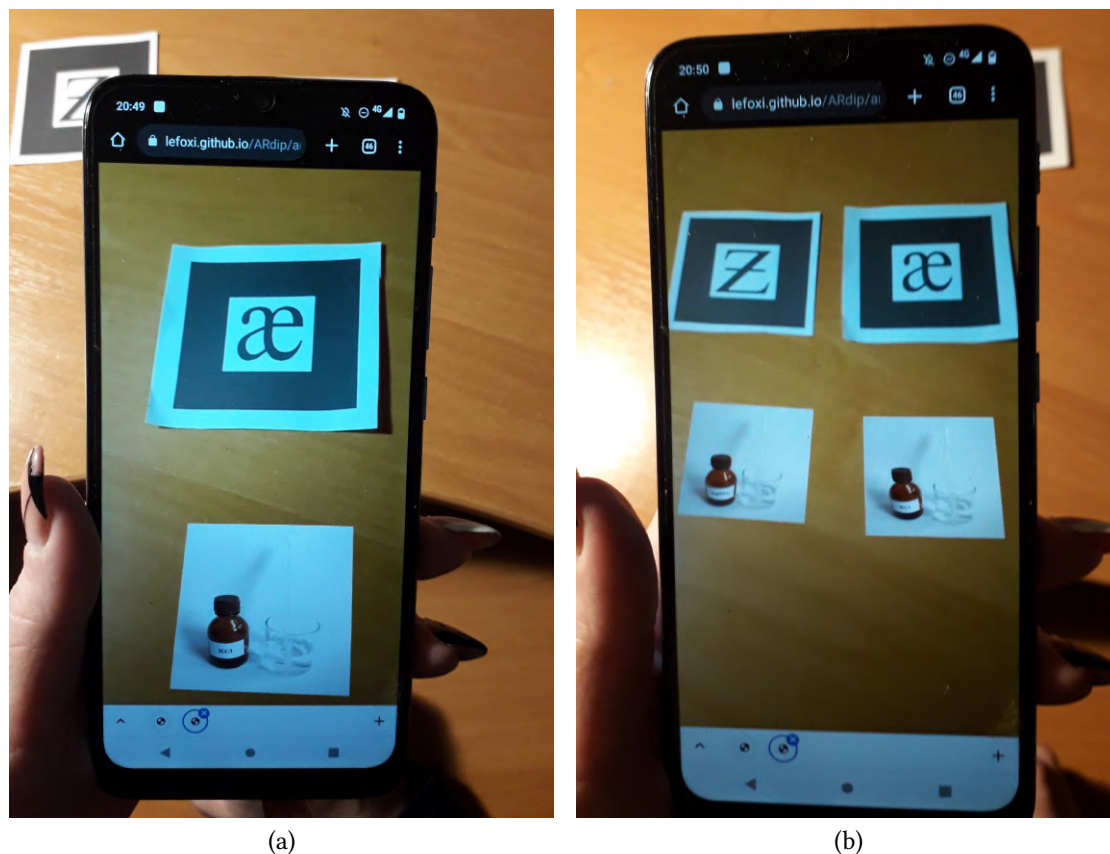


Figure 1: Displaying a reagent bound to a marker (a), and multiple reagents simultaneously (b).

years has lasted half or more of the academic year, all place restrictions on the performance of such laboratory experiments.

Because of this, we made the decision to focus our efforts on finding a solution to the aforementioned issue as well as to create a set of reagents for use in student research projects on the topic of “Qualitative reactions of chloride, bromide, and iodide ions” (this virtual chemical laboratory can be useful for performing a laboratory work “Qualitative reactions to bromide and iodide ions” and preparation for practical work “Solving experimental problems on the topic “Halogen compounds” in 11th grades with specialized chemistry teaching).

The development’s main goal is to encourage students to conduct independent, imaginative research projects, particularly when using a virtual chemistry laboratory with augmented reality, the student will be able to:

- to see and describe the result of performing experiments that for certain reasons he could not perform on his own;
- to carry out experiments within the proposed set of reagents, but at your own will, with a “scenario” created in your imagination;
- to repeat experiments many times at a convenient time;

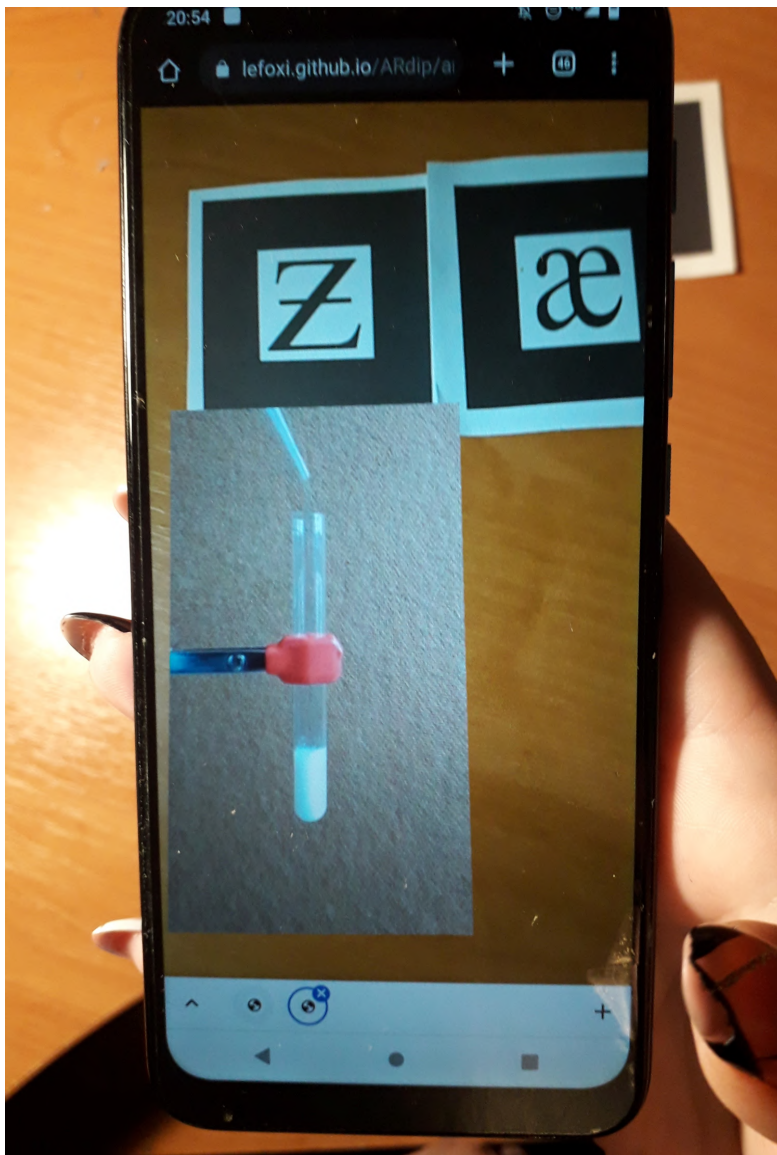


Figure 2: Demonstration of a video recording of a chemical reaction when combining a pair of markers.

- to carry out experiments safely and without spending on reagents and equipment;
- to engage in active, hands-on activity requiring chemicals, but in an objectified manner (in a virtual environment);
- to experiment with various reagent combinations and, based on the results, independently create hypotheses, identify patterns, and come to conclusions.

Such a virtual chemical laboratory provides opportunities for teachers to engage students in autonomous learning and research projects, increase the variety of chemical experiments





available, plan extracurricular activities and independent projects with gifted students, and more.

We determined that the laboratory experiment would require ten reagents before beginning work. We took pictures of each of them. If we have ten reagents, it is reasonable to anticipate that the student will try to combine them all in pairs, resulting in 45 reactions and the same number of recorded films. Then, like reagents, we design custom markers; there are ten of them.

It is required to select a method of compiling images and determining their reference points, which corresponds to the used augmented reality engine, in order to prepare the markers. So, when choosing AR.js as an engine, the compiler will be "AR.js Marker Training" (<https://ar-js-org.github.io/AR.js/three.js/examples/marker-training/examples/generator.html>) that generates colored square markers with a resolution of 16x16 in .patt format: 3 color planes (red, green and blue) and 4 orientations (rotation angles 0°, 90°, 180° and 270°).







The created markers are numbered 0 to 9 and are matched with reagent names and images (table 1).

Table 1: Table of compatibility of reagents, markers and images.

No	Reagent	Marker	Image
0	Silver nitrate AgNO_3	pattern-0.patt 	AgNO3.jpg 
1	Lead(II) nitrate $\text{Pb}(\text{NO}_3)_2$	pattern-1.patt 	Pb(NO3)2.jpg 







Continued on next page

Table 1 – continued from previous page

No	Reagent	Marker	Image
2	Hydrochloric acid HCl	pattern-2.patt 	HCl.jpg 
3	Potassium chloride KCl	pattern-3.patt 	KCl.jpg 
4	Sodium chloride NaCl	pattern-4.patt 	NaCl.jpg 





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Table 1 – continued from previous page

No	Reagent	Marker	Image
5	Ammonium chloride NH_4Cl	pattern-5.patt 	NH4Cl.jpg 
6	Potassium bromide KBr	pattern-6.patt 	KBr.jpg 
7	Ammonium bromide NH_4Br	pattern-7.patt 	NH4Br.jpg 

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Table 1 – continued from previous page

No	Reagent	Marker	Image
8	Potassium iodide KI	pattern-8.patt 	KI.jpg 
9	Ammonium iodide NH ₄ I	pattern-9.patt 	NH4I.jpg 

The following 45 combinations result from the pairwise placement of 10 markers without regard for the order of combination:

0-1, 0-2, 0-3, 0-4, 0-5, 0-6, 0-7, 0-8, 0-9
 1-2, 1-3, 1-4, 1-5, 1-6, 1-7, 1-8, 1-9
 2-3, 2-4, 2-5, 2-6, 2-7, 2-8, 2-9
 3-4, 3-5, 3-6, 3-7, 3-8, 3-9
 4-5, 4-6, 4-7, 4-8, 4-9
 5-6, 5-7, 5-8, 5-9
 6-7, 6-8, 6-9
 7-8, 7-9
 8-9

Seven video files were taken and used to demonstrate the cases when the reaction does not occur when the reagents are mixed (the majority of which are 29). This action was motivated

by the requirement to reduce the size of video files, as downloading all 45 possible videos would complicate program operation, especially in areas with poor Internet signal quality, and could drain the resources of a mobile Internet user. Each video file has a size of at least 2 MB.

The created markers, images, and video files were uploaded to the GitHub repository via the link <https://github.com/Lefoxi/ARdip> to the markers, images, and video directories, respectively. Additionally, for ease of use, images of the markers have been collected in the file markers.pdf (<https://github.com/Lefoxi/ARdip/blob/main/markers.pdf>).

The initial page is an index.html file (appendix A), the body of which contains two hyperlinks:

- ar.html is the actual code of the virtual laboratory (appendix B);
- markers.pdf is PDF file with images of printable markers.

The A-Frame library was chosen for the lab's implementation, and AR.js was chosen for connecting virtual objects to generated markers.

The general structure of the ar.html file:

```
<html>
  <head>
    <!-- window title settings -->
    <title>
      Virtual chemistry laboratory in augmented reality
    </title>
    <!-- using the A-Frame library -->
    <script
      src="https://aframe.io/releases/1.3.0/aframe.min.js">
    </script>
    <!-- using the AR.js library to work with A-Frame -->
    <script src=
"https://raw.githubusercontent.com/AR-js-org/AR.js/master/aframe/build/aframe-ar.js"
    ></script>
    <script>
      <!-- the main program -->
    </script>
  </head>
  <body>
    <!-- Creating an A-Frame scene for working in augmented reality -->
    <a-scene vr-mode-ui="enabled: false;"
      renderer="logarithmicDepthBuffer: true;" embedded
arjs="trackingMethod: best; sourceType: webcam; debugUIEnabled: false;"
    >
      <!-- Filling the A-Frame scene -->
    </a-scene>
  </body>
</html>
```

The A-Frame scene consists of 4 blocks:

- 1) `<a-assets>...<a-assets>` – definition of video textures;
- 2) `<a-marker>...</a-marker>` – defining markers and attaching images and videos to them;
- 3) `<a-entity camera></a-entity>` – placing the camera on the scene;
- 4) `<a-entity run></a-entity>` – reference to the run component defined in the main program.

The video texture definition block is assembled from the following records:

```
<video id="video02" preload="auto" muted
  poster="images/starting.jpg" loop="false" src="video/16.mp4">
</video>
```

- `id` – the video identifier consisting of the video name and overlapping marker numbers. If the same video is used for multiple marker combinations, the ID becomes like `video03-04`. For cases when the reaction does not occur, video textures `video00-1 ... video00-7` are provided;
- setting `preload` to `auto` determines the need to download the video before the first access to it – this increases the initial time of loading the program, but decreases the time required for the video to appear and prevents the video from stopping due to an unstable network connection;
- `muted` reveals the need to turn off the sound if the video contains a sound track;
- `poster` refers to the picture file that appears if the video is accessed before it has completely loaded;
- `src` refers to the video file's URL.

The marker definition block is assembled from the following 9 records:

```
<a-marker type="pattern" url="markers/pattern-0.patt" id="M0"
  registerevents>
  <!-- Image definition -->
  <!-- Video definition -->
</a-marker>
```

Each marker is identified by a number from 0 to 9 (according to table 1), which is part of the marker name (`pattern-0.patt` is the marker 0 reference point file) and its identifier `id` (`M0` is the marker 0 identifier). The `registerevents` component defined in the main program is applied to each token.

The following command defines the image placed on the marker after it has been detected:

```
<a-plane src="images/AgNO3.jpg" rotation="-90 90 0" id="draw0">
</a-plane>
```


a-plane defines a textured plane. The src parameter contains the URL for the texture file, which is the reagent's picture (according to the table 1). The image is rotated by 90° around the OY axis because it is presented in portrait mode but saved in landscape orientation. The 270° (-90°) rotation around the OX axis is necessary because the A-Frame coordinate space is rotated by the appropriate angle relative to the camera coordinate space. id is the identifier of the plane with the image, consisting of the word draw and the number of the marker.

From 9 (marker 0) to 0 (marker 9) videoplanes are attached to each marker according to the scheme of marker combinations defined above:

```
<a-entity material="shader: flat; src: #video00-1"
  geometry="primitive: plane; width: 0.90; height: 1.60;"
  position="0 0 0" scale="1.5 1.5 1.5" rotation="-90 0 0"
  id="drawX01" visible="false">
</a-entity>
```

The aspect ratio of the plane is given by its width and height (specified relative to the size of the marker, which is assumed to be 1). The src property of the plane material contains a link to the previously defined and loaded video texture. The position parameter determines the coordinates of the center of the plane (0 0 0 coincides with the coordinates of the marker center), scale – one and a half times scaling (1.5 1.5 1.5) of the video texture compared to the width and height, rotation determines the rotation of the corresponding angle (analogous to image rotation). The object identifier id consists of the word drawX and the numbers of the paired markers in ascending order.

The main program consists of 3 blocks:

1) definition of variables:

- howmuch – a limit distance between markers that has been empirically determined, below which we will expect that the reaction should begin (by default 1.4);
- isReaction – a flag signaling the beginning of the reaction: if it is set, the relevant reaction video is displayed (by default false);
- distance – current distance between a pair of approaching markers (by default howmuch+1);
- markerVisible – an array of marker visibility states: if the marker is visible, the value of the element of the array with the number corresponding to the marker is set to true (the initial value for each marker is false);
- M – an array for storing markers (a-marker objects defined in the HTML document);
- d – an array for storing images superimposed on markers (a-plane objects defined in the HTML document, identified as drawN, where N is the marker number);
- X – an array for storing videos superimposed on markers (defined in the HTML document of a-plane objects, identified as drawXAB, where A, B are the numbers of converging markers);
- p – array of coordinates of marker centers, the values of which are used to measure distances;

- `isVideoPlay` – a flag indicating that a video recording of the reaction is played (ny default `false`);
- 2) registration of the `registerevents` component;
 - 3) registration of the `run` component.

The `registerevents` component is designed to track two events – detection (`markerFound`) and loss (`markerLost`) of a marker. After registration, the `init` method of this component is applied to all markers to which the `registerevents` component was added, in order to determine the index marker number and set when it is detected or remove when it loses its visibility flag in the `markerVisible` array. When a marker is detected, the associated image `d[index]` is made visible, and when it is lost, it is made invisible by setting the `visible` property to the appropriate value:

```
AFRAME.registerComponent("registerevents", {
  init: function () {
    let marker = this.el;
    marker.addEventListener('markerFound', function() {
      index = parseInt(marker.id[1])
      markerVisible[ index ] = true;
      d[index] = document.querySelector("#draw"+index);
      if(d[index]!=null)
        d[index].setAttribute("visible", "true");
    });
    marker.addEventListener('markerLost', function() {
      index = parseInt(marker.id[1])
      markerVisible[ index ] = false;
      if(d[index]!=null)
        d[index].setAttribute("visible", "false");
    });
  }
});
```

The `run` component does not correspond to any visible element: it performs general scene control, for which both the once-executed `init` method and the timed (preferably for each frame) `tick` method are registered:

```
AFRAME.registerComponent("run", {
  init: function() {
    // component initialization
  },

  tick: function (time, deltaTime) {
    // a method called by a timer
  }
});
```

In the `init` method, the previously defined arrays are filled: `M` – links to the markers, `d` – links to the images of reagents (displayed for markers that are visible), `X` – references to the video linked to the markers, and `p` – zero coordinate vectors:

```
for (let i = 0; i < 10 ; i++) {
  M[i] = document.querySelector("#M"+i);
  d[i] = document.querySelector("#draw"+i);
  p[i] = new THREE.Vector3();
  if (markerVisible [i])
    d[i].setAttribute("visible", "true");
  for (let j = 0; j < 10 ; j++)
    if(i!=j)
      X[i][j] = document.querySelector("#drawX"+i+""+j);
}
```

The `tick` method constantly monitors the visibility and relative location of markers:

- 1) we enter the numbers of markers that are currently visible into the `visible` array – for this, we analyze the contents of the `markerVisible` array, set by the `registerevents` component:

```
let visible = [] ;
for (let i = 0; i < 10 ; i++)
  if (markerVisible[i])
    visible.push(i);
```

- 2) we will assume that exactly 2 reagents are needed for the reaction, so we will ignore the cases when less than two markers (or more than two) are visible – if a video was shown, we make it invisible and set the `isVideoPlay` flag to `false`:

```
if(visible.length!=2) {
  for (let i = 0; i < 10 ; i++)
    for (let j = 0; j < 10 ; j++)
      if(i!=j && X[i][j]!=null)
        X[i][j].setAttribute("visible", "false");
  isVideoPlay = false;
  return;
}
```

- 3) determine the numbers of two visible markers – `marker1` and `marker2`:

```
marker1 = visible[0];
marker2 = visible[1];
```

- 4) determine the coordinates of the markers and store them in the corresponding elements of the coordinate array `p`:

```
M[marker1].object3D.getWorldPosition(p[marker1]);
M[marker2].object3D.getWorldPosition(p[marker2]);
```

- 5) find the distance between the markers:

```
distance = p[marker1].distanceTo( p[marker2] );
```

- 6) the `isReaction` flag will set whether the markers are close enough for the reaction to occur:

```
isReaction=(distance <= howmuch);
```

- 7) the `isReaction` doesn't show if the reaction occurred prior to the present; instead, you may determine this by looking at whether the video has already started playing: if not, take the image out of both markers, make the relevant video visible, and begin playing it from the beginning:

```
if(isReaction) {
  if(!isVideoPlay) {
    if(d[marker1]!=null)
      d[marker1].setAttribute("visible", "false");
    if(d[marker2]!=null)
      d[marker2].setAttribute("visible", "false");
    X[marker1][marker2].setAttribute("visible", "true");
    var id="#" + X[marker1][marker2]
      .getAttribute("material").src.getAttribute("id");
    var video=document.querySelector(id);
    video.currentTime=0;
    video.play();
    isVideoPlay = true;
  }
}
```

- 8) if the markers have moved away to a distance corresponding to the termination of the reaction, we will pause the video, make it invisible and again overlay the image of the reagents on both markers:

```
else {
  if(d[marker1]!=null)
    d[marker1].setAttribute("visible", "true");
  if(d[marker2]!=null)
    d[marker2].setAttribute("visible", "true");
  X[marker1][marker2].setAttribute("visible", "false");
  var id="#" + X[marker1][marker2]
    .getAttribute("material").src.getAttribute("id");
  var video=document.querySelector(id);
```

```
video.currentTime=0;  
video.pause();  
isVideoPlay = false;  
}
```

The software's deployment was carried out on GitHub Pages because the software's codes were stored in the GitHub repository. In the repository settings (Settings – Pages), the main branch of the repository and its root directory (/) containing the first page (file `index.html`) were chosen for this reason, and saving was carried out. The software deployment process (site publication) is performed at the URL <https://lefoxi.github.io/ARdip/>. The presence of the `index.html` file on the published site provides an opportunity to automatically go to the initial page after clicking on the above link.

To update the deployed software, it is enough to upload the changed files to the repository.

4. Results

In the second semester of 2020–2021 and the first semester of 2021–2022, the developed AR-based virtual chemistry laboratory, “Qualitative reactions of chloride, bromide, and iodide ions”, was utilized in chemistry lessons for students in grades 11 at Kryvyi Rih School No 21. The courses did not fully utilize the created laboratory because chemistry in this class is studied at the standard level. The topics of “Inorganic compounds and their properties” and “Chemical reactions” were studied using separate experiments. The majority of the experiments were performed outside of school hours using the developed AR-based virtual chemical laboratory, “Qualitative reactions of chloride, bromide, and iodide ions”. Students were given instructions for using the program and were given a description of the theoretical background of the experiments that can be performed in it, but the actual experiments were performed entirely independently, in the quantity and order that they themselves felt was necessary. The program was mostly utilized on smartphones by going to <https://lefoxi.github.io/ARdip/>. In addition to being distributed in advance in printed form, a set of markers may be downloaded for use at home at the following URL: <https://lefoxi.github.io/ARdip/markers.pdf>.

The developed AR-based virtual chemistry laboratory has a number of drawbacks, the most significant of which are the inability to conduct reactions between three or more reagents (at least for now, with the available software options); the inability to observe the reaction's progress from different angles and change the order of adding reagents, etc.; the inability to receive information from all sensory experiences – only visual information transmitted in video; there is a finite number of reagents available for conducting virtual experiments, and it is not possible to mix reagents from various sets.

Following the completion of the work using the program, a survey of the students was undertaken, and it was discovered that this style of work is attractive to contemporary eleventh graders. They listed the freedom to experiment with the supplied virtual reagents and repeat the activities numerous times as one of the benefits of the developed AR-based virtual chemical laboratory. The lack of reagents, inconsistently poor video quality, and reliance on a strong Internet connection were all mentioned as drawbacks.

5. Discussion

The key strategy suggested in this article and backed by numerous studies is the use of cloud-based augmented reality technology (such as WebAR).

The COVID-19 pandemic has affected schooling and has become a global health concern during the spring 2020 semester. Many universities unexpectedly switched their courses from in-person instruction to remote learning, which makes it challenging to keep students' attention while they are trying to understand a challenging idea, particularly in organic chemistry. As a result, Prasanson, Thanyaphongphat and Pinthong [24] created an augmented reality interactive 3D game that is utilized as a door-opening exercise for the online flipped classroom. The high school students' interest in organic compound isomers may increase as a result of this game.

In order to visualize the 3D Bohr atomic models of the chemical elements from the periodic table, organic and inorganic chemical molecules, Austria-Melo et al. [5] tested the following tools: 1) Unity3D in conjunction with the EasyAR SDK, 2) HTML 5, CSS, and the Google ARCore software development kit, 3) Spark AR Studio, and 4) Adobe Aero with Glitch and HTML 5. Due to the potential usage of the immersive experience with WebXR, the second option appears to be the most promising.

Cortés Rodríguez, Dal Peraro and Abriata [9] launched in 2020 *moleculARweb* (<https://moleculARweb.epfl.ch>), a website that offers interactive content for chemistry education through commodity web-based AR that works on smartphones [2]. To allow users to build their own material, authors built a web interface where they can create online AR experiences in few steps starting from Protein Data Bank, AlphaFold or custom uploaded structures, or from virtual objects/scenes exported from the Visual Molecular Dynamics program, without any programming knowledge. The web tool also returns WebXR sessions for viewing and manipulating the models in WebXR-compatible devices including smartphones, tablets, and also immersive VR headsets with WebXR-capable browsers. Virtual modeling kit 2.0 allows to use a pair of markers simultaneously [8], as in our developments. *MoleculARweb* is developed using A-Frame, AR.js, and ModelViewer components (the similar use of Sketchfab is proposed by Aristov, Moore and Berry [3]).

As Fombona-Pascual, Fombona and Vicente [14] emphasizes, "the increasing connectivity of the AR technology to web platforms and scientific networks should translate into new opportunities for teaching and learning strategies".

6. Conclusions

The educational and research activities of the students are an essential component of the learning process. According to contemporary educational theories, these activities take the lead in the learning process, and it is the teacher's responsibility to coordinate and encourage these activities. The active use of a chemical experiment as a learning tool is one of the elements of the students' educational and research activities in chemistry. Because active knowledge acquisition by the student leads to the most effective and solid assimilation, the utilization of a chemical experiment is a precondition for teaching chemistry.

Due to the insufficient material support of chemistry classrooms, the increased level of danger,

the lack of time available, and the requirement to conduct experimental research in a remote format as a result of the challenging epidemiological situation in the world in the last two years, the implementation of experimental work in chemistry in the 11th grade is associated with a number of complications.

Modern ICT tools, such as augmented reality tools and virtual chemistry laboratories, can be used to implement various educational and research activities. Today's augmented reality technologies may be seen in action on relatively low-cost and accessible devices like smartphones, and they can be seen in action right in the browser without the need to download and install any specialized software. This considerably widens the pool of potential users of augmented reality and, to some extent, streamlines the creation and dissemination of augmented reality-based software tools.

The best APIs for creating Web-based augmented reality software tools nowadays are A-Frame and AR.js. A big portion of the applications that use these APIs are written in HTML-like code that utilizes JavaScript on the server. In a web browser, A-Frame is used to build scenes, objects, animations, and other 3D features. A scene built with an A-Frame can be displayed directly on a marker thanks to AR.js's ability to track a marker.

The ability to safely conduct a variety of chemical experiments at any moment that is convenient for students, in such a quantity and sequence as defined by the users themselves, is one of the created AR-based virtual chemical laboratory's primary features. As a result, even though they are working in a virtual environment, students actively engage in using reagents and flasks, and the conclusions they derive from the results of numerous experiments are fairly real and independently acquired.

The downsides of the proposed AR-based virtual chemical laboratory include a limited set of possible experiments, poor video quality, and the impossibility to learn how to work with genuine chemical equipment and reagents.

The move from augmented reality on the Web, or WebAR, to immersive experiences, or WebXR, is the key route for future study. This makes it possible to integrate 360-degree 3D videos of scientific experiments with high-definition models of chemical laboratories and cutting-edge control methods like the virtual glove.

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A. Start page for an augmented reality-based virtual chemical laboratory – index.html

```
<html>
  <head>
    <style>
      button { color: lightgreen; background: #0000aa; height: 150px;
        width: 450px; font-size:200%; border: 2px solid powderblue;
        padding: 30px; position: fixed; padding: 1vh; bottom: 1vh;
        left: 50%; transform: translate(-50%, -50%); top: 50%; }
      #markers { font-size: 138%; border: 2px solid powderblue;
        padding: 30px; position: fixed; bottom: 1vh; left: 50%;
        transform: translateX(-50%); }
    </style>
  </head>
  <body>
    <a href="ar.html" target="_blank">
      <button>Go to the virtual laboratory</button>
    </a><p>
    <a href="markers.pdf" target="_blank" id="markers">Click to download a
      set of markers - print and cut them out. In the virtual laboratory, show
      them to the camera, and after the image appears on the marker, try to
      bring them together, but without overlapping.</a>
    </body>
</html>
```

B. Augmented reality-based virtual chemical laboratory – ar.html

<https://github.com/Lefoxi/ARdip/blob/main/ar.html>