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Android applications as an additional tool in inorganic chemistry teaching: A short-review

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ABSTRACT

The concept of mobile access to information is present in all aspects of society today and it constitutes the digital need of the individual. The aim of this paper is to provide a brief overview and systematization of various easily accessible android applications for mobile phones and tablets that would promote proper understanding of chemical concepts, as well as facilitate the acquisition of knowledge in chemistry by students in both primary and secondary schools. Mobile learning has many advantages such as diversity, entertainment, communication, interactivity, but also learning completely adjusted to the needs of the individual regardless of place and time. The use of these tools has a great impact on a different approach in teaching chemistry and contributes to improving of the final learning outcomes. That is why it is important for every teacher to integrate technology into pedagogy and use it to promote student-centered learning.

Keywords: android applications, mobile learning, teaching tools, interactivity

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INTRODUCTION

Chemistry is largely an abstract science. Years back, this subject was not a favorite among students, and there are numerous factors for that: abstractiveness, excessive curricula, inadequate textbooks, non-existence or poor equipment of the chemistry cabinet, poor motivation and engagement of teachers and disinterest of students (Ristić and Milošević, 2019).

Previously, classes were traditionally realized through chalk, blackboard and oral lectures.

Science today follows the trends of modern information technologies. Therefore, it is necessary to keep up trends in the field of teaching and knowledge transfer. In order for teaching to be more efficient, a multidisciplinary approach is introduced in its realization. Multimedia teaching tools satisfy modern didactic-methodical principles of teaching.

A form of learning that implies that part of the activities, in addition to the traditional classroom, also takes place on the Internet, is called combined or hybrid teaching. If the teaching material is modified and a learning tool or platform is chosen, students can receive exceptional support during learning. They can access teaching materials and study them further, practice or check the degree of mastery of teaching contents, progressing at their own pace and in accordance with their own abilities. With the help of the Internet, communication and cooperation skills, creativity and knowledge exchange are developed (Priručnik, 2014). This form of e-learning serves as a supplement to classical teaching, not as its substitute.

In the 21st century, the application of PPt in teaching has become widespread. Many studies show that this method has significant advantages over traditional teaching, but also a number of disadvantages (Kostic et al., 2018; Kostic et al., 2011; Zarubica et al., 2012; Nikolic et al., 2014).

In this paper, we will focus only on the application of mobile devices (mobile phones, tablets) in the learning process, the so-called mobile learning (m-learning). This form of learning has advantages, because it does not limit people who learn to sit, for example, in front of a computer, but it is possible to learn anywhere and anytime. This approach was adopted as A3 (abbreviation for "Anywhere, Anytime, Anyplace") (https://en.wikipedia.org/wiki/Android_(operating_system) Access: 20/3/2017).

How much the appearance of mobile devices has affected society positively or negatively in general remains for each individual to conclude. Opinions of teachers and attitudes also differ (O'Bannon and Thomas, 2014).

It is inevitable that the younger generations are increasingly using mobile devices in their daily activities, whether they are used for communication, entertainment or learning. This leads to a number of negative phenomena such as physical inactivity, loss of concentration, non-acceptance in society if the mobile phone is not of a newer generation, *etc*. However, there are also positive aspects of the proper use of mobile devices, such as: adoption of new technologies, learning new contents or good information (Heflin et al., 2017).

At the moment, the most widespread phones in the world are with the Android operating system (Figure 1). With the appearance of the Android OS in 2010, the representation grew from 33.2% in 2011 to 86.8% in 2016 (İlhan, 2016). iOS is the mobile operating system of Apple. It was originally developed for the iPhone, and later for the iPod, iTouch, iPad and Apple TV. The market for Apple devices fluctuated between 15% and 12.5%. Apple does not allow the iOS operating system to be run on the third-party hardware. From September 1, 2010, Apple's App Store service contains more than 250,000 iOS applications, which have been downloaded more than 6.5 billion times (https://prezi.com/p/ekhzkjtnuyg5/aplikacije-za-iphone/).

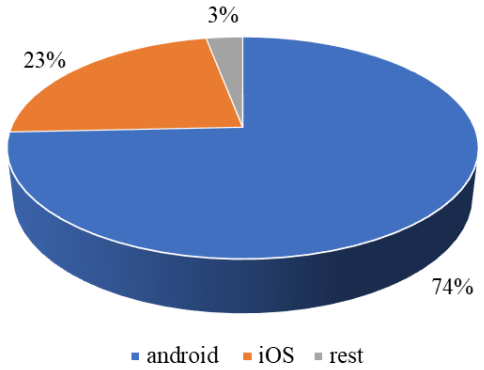

Figure 1. The share of operating systems in mobile phones in the world

As the android operating system is more represented in this paper, we provide an overview of selected applications that can be used as additional (interactive) tools in the teaching of inorganic chemistry. By using omnipresent and easily accessible android applications as additional tools in teaching chemistry, the acquisition of knowledge in chemistry by pupils in both primary and secondary schools can be facilitated and improved.

As corresponding applications are not always available (free of charge), teachers experiences difficulties to assess their characteristics solely on the basis of reviews. Therefore, there is a need to create specific mobile learning applications, and in addition, empowering educators to create their own mobile applications is likely to lead to the integration of mobile technology into teaching.

With the appearance of the Internet and the evolution of smartphones and tablets, pupils /students have instant access to a wealth of information. Of course, adopting integrative technology-based technology strategies is a major challenge for both teachers and students(Williams et al., 2011).

Hew and Brush (2007) pointed out that the lack of resources and knowledge and skills on how to make the best use of these technologies are some of the main obstacles. However, continuous education in this area, activity of educators and engagement of students can lead to significant results.

Data collected during several semesters of using mobile applications in teaching showed that the interest of students in chemistry has increased significantly which has led to better results in terms of knowledge and its application (Naik et al., 2015).

Android applications as educational tool

Technology such as iOS and Android based mobile apps can be used as an interactive educational tool, which allows a dynamic learning experience that directly benefits students. The mobile apps can be used in a General Chemistry course to teach the subjects of atoms, elements and the periodic table. Because these apps are interactive, they enhance student engagement and spark interesting learning of these fundamental concepts (Libmanet and Huang, 2013).

Google play store offers many interesting apps in chemistry, but here it will be presented selected apps that can be used in teaching of inorganic chemistry. They could be grouped into a dozen categories based on the content they offer and they are: Periodic table of elements, complete applications, applications with video content, chemical reactions, 3D display, minerals, electronic configuration, equalization of equations of chemical reactions, solutions, notes. This is not a sharp division of applications, because they enable a large number of functions, but there is one representative from each.

The described applications can be accessed easily *via* a mobile phone from the Google Play Store or using the QR codes given at the end of the description of each application.

Periodic table of elements: Merck PTE

The "Merck PTE" application enables the user to understand the complex science of chemistry and provides quick access to all the necessary information. Whether it is a pupil or a teacher, a student or a professor, an amateur or an expert, a hobbyist or a technician, "Merck PTE" provides broader information about each element of the Periodic Table. The periodic table of elements is shown in a digital form, which can be seen in Figure 2a, where information about each element can be found immediately, calculations can be made, such as calculating the molar mass of any compound, comparing elements in terms of atomic gradation, electronegativity and many other features. The app also contains historical facts and that is why it can be very entertaining.

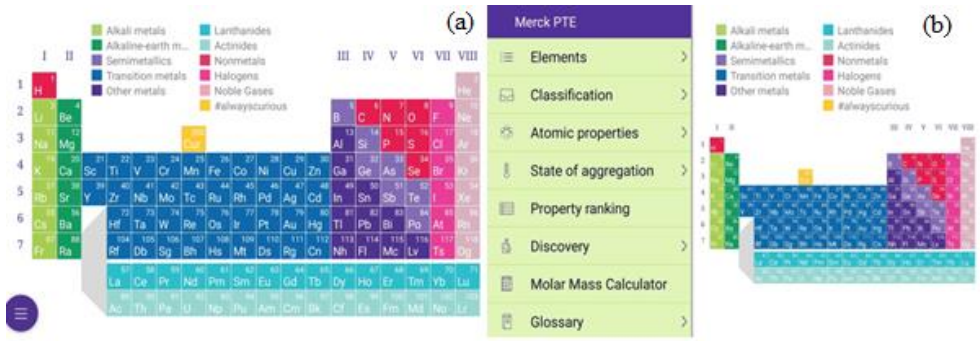

Figure 2. (a) The initial interface of the "Merck PTE" application and (b) the appearance of the application menu

By clicking on any element of the Periodic Table, an image of that element appears with general information about it. The application menu (Figure 2b) is quite simple, clear and provides a large number of options:

1) *the possibility of classification according to different criteria.* With this application it is possible to classify elements according to which group they belong to (metals, non-metals, *etc.*) (Figure 3a), according to radioactivity or percentage share in the Earth's crust;
2) *displaying the properties of atoms.* We can get information about the atomic radii of the elements (Figure 3b), values for electronegativity (according to the Allred-Rochow and Pauling scale), ionization energy and relative atomic mass;
3) *state of aggregation of the elements.* This application provides information about the state of aggregation of the element at a certain temperature, which is adjusted by moving the cursor (with a finger) on the temperature scale (Figure 3c);
4) *historical data about the element.* Merck PTE provides data on when an element was discovered as well as which scientist discovered it (Figure 3d);
5) *calculating the molar mass of the compound* (Figure 3e);
6) *explanation of chemical terms.* This application also offers a list of terms in alphabetical order that occur using the same, as well as an explanation for each of them (Figure 3f).

The internet is not required for this application to work; it works in offline mode, which can be an advantage in some situations. It has dynamic design, economical handling access rights, an interactive operating system, as well as smart controls and numerous choices.

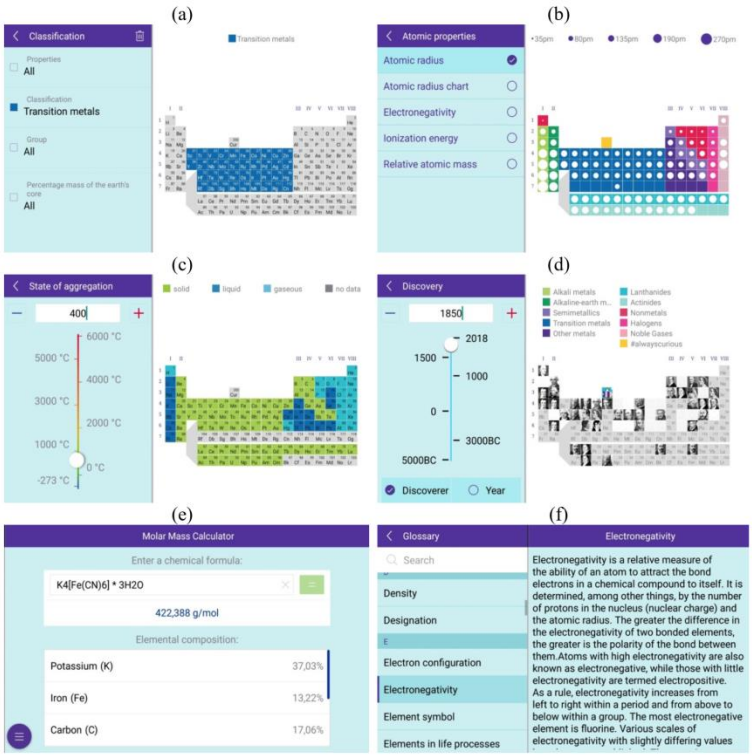

Figure 3. Examples of user interface: (a) transitional metals, (b) relation of atomic radius of atoms, (c) state of aggregation of elements at a temperature of 400℃, (d) elements discovered until 1850, (e) calculating the molar mass of the compound, (f) explanation of the term electronegativity. The Merck PTE application can be easily accessed by scanning the QR code from Figure 4.

Figure 4. QR code for Merck PTE app

Complete apps: Chemical suite free

The initial interface of this application is the Periodic Table of the Elements (Figure 5).

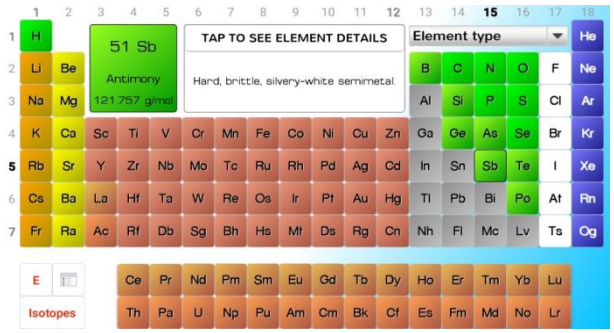

Figure 5. The initial interface of the app Chemical suite free

Each element is described with more than 30 characteristics, including general and physical properties (Figure 6a), history, *etc*. This application also provides information on the isotopes (natural, radioactive) that are characteristic of each element.

In an easy and simple way, this application allows the calculation of the molecular weight of the compound (Figure 6b), then it has a list of chemical and physical constants that can be searched using the search option (Figure 6c) and they are divided by scientific fields. Each constant is defined by a numerical value and the unit in which it is expressed, with the existence of a unit converter (Figure 6d). Through this application chemical reactions can be equalized, the search of elements in a given range of values of relative atomic mass can be performed (Figure 6e), you can apply the equation of state of an ideal gas with conversion (pV = nRT) and the trend of changing a certain element property can be graphically displayed (relative atomic mass, ionization energy density, atomic, ionic, covalent radius) (Figure 6f).

Figure 6. Overview of application functions: (a) characteristics of phosphorus atoms, (b) calculating the molecular weight of the compound P_2O_5, (c) Planck's constant, (d) unit conversion, (e) elements of relative atomic masses in the range from 5 to 10 and (f) graphical representation of the first ionization energy of the elements of the Periodic Table

Chemical Suite free application can be easily accessed by scanning the QR code from Figure 7.

Figure 7. QR code for Chemical Suite free app

Video: MEL chemistry

"MEL Chemistry" provides an amazing experience of performing experiments. Namely, there is a large number of experiments here the conduct of which was recorded by a camera.

The experiments are listed on the initial interface where each of them has an appropriate creative name. By clicking on one of them, the application offers new possibilities such as information on safety, expected result, waste disposal, as well as a scientific explanation of a given experiment.

Each experiment was characterized by a certain degree of difficulty, danger and duration (Figure 8a). The application can become a personal assistant to the user in performing experiments because it leads them step by step towards the ultimate goal of the experiment and also provides help in solving problems. This application can be used at home because children actually want real chemistry, not toys- "plastic accessories" to play with. Real chemistry means real opportunity, real responsibility, but also real danger. There is the possibility of ordering sets with utensils and dishes on the *MEL Science* website.

The Mel Science kit is organized into several packages. The first package is a starter kit that contains all the equipment needed for future experiments. The set includes a cardboard set with VR glasses, glass instruments, telephone stand, goggles and much more. The second and third packages are systematized according to the topics they deal with. Each package has enough material to do (and repeat) several experiments on the same topic. The kits are marked with warning labels and safety instructions for security reasons.

In addition, the application offers the ability to detect the real structure of substances found in the environment and visualization of molecules in 3D (Figure 8b). *What does kitchen salt actually look like at the molecular level?* "MEL Chemistry" will show the structure of these and hundreds of other molecules including, for example, sulfuric acid, hydrochloric acid, sodium carbonate, sodium bisulfate, potassium permanganate, calcium hydroxide, *etc*. In addition, the molecules of new compounds are constantly updated on this list.

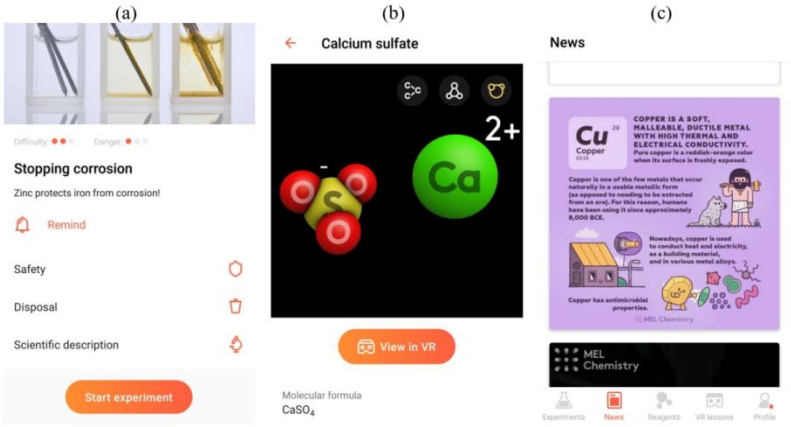

Figure 8. Overview of application functions: (a) properties of the corrosion inhibition experiment, (b) 3D structure of CaSO4 molecules and (c) interesting information about copper

This application also offers other options such as "news" with many interesting facts from the world of chemistry (Figure 8c); MEL code reader by scanning the substance bottle, using the phone to detect the

molecules it contains; VR experiences that gain a new level of understanding science. There are over 80 different VR classes and tests that cover the standard school chemistry curriculum. The only deficiency of this application can be the lack of search option for experiments, which can make it a little difficult to use. MEL application can be easily accessed by scanning the QR code from Figure 9.

Figure 9. QR code for MEL chemistry app

Beaker mix chemicals

The "Beaker" application has the role of a virtual chemical laboratory, where everyone can try themselves in the role of a scientist. A mobile phone becomes a glass that can be held, shaken, heated, covered, and it can contain various substances. You can do experiments with more than 150 chemicals. The app offers acids, salts, bases as well as atoms and molecules of elements in the appropriate state of aggregation, arranged in alphabetical order (Figure 10a).

This app offers interactive options during the experiments as well:

1) adding: clicking on any of the chemicals, they go to the beaker. If there are more, in addition to the visual and sound experience, their reaction is accompanied by chemical equations, molecular formulae of the product and the current temperature (° C) of the reaction in the beaker (Figure 10b);
2) heating (burner): dragging a finger from the lower right to the lower left corner of the screen turns on the burner;
3) shaking: to speed up the reaction (Figure 10c);
4) covering the beaker (lid): dragging a finger from the upper right to the upper left corner of the screen covers the beaker;

The application also provides information about the density, molar mass, mass concentration of all offered substances represented by both the molecular formula and the name. The Air Mick option requires internet connection and geolocation services, while other possible options (cooling, mixing, and separation) need to be paid for, so unfortunately the application is not completely free.

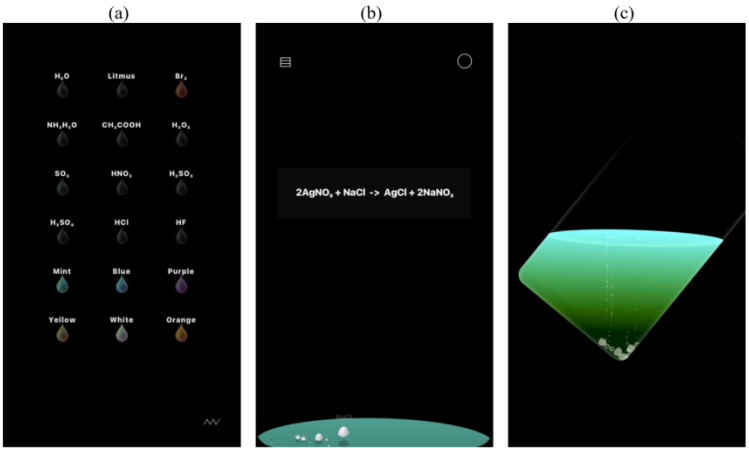

Figure 10. Examples of application user interface: (a) some of the substances to use, (b) sedimentation of AgCl and (c) mobile phone manipulation

The dark background of the application makes it easier to monitor the course of reactions, as well as all chemical and physical phenomena, but it can also be changed by the color of your choice. By using this application, real work with toxic and dangerous substances is excluded, but the same or even better effect of students' acquiring new concepts and knowledge is achieved. There are no more worries about rough reactions because they are happening on the screen. This app is a solution for schools which have no laboratories or whose laboratories are not equipped well enough. As the safety and health of the participants in the laboratory is a priority, this app can be an extremely useful teaching tool in schools and colleges. Beakers Mix Chemicals application can be easily accessed by scanning the QR code from Figure 11.

Figure 11. QR code for Beakers Mix Chemicals app

3D: Virtual orbitals 3D chemistry

It is very difficult to understand atomic orbitals drawn on the blackboard or a piece of paper (2D view). The "Virtual Orbitals" app provides better orbital visualization in three-dimensional (3D) form and helps to understand them (Figure 12a). This app provides interactive manipulation with selected atomic orbitals "finger touch and move"; the way the orbital can be seen from all aspects (3D view) enables students' visual understanding of the concept and appearance of the orbital.

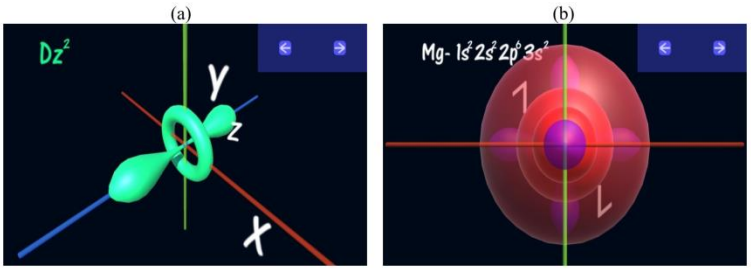

Figure 12. Examples of user interface: **(**a) orbital d_{z2} and (b) atomic orbitals of magnesium

This application includes the following atoms with their electronic configuration: hydrogen, helium, lithium, boron, carbon, oxygen, neon, sodium, magnesium (Figure 12b), silicium, potassium, argon, calcium, zinc, iron, *etc*. The Virtual orbitals 3D chemistry app can be easily accessed by scanning the QR code from Figure 13.

Figure 13. QR code for Virtual orbitals 3D chemistry app

Minerals

As its name suggests, the app presents basic concepts about minerals. The application also offers instructions for macroscopic and microscopic determination of some minerals.

This application provides a spreadsheet of the most important information about each mineral: group, cristal system, the class of symmetry, the mode of appearance, firmness, solidity, colour, genesis, the use, the deposits (Figure 14a).

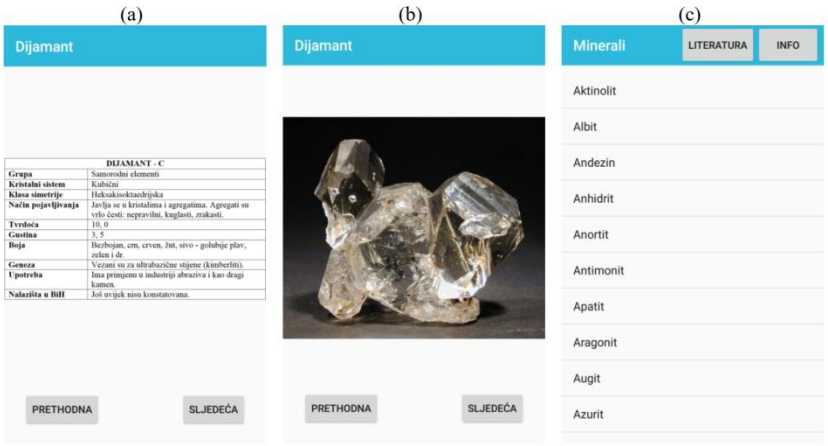

Figure 14. Examples of user interface: (a) characteristics of the diamond, (b) the appearance of a diamond and (c) the list of offered minerals

The app is in Serbian which highly facilitates its use. The defect of the app is that there are not so many images and their quality is not at high level (Figure 14b). There is no search option either but all the minerals are listed in alphabetical order (Figure 14c). The Minerals app can be easily accessed by scanning the QR code from Figure 15.

Figure 15. QR code for Minerals app

Electron configuration

Writing an electronic configuration of elements is often an unsolvable problem for students. However, using this application can make it much easier.

"Electron configuration" is an application designed for students, but it is also useful for enthusiasts in chemistry, because it is very easy to use it, it provides help as well as checkout in learning. It is based on a simple and nice user interface. The app can be used in two ways: selecting elements from a ready-made list (Figure 16a) or selecting one specific element in the search (Figure 16b). Further information about the element is available *via* the “Google” icon which leads to Google search engine (Figure 16c).

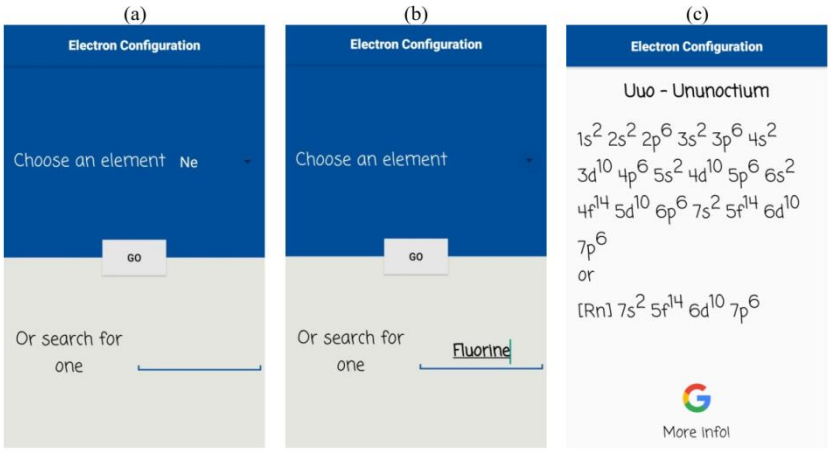

Figure 16. Examples of user interface: (a) selecting elements from the list, (b) search for a specific element and (c) user interface

The Electron configuration app can be easily accessed by scanning the QR code from Figure 17.

Figure 17. QR code for Electron configuration app

Chemical balancer

The "Chemical Balancer" application enables the equalization of chemical reaction equations. The use involves entering the molecular formulae of the reactants and products and then by clicking on "balance" the equalization process is performed. The result is displayed in a very short time (Figure 18a). It is suitable for any chemical equation, as long as it is not written in ionic form.

It is a very useful tool for chemistry students, as well as for teachers, researchers, analysts and pharmacists. "Chemical Balancer" is a free and very easy to use application. This application can be used to check the accuracy of the examples done during the exercise. The Electron configuration app can be easily accessed by scanning the QR code from Figure 18b.

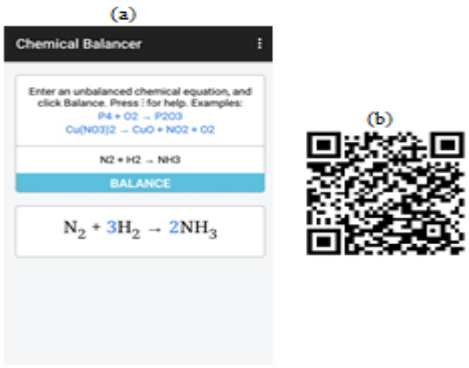

Figure 18. (a) User interface layout (b) QR code for Electron configuration app

Solution calculator lite

"Solution calculator lite" is a practical and very simple app for both chemistry students and researchers/ scientists working in the laboratory for chemistry, biochemistry or biology.

This application offers the following features:

1) *suitable calculator for making chemical solutions.* In the "Make" section, it is necessary to enter the required concentration, volume of solution and molar mass of the compound. Clicking on the "calculate" option, the result is obtained, *i.e.*, the mass of the compound necessary for the required concentration of a solution. The app remembers all previous calculations that are easily visible. Each value can be expressed in a pair of offered units (Figure 19a). It is also possible to calculate the dilution of the solution using the stock solution in the "dilute" section. The app helps to quickly determine how much chemical / stock solution is needed (Figure 19b). This way there is no waste of time and all attention is focused on working in the laboratory.
2) *calculating the molecular weight (MW) of common chemicals in the laboratory.* This is done by entering the molecular formula of the compound (Figure 19c), while for some substances listed in alphabetical order, molar masses (ATP, EDTA) have already been introduced.
3) *provides detailed information about each of the 118 elements*, such as: atomic and mass number, position determined by a group and period, original name and the year of discovery, density, melting point, electronic configuration, but also a suitable description of that element.

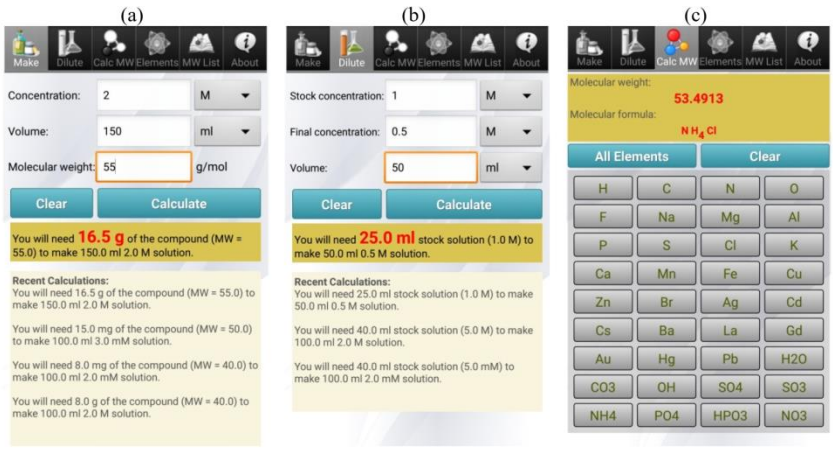

Figure 19. Functions of the app: (a) making a solution, (b) dilution of the solution, (c) calculating the molecular weight

The Solution calculator lite app can be easily accessed by scanning the QR code from Figure 20.

Figure 20. QR code for Solution calculator lite app

CHEMISTRY NOTES Offline

Chemistry Notes

The "Chemistry Notes" application is specially designed for high school students and can be used for practice and preparation of control tasks. This app contains notes that are grouped into 45 chapters and some of them are: atoms and molecules, the structure of atoms, acids, bases and salts, metals, *etc*. A graphic representation of some of the chapters can be seen in Figure 21.

Irregular order of chapters as well as the lack of search option can be suggested as disadvantages, but this is compensated by very concise notes, accompanied by Figures and examples. The app is easy to use and does not take up much memory space on a mobile phone and it can be used in an offline mode. This application is a good IT tool and repetitorium.

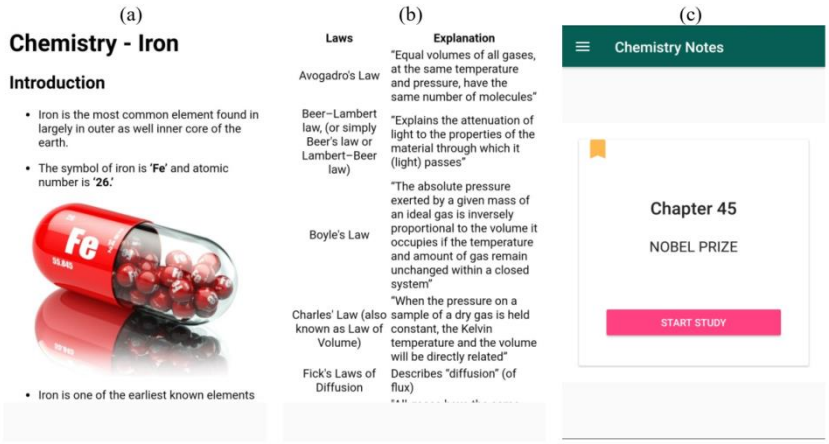

Figure 21. Chapter: (a) Iron, (b) Chemical laws and (c) Nobel Prizes

The Chemistry notes app can be easily accessed by scanning the QR code from Figure 22.

Figure 22. QR code for Chemistry notes app

The following applications are not free of charge and that is why the scope of reviews has been reduced. However, they can make a significant contribution as additional tools in teaching inorganic chemistry.

Chemist virtual lab

The "Chemist virtual lab" application is a virtual chemical laboratory. It is great for various experiments, research, learning or just for playing.

Laboratory utensils and accessories are on a virtual shelf; 17 basic laboratory elements that are sufficient for all manipulations in the laboratory: glasses, Erlenmeyer flasks, round bottom flasks, a test tube, a reagent bottle, a ring stand, a tripod, an alcohol burner, a porcelain cup, a watch glass, a funnel, extensions and a plug. Equipment also includes a paper indicator, a thermometer, a glass rod, a pipette and matches and they can be selected from the drop-down menu. Clicking on a selected dish, it moves to the desktop where a large number of dishes can be found at the same time with an arrangement that suits the user (Figure 23a).

The application offers more than 200 inorganic and about 60 organic chemical reagents. This way, the needs of both primary and secondary school students, but also students at the faculty are included. Chemicals are grouped into 4 categories: mixtures, solids, liquids, gases and all of them are on the virtual

shelf in reagent bottles, displayed in the appropriate state of aggregation and color. The "search" option will speed up finding the required reagent.

In order to see the physical and chemical properties: molecular weight, volume, temperature, concentration, reactions with other substances, you can click on a chemical substance (Figure 23b). By dragging the reagent bottle with the substance to the container, a window appears showing the mass and amount of the substance poured into the container. This way you can see what is happening in the beaker, not only visually, but also in the exact ratio of the reactants.

The course of the experiment is followed by the equation of the chemical reaction that appears in the upper part of the screen (Figure 23c). 6 practical application options can be tried out with one touch and dragging (change of laboratory temperature, adjustment of air composition, time acceleration ...). The experiment can be saved with all the steps that have been done.

Experimenting with different substances is a fun, but sometimes not so safe. However, the application provides the possibility of complete freedom, without fear of cracking the dishes due to some untested reaction or possible injuries. It will make for all the necessary chemicals to be at your fingertips, without previous purchasing; there will never be a mess and possible "explosions" can be stopped at any time. This application helps you gain real experience, like in a real laboratory, because it goes through the whole experimental process, to which excellent visual and sound effects also make a contribution.

The application has passed the security test for viruses and other malicious attacks and contains no threats, so the security of the mobile phone and personal data is ensured. It should be emphasized that the application is not free of charge.

Figure 23. Examples of user interface: (a) working area with laboratory utensils, (b) solid-state substances with characteristics and (c) chemical reaction process

The Chemist virtual lab app can be easily accessed by scanning the QR code from Figure 24.

Figure 24. QR code for Chemist virtual lab app

The following applications are made by "Ajax media tech" on the same principle. Each contains learning, practice and quiz options.

Mole concept in chemistry

"Mole concept" is an interactive application with the help of which students can learn the meaning of the term mole in chemistry in a simple and comprehensive way, as well as formulae for calculating numerical values. It is intended for lower grade students.

The app “Mole concept” is simple to use and it offers three functions:

1) learning- mastering knowledge in an interesting way (Figure 25a),
2) exercising- checking learnt concepts (Figure 25b),
3) quiz- application of acquired knowledge (Figure 25c).

The application contains 3D simulations and videos to make learning the concept of the mole more understandable and easier to learn with minimal effort and long-term memory.

Figure 25. Application functions overview: (a) learning, (b) practice and (c) quiz

The Mole concept in chemistry app can be easily accessed by scanning the QR code from Figure 26.

Figure 26. QR code for Mole concept in chemistry app

Reactivity series of metals

The "Reactivity Series of Metals" application helps students learn all about the reactivity of metals and the various changes that occur during reactions. This application shows a series of reactivity of metals and the most reactive metals, but also chemical reactivity trends in a simple way with interesting “do-it-yourself” activities. Students can research and practice what they have learnt through interesting examples. The application will make learning more interesting through interactive activities, 3D simulations and videos for better understanding of the concepts (Figure 27).

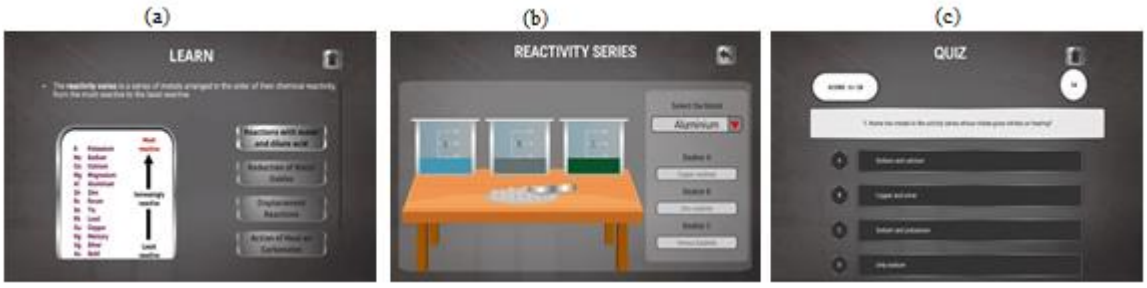

Figure 27. Application functions overview: (a) learning, (b) practice and (c) quiz

The Reactivity series of metals app can be easily accessed by scanning the QR code from Figure 28.

Figure 28. QR code for Reactivity series of metals app

Acids and Bases in Chemistry

The application is based on the concept of acids and bases and their properties, especially chemical ones. It describes in more details the reactions of metals with acids or bases. All differences are in the spreadsheet in order to be better noticed and remembered (Figure 29).

Figure 29. Application functions overview: (a) learning, (b) practice and (c) quiz

The Acid and Bases in Chemistry app can be easily accessed by scanning the QR code from Figure 30.

Figure 30. QR code for Acid and Bases in Chemistry app

Ammonia Structure & Properties

The application describes the structure of ammonia and its properties. The geometry of NH_3 molecules, its physical and chemical properties, as well as the entire procedure of the Haber-Bosch process shown in a Figuresque way are considered (Figure 31). The questions in the "quiz" section are not trivial, but they encourage the user to think.

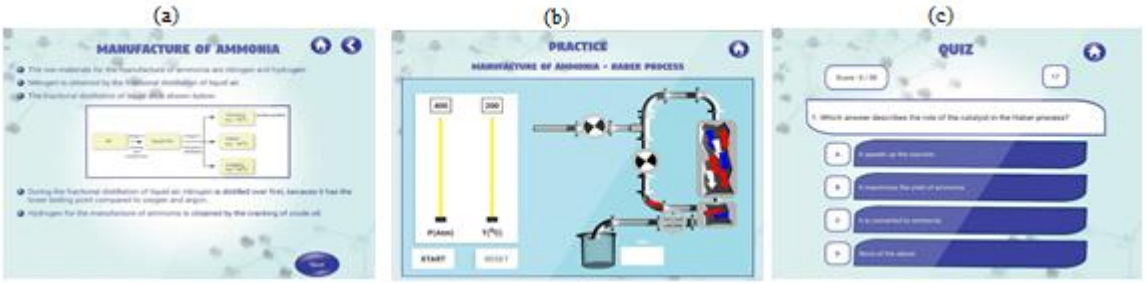

Figure 31. Application functions overview: (a) learning, (b) practice and (c) quiz

The Ammonia structure & properties app can be easily accessed by scanning the QR code from Figure 32.

Figure 32. QR code for Ammonia structure & properties app

Salts in Chemistry

The application is excellent for the teaching unit "Salts". It describes the reaction of salt formation, types of salts (acidic, basic) and NaCl is taken as an example. It is intended for lower grade students who encounter this term for the first time. Spreadsheets, animations and creative illustrations of the structure of salt contribute to better understanding of the new concept (Figure 33).

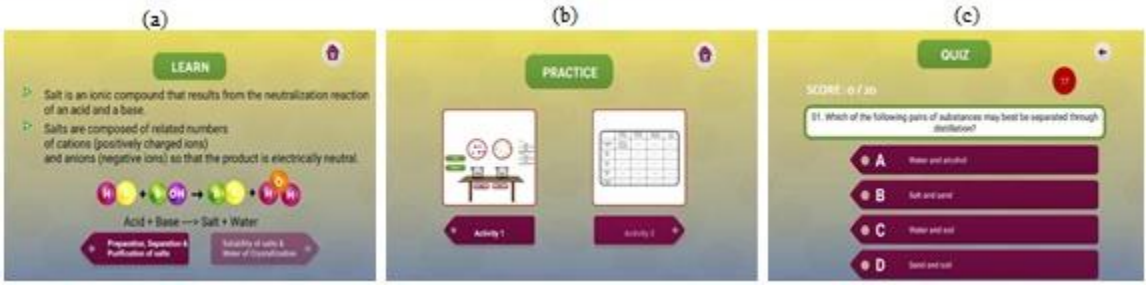

Figure 33. Application functions overview: (a) learning, (b) practice and (c) quiz

The Salts in chemistry app can be easily accessed by scanning the QR code from Figure 34.

Figure 34. QR code for Salts in chemistry app

Redox Reaction – Chemistry

This application includes oxidation and reduction reactions. As they can be very problematic for students, the application will help them master the reactions faster. With very simple but useful explanations of the terms of reduction and oxidation, the app offers users the possibility to equalize redox reactions, which is great for exercise (Figure 35).

Figure 35. Application functions overview: (a) learning, (b) practice and (c) quiz

The Redox Reactions - Chemistry app can be easily accessed by scanning the QR code from Figure 36.

Figure 36. QR code for Redox Reactions – Chemistry app

Water Treatment Plant Process

Water, a compound that is irreplaceable for the functioning of the organism, is shown in this application from the chemical side. Namely, the application, in addition to chemical and physical properties, also describes water pollution, as well as the process of its purification. Very suitable content (Figure 37), in addition to providing scientific knowledge, pays attention to raising users' awareness of the importance of water, which is now neglected. That is why it is necessary to show younger students what are the negative actions that can endanger the survival of the human species, so as not to be repeated.

Figure 37. Application functions overview: (a) learning, (b) practice and (c) quiz

The Water treatment plant process app can be easily accessed by scanning the QR code from Figure 38.

Figure 38. QR code for Water treatment plant process app

DISSCUSION

Visualization is a convenient method in teaching. In chemistry, visual representations have several important functions: to make the connections visible, to present the dynamic and interactive nature of chemistry, to provoke the transformation from two-dimensional to three-dimensional ways of thinking and to determine how much time a student needs to remember that information (Vavra et al., 2011). Pedagogical experiments implemented in primary and secondary schools have shown that a multidisciplinary approach (visualization, ppt presentations with video and audio recordings, performing experiments in front of students) in teaching inorganic chemistry significantly increases students' interest in chemistry and science and better knowledge acquisition by students from processed teaching units (Nikolic et al., 2014; Nikolic et al., 2018).

The student can actively participate in the lessons *via* their mobile phone or tablet. Practicing tasks through online tests, reading books in electronic form, learning and research provide greater motivation for the work of each child and create a desire for better results. The essence of multimedia is interactivity as the main feature of the media.

Teachers are always there for all questions, advice and problems of their students, they can communicate with them, consult them for everything that is not clear to them whenever they want. All this is the credit of many important and tempting applications. With popular applications, learning on tablets becomes easier and more interesting, students are more imaginative, more active in class and motivated to explore and learn, they progress faster and become more successful.

Mobile learning, known as "m-learning", refers, as the name suggests, to learning on the go. What makes m-learning special is the simple and fast access to the necessary information in different locations using mobile devices that are adapted in size and shape to easy portability (Krmek, 2017). The most widespread phones in the world are those with the Android operating system at the moment.

The advantages of m-learning are reflected in the following: introduction of new technologies in teaching processes; mobile devices are easier to manipulate (transfer) than PCs and books; they are important for students with special needs; they are cheaper than laptops or computers, and can also be used as means of communication; multimedia content has a greater impact on perception and memory; reducing costs of training; support for continuously learning in any situation.

According to the literature, m-learning has also some disadvantages: limited power supply of mobile devices; monitor and key size; different mobile devices have different screen sizes and different operating systems; additional work is necessary to transfer existing electronic learning materials to mobile platforms; limited memory; safety; high costs of buying the latest models of mobile devices (Ristić and Milošević, 2017).

However, considering that the development of science and technology is going at a high speed, some of these shortcomings can be overcome. For example, using a power bank as an additional power source for mobile phones; using the "screen mirroring" option when the display of the phone or tablet is copied on a monitor (TV, video beam, PC monitor, *etc.*). Lack of memory can be compensated by using the cloud and external memory which is now more affordable. And finally, the purchase of the latest phones as one of the disadvantages makes no sense, because cheaper phones of the newer generation can also be used.

CONCLUSION

In a traditional school, the teacher was the mediator between the teaching content and the students. The teacher was the exclusive organizer of the educational work, and the relations between the teacher and the student were based on hierarchical principles. The student was in a subordinate position.

A modern school is also looking for a modern teacher who should be new, unrepeatable, up-to- date. The modern approach to teaching chemistry is based on the strategy of learning by discovery. This enabled the students to no longer be passive listeners sitting in the desks, but active participants in the learning process. Students learn best when they are helped to discover the principles on which phenomena are based. The teacher only becomes the moderator who guides the student.

Research shows that the use of information technology and educational software enables better control and management of the teaching and learning process through constant feedback, which has a strong stimulating and motivating role. Their use favors the development of abstract thinking and enables planned progress in the process of acquiring knowledge. The concept of mobile access to information and social networks that are present in all aspects of society today constitute the digital need of the individual. In addition, the availability of mobile technology allows students today to use that technology in education as well.

Recommendations for using the applications are as follows:

1) improving students' attention in class, increasing both motivation and engagement,
2) focusing on important learning goals,
3) showing movement or a better explanation of a concept by presenting it in three dimensions,
4) fulfilling the request of visualization,

5) short, simple and clear representation of the teaching unit,
6) combining with other forms of teaching, and not as a substitute for good teaching,
7) adjusting the content with the level of knowledge that students possess as well as their abilities,
8) planning a suitable date for the use of application in teaching, because students, who are at the beginning of learning, are not able to distinguish between important and less important segments,
9) explaining concepts that cannot be seen (such as atomic collisions).

The introduction of mobile phones and tablets in teaching represents a real revolution in education. It is now necessary to enable digital education of teachers who will not avoid technology, but will use all its advantages and provide students with exciting and modern teaching suitable for new, net- generations. Present research provides evidence that visualization has an important place in teaching and learning science. Nevertheless, chemistry teachers must be careful in choosing the facilities and activities that can be realized *via* mobile phones, so that they justify the teaching purpose and are adapted to each student individually.

This work represents a good basis for the realization of a new pedagogical experiment in primary and secondary schools for monitoring the improvement of the teaching of inorganic chemistry, which will be the subject of our future research.

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Conflict-of-Interest Statement

Authors declare no conflict of interest.

REFERENCE

Heflin, H., Shewmaker, J., & Nguyen, J. (2017). Impact of mobile technology on student attitudes, engagement, and learning. Computers & Education, 107, 91-99.

Hew, K. F., & Brush, T. (2007). Integrating technology into K-12 teaching and learning: Current knowledge gaps and recommendations for future research. Educational Technology Research and Development, 55, 223–252.

https://prezi.com/p/ekhzkjtnuyg5/aplikacije-za-iphone/, access 23/07/2020

İlhan, I. (2016). Mobile device based test tool for optimization algorithms. Computer Applications in Engineering Education, 24, 744–754.

Kostić, D. A., Mitić, S. S., Gošnjić-Ignjatović, A. J., Ranđelović, J., & Zarubica, A. R. (2011). A correlation between traditional and computer-based interactive teaching method in the presentation of the lesson Proteins. The New Educational Review, 25, 172 -182.

Kostić, D. A., Nikolić, R. S., Krstić, N. S., Nikolić, M. G., Dimitrijević, V. D., & Simić, S. (2018). Multidisciplinary approach to teaching inorganic chemistry in high school: an example of the topic of metals. Current Science, 115, 268–273.

Krmek, M. (2017). Mobilne tehnologije u nastavi (B.Sc. Thesis). Učiteljski fakultet. Zagreb. https://urn.nsk.hr/urn:nbn:hr:147:246288 (in Croatian)

Libman, D., & Huang, L. (2013). Chemistry on the go: Review of chemistry apps on smartphones. Journal of Chemical Education, 90, 320–325.

Naik, G., & Ramirez, M. (2015). Integrating audio-visual materials and mobile app technologies into chemistry course curriculum. Selected papers from the 26th International Conference on College Teaching and Learning, 154−161.

Nikolić, R. S., Kostić, D. A., Krstić, N. S., Trajković, A., & Stojanović, N. (2014). A Multidisciplinary Approach to Teaching Metals as Part of the Elementary School Curriculum in Serbia: a review. The New Educational Review, 36, 95-103.

O'Bannon, B. W., & Thomas, K. (2014). Teacher perceptions of using mobile phones in the classroom: Age matters!. Computers & Education, 74, 15–25.

Priručnik 2014 – Primena informaciono-komunikacionih tehnologija u nastavi, Zavod za unapređivanje obrazovanja i vaspitanja, Beograd, 2014 (in Serbian).

Ristić, O., & Milošević, M. (2017). Primena android aplikacija u obrazovanju, Selected papers from National conference with international participation about information technologies, education and entrepreneurship, http://www.ftn.kg.ac.rs/konferencije/ITOP17/Radovi/Olga%20Ristic,%20Marjan%20Milosevic.pdf, accessed 23/07/2020

Vavra, K., Janjic-Watrich, V., Loerke, K., Phillips, M. L., Norris, P. S., Macnab, J. (2011). Vizualisation in science education: a review. Alberta science education journal, 41, 22-30.

Williams, A. J., & Pence, H. E. (2011). Smart phones, a powerful tool in the chemistry classroom. Journal of Chemistry Education, 88, 683–686.

Zarubica, A., Kostić, D., Rančić, S., Popović, Z., Vasić, M., Radulović, N. (2012). An Improvement of the Eighth Grade Pupils` Organic Chemistry Knowledge with the Use of a Combination of Educational Tools: An Evaluation Study - Expectations and Effects. The New Educational Review, 30, 93–102.