World Journal of Chemical Education, 2021, Vol. 9, No. 1, 1-7
Available online at http://pubs.sciepub.com/wjce/9/1/1
Published by Science and Education Publishing
DOI:10.12691/wjce-9-1-1

Possibilities of Learning Contemporary Chemistry via Virtual Reality

Mareike Frevert*, David-Samuel Di Fuccia

Department of Science and Mathematics, University of Kassel, Kassel, Germany
*Corresponding author: mfrevert@uni-kassel.de

Received October 28, 2020; Revised November 10, 2020; Accepted November 17, 2020

Abstract The fundamental challenge for understanding and thus for teaching chemistry is that chemical processes at the atomic level are all inaccessible to sensory experience and must therefore be represented by models. For learners these models are often difficult to understand and to use, as they pose high demands regarding cognitive and spatial ability as well as abstraction. This applies especially when it comes to current developments and research topics of chemistry, like nanoscience. It leads to a situation where modern chemistry and chemical research is more and more inaccessible for learners at universities. Using learning environments that utilize virtual reality may help to overcome this problematic situation as they allow new ways of visualization, a more direct interaction between learner and chemical object and they are open to more game-based approaches. By using VR-technology in combination with aspects of actual chemical research topics, chemistry education students may gain better understanding of modern chemistry. As a result, they should be better prepared to realize modern chemistry lessons in the future, that delivers a realistic view of modern chemistry, cover topics of actual relevance and use digital methods that foster learning. In the following, two projects which focus on VR and contemporary chemistry will be presented. In the first project a virtual reality game was created and embedded in a course of chemistry education. The aim is to present the students a kind of real situation with aspects of modern chemistry, where they have to act as a forensic scientist. Additionally, they should use this VR game as basis for conceptualizing teaching materials for chemistry lessons at school and as a means to promote their digital competencies. In the second project, another context and software for learning contemporary chemical contents via VR is used. Students focus on chemical aspects of the Corona-Virus (Sars-CoV-2) as content and use the VR-software *nanome* for learning about complex molecular systems and making these chemical aspects teachable afterwards.

Keywords: *contemporary chemical research, virtual reality, higher education, molecular structures, models*

Cite This Article: Mareike Frevert, and David-Samuel Di Fuccia, "Possibilities of Learning Contemporary Chemistry via Virtual Reality." *World Journal of Chemical Education*, vol. 9, no. 1 (2021): 1-7. doi: 10.12691/wjce-9-1-1.

1. Introduction

Chemistry education students are challenged to understand modern chemical contents. This is necessary for having the possibility to teach relevant contents in chemistry lessons in the future as today's modern aspects of chemistry may easily be a standard application of chemistry in the future. For gaining a better understanding of modern chemical contents, the VR-technology can be used for offering students visual ways of understanding chemistry. Beside the aspects of learning and teaching modern chemistry, by using VR-technology digital compencies of students can be trained. In order to cover these two aspects, first it has to be defined, what 'modern' chemistry means and how it is characterized and - second - extensive VR learning environments must be developed.

Two different learning environments will be presented in the following which shall help students to prepare for modern chemical contents while using virtual reality.

2. Aspects of Contemporary Chemistry

Modern chemical research is important in the industry as well as in our every day's life. Often, we are using the products that chemists have created without even knowing about their background in chemical research. But what is modern chemical research all about? In the following we will define characteristics of contemporary research in chemistry, especially concerning the challenges they pose for chemical education and chemistry teachers.

2.1. Modern Research in Chemistry

Chemistry deals with objects we can´t see because atoms and molecules are too small for observing them. But the question how atoms and molecules interact with each other is important in chemistry as it explains reactions and the production or even the structure of new substances. There is not only one but several ways of producing chemical artefacts, so that chemical practices as well as theories of chemistry are complex. As the reactivity of substances as well as possible ways of producing a target molecule can at least partially be derived by the structures of the molecules, understanding the spatial structure of molecules has become more and more important. That is why chemists who want to find out how they could produce a special or new substance without side reactions and products, today often use computer simulations to predict the possibility of new synthetic reactions. So, in today's chemical research the experimental "trial and error" technique is often accompanied - if not substituted - by computer simulations for the visualization and prediction of properties and reactions of substances. [1] This can help to reduce the complexity of chemical processes and make it more descriptive, at the same time showing that the stereotype of the chemist just mixing substances in the lab is mostly outdated. But not only for synthesis, the spatial structure of a molecule is also important concerning the analysis of new chemical products. That is why the constitution of complex molecular structures are often simulated by a computer, resulting in a 3-dimensional model which may not misinterpreted as a picture of reality. For structural clarification, there are several methods like NMR-, IR-Spectroscopy, electron microscopy or mass spectrometry. [2] In order to be interpretable, the resulting data are mathematically converted into spectra that then can be used to understand the structure of a compound, which makes the analysis highly abstract, complex and mathematical.

So, summing up we can conclude, that - besides other aspects - modern chemistry in general is characterized by high abstraction, high complexity, a high grade of mathematization and an increased use of digital methods.

2.2. Chemical Research in Chemistry Education

In chemistry education (at least in Germany) modern chemical research doesn´t play an important role for preparing future chemistry teachers. This has several reasons.

A first reason for the absence of modern chemistry in chemistry education can be found in the curricula for teaching chemistry in school. The curricula in Germany seem to reflect the status of chemistry until the first fifty years of the last century with contents like the synthesis of nylon or the development of early transistors being the most modern aspects. [3] So chemistry education students as well as chemistry teachers don´t see a need to focus on more modern chemical contents.

The second reason is that a lot of chemistry education students don´t feel as a representative of their subject. [4] They think of themselves only as a teacher. This could be a consequence of an insufficient contact with modern chemical research during their studies at the university. If they don´t stay in contact with chemical research anyway it is hard to believe that this will be important for their future chemistry lessons as a teacher.

In contrast to that in the last years context orientated approaches (like "Salters Chemistry Project") [5] were increasingly promoted as modern aspects of chemistry that can be found in everyday's life. This can underline the relevance of modern chemistry and could go hand in hand for a better understanding of science in school. But in order to combine chemical knowledge and contents with pupils´ life and interests, teachers are in a need to know more than the history of chemistry, as understanding the chemistry around us today requires a deeper comprehension of modern chemical technology, procedures and productions. So, it could be stated that teachers´ professionalism demands a modern understanding of chemistry, its contents and methods, that seems not to be delivered by their actual teacher training.

Today's reality in school is, that pupils aren't "touched" by chemical contents and often don´t see relevance in chemistry. The reason is that the topics covered in chemistry lessons have nothing to do with their lives as modern applications like smartphones, laptops etc. cannot be explained with what they learn in their chemistry lessons currently. In addition to that, pupils tend to have a quite naïve view on what science is like and what scientists do which could be caused by the fact, that even their teachers didn't get a realistic inside into real research in chemistry during their studies. [6]

As chemistry teacher students have to teach chemistry for the next 30 or 40 years in their life's. There is the thread that chemistry lessons in school could become more and more antiquated if teachers don´t have a wider view of how modern chemistry works. It therefore seems to be highly desirable to close the gap between chemistry education and chemical research soon.

One important step in this direction surely is to make sure that future chemistry teachers have a more appropriate view on modern chemical research so that they are better trained for considering a modern view on chemistry and its applications in their chemistry lessons at school.

Thus, teachers and teacher students will be better prepared to explain occurrences which have a contiguity to chemistry - like nowadays the outbreak of Covid-19 - and to use them for their science teaching.

Which possibilities exist to integrate aspects of contemporary chemistry in studies of chemistry education to better prepare future chemistry teachers?

In which way could it be possible to give them a realistic view of the complexity, the abstractness, the mathematical aspects and the use of digital methods and at the same time offering them a method that helps them to understand the complex issues of research and - even more - enables them to deliver them in the classrooms in a motivating, inspiring and modern way?

The VR technology could provide a solution for these challenges.

3. VR-Technology as Approach to Learn Chemistry

3.1. The Meaning of Models in Chemistry

The opportunities of the VR technology are already being used in chemical research: researchers visualize molecules in the VR space in order to understand their behavior, their structural situation, their reactivity or possible ways of synthesis. [7] It therefore seems feasible to use the VR technology within chemistry education as well: it offers the possibility to visualize complicated spatial settings, by this it reduces the complexity of the real system as well as the abstractness often perceived by students when dealing with models to understand the sub-micro world. It literally makes the invisible visible. It therefore stands in the tradition of chemistry teaching where new teaching and learning materials are constantly being developed for conveying knowledge and ideas in chemistry. In the field of such materials, which reduce the abstractness of the contents and help to visualize the spatiality of chemical objects, thus making them easier to grasp, perspective images in books or, more recently, in digital form are particularly frequently used. With them, it is possible to rotate and view the object from different angles, but these representations do not possess an experience able three-dimensionality. A more "real" spatiality, on the other hand, is provided by physical models such as molecule construction kits or stereo images. While the latter are repeatedly discussed in the chemistry education community as a possibility of "real" three-dimensional perception [8], their main shortcoming remains that the object itself cannot be manipulated during observation but is static. This is different with physical models, they can be rotated and turned by the learner, but often at the price that these models have very restrictive construction conditions (i.e. the correct information about the structure is usually already stored in the model) and that these models for stability reasons often contain physical objects without chemical meaning, which can be misinterpreted by the learner. The chances and limits of all these models are an area much researched and discussed in chemical education, whereby all these models have one thing in common, namely the limited possibility of interaction between learner and object, the "viewing distance" between them, the missing possibility of being able to "put oneself inside" the objects. On the one hand, such a "putting oneself in the place" would offer opportunities for understanding, for example a learner could estimate binding angles on an atom by taking its place, and on the other hand it would also open up an additional affective channel of experiencing and understanding the spatiality of chemical objects and their effects. By using VR technology this “direct interaction” between learner and chemical object as well as establishing a special affective channel could be realized: In a VR-environment the chemical objects could not only be visualized in 3D but the learner could interact with them and “touch” atoms, molecules and reactions being on the same scale with them. As VR experiences address several senses at the same time, being really holistic, the learner can completely focus on the VR environment and its chemical content, which could result in the desired affective relationship between learner and object as well as good learning outcomes. Finally, as students and pupils tend to know and use VR technology within computer games, using VR for teaching chemistry could pave the way to more game-based teaching approaches, using aesthetics that are known from non-educational settings.

3.2. Using VR-Technology in Education

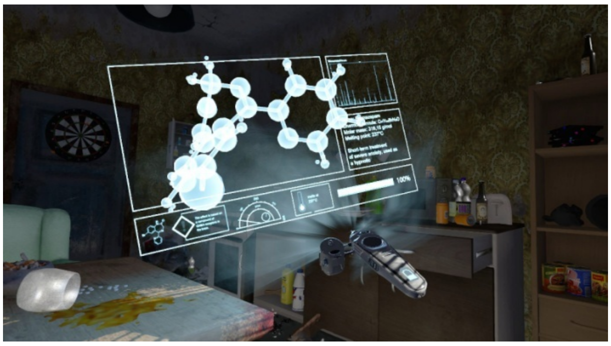
First experiences with using VR-technology for educational purposes show that this approach seems to have a positive influence on students understanding of chemistry. [9] Other studies focusing on learning with digital technology like Bamford [10] report the effects of using technical equipment that is not quite high specialized as a VR-equipment is. In these studies, simple 3D-glasses are used as instrument for several digital learning environments. These media don´t seem to have the advantages a VR-equipment with VR-glasses has. The potential of the interaction between learner and learning object seems to be smaller in the augmented reality of these studies as it would be the case in a VR-environment. Even the possibility to disregard the real world and focus only on the learning environment is bigger in a VR-environments as they are in augmented reality. Nevertheless, those studies show high motivation and positive learning effects of the students by participating in modern teaching concepts with digital media. Therefore, it seems reasonable to expect even better results using VR technology.

4. First Project: “Dead Herring”

The problem with learning chemistry in a VR-environment is that there are rarely programs or learning environments available which for example give students a feeling of acting as a ‘real’ chemist. Although the advantages of VR give reason to hope for positive learning effects. So, the first step for using VR for learning chemistry was to create a VR-learning environment which give chemistry education students the opportunity to act and feel as a scientist.

4.1. Creating a VR-learning Environment

We created a VR-learning environment which should help to experience modern chemistry by using the advantages of VR, especially incorporating a game-based approach by developing a VR-game called “Dead Herring”.



Picture 1. The analyzer shows the hint of a molecular structure

The aim of the game, that has been developed by future chemistry teacher students in cooperation with the School of Arts of the University of Kassel, and which features a modern aesthetics, is to solve a murder case. The learner or player takes the role of a forensic scientist with modern forensic equipment. He must find important evidence at the VR-scene and combine the hints given, of which most have a meaning on the macroscopic level (e.g. there are pills) and the sub-micro level (e.g. the chemical composition of the pills).

By that the VR-environment enables the learner to easily switch the levels of observation important when dealing with chemical topics and for solving the case a proper combination of the hints on both levels is crucial.

The player can move free in the VR-environment, which shows a kitchen and gives enough space for getting an insight in the life of the victim. The dead person in the kitchen is Benjamin Herring, who obviously had a seedy life. The kitchen is dirty and damaged. You can see broken glass, white powders, bloodstains and bloody food prints beside the corpse. In total 11 hints can be found in this environment of which some only reveal their meaning when analyzed on a sub-micro level. Therefore, the player can use an analyzer that gives the information that cannot be seen. To analyze and get information to some of the hints the player has to look up on the microscopic level. If the player needs assistance a person called Mrs. Rothenstein appears in a hologram and tries to help the player. It takes about one hour to find and combine all 11 hints. [11]

Picture 2. Analyzing the blood trail of the victim

The game has a dense atmosphere which tries to give the player the feeling of a crime scene and matches the aesthetics of modern computer games.

4.2. The Structure of the Course

With the game Dead Herring a digital learning environment has been created that deals with modern chemistry in explicit as well as implicit ways. It was designed to use the advantages of VR to help chemistry teacher students to learn about chemistry and to prepare them to teach contemporary chemistry in a modern way.

The university seminar in which this game is embedded focusses on experienced chemistry teacher students and is conceptualized by considering contemporary chemistry, a realistic view on the use of digital methods in chemical research, as well as the potential of using digital methods like VR for teaching chemistry.

The structure of the course is as follows:

At first students are invited to share their view or preconception of modern chemical research. After that the students prepare themselves for the learning environment Dead Herring by naming their expectations for being, working and feeling as a modern researcher - in our case a forensic scientist. In this stage they also reflect and discuss possible ways of thinking as a modern scientist.

Prepared in such a way, the students pass through the game "Dead Herring" individually, considering the following questions: What is my methodological approach when "being" a forensic scientist? What do I learn about chemistry? How does it feel to be in a VR environment?

After passing through the game the individual answers to those questions are discussed and each student reflects the answers considering his first view on what he thought modern research in chemistry is all about.

In the following second part of the course each student develops teaching material for chemistry lessons in school. This material contains, depending of the focus the students chooses, aspects of contemporary chemistry or modern digital methods like VR. The student is free to develop creative, innovative and interesting material. The teaching materials are then discussed with the whole group of students, so that everyone gets a feedback on his work.

Summing up, students in this course are challenged in many ways considering several aspects of the work of future teachers: learning about and integrating modern digital methods, learning aspects of how modern chemistry "works" and applying them into teaching material conceptualized for learners in school. At least the students are encouraged to give a feedback to the game "Dead Herring". This is important for remastering the game and makes it better for using it in future classes at university.

4.3. Learning Opportunities for Chemistry Education Students

Besides the aspect of bringing the students in contact with topics and methods of modern chemical research, the course gives the opportunity to experience typical tasks of a teacher in several ways.

First, chemistry education students have to choose aspects of modern chemical topics and methods they experienced, which they think are teachable in school. They even have to decide how they realize these aspects. In most cases, they will have to reduce some of the chemical contents [12] to make them understandable in chemistry lessons at school. The addressed activities of analyzing, selecting and reducing topics [13] as well as choosing a method to teach them are main responsibilities of teachers in school.

Second, teachers and future teachers are challenged to utilize more modern digital equipment in their chemistry lessons. To enable them to do so, they technically have to know how to use these methods, but it seems equally important that they know when and why such methods are useful. The VR-environment and the above-mentioned course may serve as an approach to confront students with those questions and provide first answers. In addition to that, they directly see, experience and train a modern digital method.

Third, this approach is a first step for students, teachers and researchers into the field of VR-game-based learning in chemistry.

In terms of teacher's professionalism, the seminar focusses on three knowledge types: Content Knowledge, Pedagogical Content Knowledge [14] and Technical Pedagogical Content Knowledge [15].

As far as Content Knowledge is concerned, it's one of the prerequisites for teaching. Literature shows, that the higher the content knowledge of a teacher is, the higher the teaching-skills are. [16] In the course described here, Content Knowledge is addressed by getting in touch with modern chemical contents and the experience of “being a scientist”. An improvement of the students’ Content Knowledge concerning modern chemical topics could (1) help to better prepare them to teach chemistry for the next decades and (2) help to make them feel more as a representative of their subject. It is known that the latter can be an advantage for teaching chemistry at school.

The Pedagogical Content Knowledge can be described as a special form of knowledge in which the Content Knowledge is somewhat “transformed” with a view to teaching chemistry. The Pedagogical Content Knowledge of the students is addressed by the necessity to analyze, select and reduce contemporary chemical topics as well as choosing a method to teach them.

The Technical Pedagogical Content Knowledge “requires an understanding of the representation of concepts using technologies; pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of the problems that students face; knowledge of students’ prior knowledge and theories of epistemology; and knowledge of how technologies can be used to build on existing knowledge and to develop new epistemologies or strengthen old ones.” [17] By experiencing the VR-game and applying this technique in the students´ teaching material students of chemistry education are explicitly and implicitly supported in this important field of teachers’ professionalism.

The potential of the designed course with regard to developing teachers’ digital competencies can be described even more precisely by using the framework for digital competencies of teachers (DigComEdu) [18] as reference. Based on DigComEdu, the following digital competencies are addressed by our approach:

Creation and adaptation of digital resources means modifying and further developing existing digital resources and taking into account learning objectives, context or didactic approach when adapting digital resources. [18] By their reflection and feedback on the VR-environment, students help to improve and further develop the VR-environment. In order to use (parts of) it in their teaching material they furthermore have to adapt it, its methodology and/or its content to their teaching objective.

Teaching includes planning and designing the use of digital devices and materials in class, as well as embedding, organizing and designing digital teaching methods appropriately. [18] By developing accompanying material in which a digital method is embedded, students plan and design fictitious partial concepts for chemistry lessons, so that this aspect is also addressed in our teaching approach.

Finally, the competence of *active involvement of the learners* promotes the active and creative engagement with a chemical topic. [18] By experiencing the manipulable and interactive virtual world of Dead Herring, students can become active themselves and understand, in which way pupils at school can be cognitively and affectively activated by VR learning environments. In this way, they experience the use of VR as a way of making their teaching in the future more open to virtual reality and/or digital methods in general and are sensitized for the potential of creating learning arrangements that allow an affective approach.

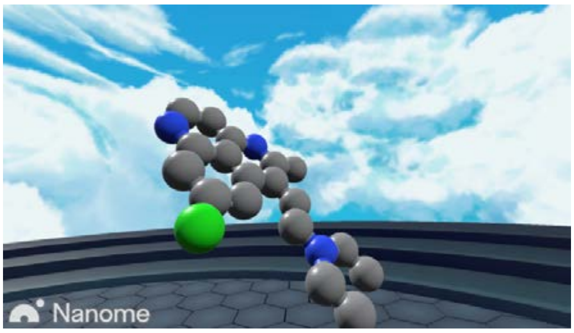
Due to arrangement of the course, future teachers can, according to the demands of the situated learning theory [19] take multiple perspectives by experiencing and reflecting the seminar contents professionally, didactically and under consideration of a modern digital medium. They experience authentic learning opportunities in the development of teaching material, in a modern research content and in the integration and use of a digital medium in teaching. This course concept is therefore designed to help future teachers familiarize themselves with the possibilities digital media offer for teaching modern chemical contents at an early stage, thus providing them with ideas for a future-oriented chemistry class.

5. Second Project: Virus Experiences for Chemistry Education

The second project is a result of the pandemic situation with COVID-19. VR-technology could help students to understand the structure and biochemical functionality of the corona-virus by establishing a “contact” between the object (Corona-Virus) and the students. Therefore, this approach can serve as an example of how contemporary topics can be taught by using modern digital media and can be used to address and foster the chemical content knowledge as well as the digital competencies of the students. Within our learning environment, students can practice how they could include this modern aspect of chemistry and research in school lessons by using digital media.

5.1. Description of the Learning Environment

After a short introduction, the students´ task is to come up with information about SARS-CoV-2. Therefore, they do some research on their own. Additionally, every student uses the VR-software nanome [20] to 1. experience the submicroscopic level, 2. collect information about the biochemical structure of SARS-viruses and 3. get used to the VR technology.



Picture 3. Structure of chloroquine

Nanome is a VR-Software which was created for scientists. A user can design and manipulate molecules at the nanoscale level and thereby learn about structures and properties. Nanome offers a platform where interaction with objects on the molecular level as well as communication with other scientists around the world is possible. The software allows the collection of information on the submicroscopic level, like bond lengths, bond angles, functional groups or even a walk through the molecule by watching every single atom.

Beside nanome itself, a collection of links and video-materials like “COVID19 in VR” [21] is offered to the students, where researchers in Australia and the United States communicate via nanome, contributing to the structural clarification of SARS-CoV-2. Students experience not only by using nanome themselves, but by watching the work of scientists what contemporary research could be all about.

Picture 4. Part of a protein structure of Sars-CoV-2

As a first step towards designing learning material, the students are asked to clarify the pure chemical content of the topic. Therefore, the students use all the information and experiences they collected for writing a scientific abstract about chemical aspects of the corona-virus as a first task in the university course. They consider aspects like protein chemistry, lipids or methods of structural clarification. The students get a feedback for their abstract in order to provide a solid content basis for the next steps.

The second task for the students is to develop ideas for using chemical contents of the coronavirus for chemistry lessons in schools. The students should reinforce their ideas by considering theories and empirical results on chemistry education. For the second abstract students get a feedback of their ideas and some support on how they could address chemical contents of corona in an interesting, precise and accessible way.

In their third abstract students should include digital media which would help pupils in chemistry lessons to understand structural aspects and chemical contents of the corona-virus with special attention to the VR-technology. For example they can work out ways to include the software nanome in their chemistry lessons and underpin their decision. They describe how and why the VR-technology could be used in chemistry lessons for allowing pupils an individual way of learning.

At the end of the seminar students present the whole learning environment they developed on using corona as a topic in chemistry lessons in a virtual presentation.

5.2. Learning Opportunities

By considering the different types of teachers’ professionalism mentioned above, the seminar focusses on an improvement of future chemistry teachers’ content knowledge, pedagogical content knowledge [14] and technical pedagogical content knowledge [15]. In this course students use professional software for scientists as starting point and transfer the knowledge they collected in approaches to learn about contemporary topics.

Content knowledge is promoted by collecting and acquiring information about the corona virus and research about it. Pedagogical Content Knowledge is promoted by developing ideas for learning about the chemical contents of this topic. At least the technical pedagogical knowledge should be improved by using the VR-technology and by supporting the ideas of learning about the corona-virus by modern digital media.

Concerning the DigCompEdu [18] the following competencies of the students are addressed:

1) Future chemistry teachers should be able to *select digital resources*. They identify digital resources for teaching and learning and are challenged by considering contemporary chemical topics of corona-viruses. For planning the use of digital media, they must bring together these contents with the possible use of media.

2) Future chemistry teachers should *learn* how digital media are used in chemistry lessons. So, they have to organize and create new ways of including digital media and methods in their teaching of special, modern topics.

3) Future teachers should *facilitate the digital competencies* of learners. They use their digital competencies and their chemical knowledge for separating fake news from other “news” their pupils might come up with. This should enable and encourage learners for a critical analysis and interpretation of information.

6. Experiences and Conclusion

Today’s chemistry teaching in schools does neither reflect the topics nor the methods of contemporary chemical research. Characteristics of modern chemistry like abstractness, complexity, mathematization and the use of digital methods aren’t part of the chemistry curricula no more than being addressed in chemistry teacher education.

Therefore, the virtual reality game “Dead Herring” was designed and is now used embedded in a course on chemistry education. In this VR-environment chemistry teacher students are challenged to act as a forensic scientist and to use modern chemical methods to solve a murder case. This ludic approach prepares the students for using digital methods and gets them in contact with contemporary chemical topics and research methods and integrates all these aspects in the development of teaching material for chemistry lessons at school.

By this, students are motivated to experiment with alternative approaches for teaching chemistry, which focus on modern chemical contents that are not exactly part of the curricula. Furthermore, the contact with and the experience of the VR-environment helps to promote the students’ digital competencies and to show them the potential of learning environments that allow a more affective and not only a cognitive approach.

The second approach of teaching modern scientific topics via VR-technology focuses on the contemporary situation of COVID-19 and the respective research about the virus. The structure and contents of the seminar allow students to develop own and creative ideas for an up-to-date topic and promote their knowledge by including digital media.

Due to a small number of chemistry education students on the one hand and restrictions due to the corona-pandemix on the other hand, there is no quantitative, statistically valid data available so far. Interviews with students involved in these two projects nevertheless showed, that students

- feel highly motivated by the learning environments,
- report a high gain of content knowledge,
- felt the task to converge digital media and contemporary chemistry in a learning environment to be as challenging as helpful for their future job,
- state the opinion that the VR-technology is of big help when dealing with highly abstract submicroscopic aspects.

7. Outlook

The mixture of contemporary chemistry and virtual reality has several advantages for students studying chemistry education at university. More VR-Learning environments should be developed to give students (and even pupils at schools) the possibility to learn about chemistry specially on the submicrolevel. Therefore, we will focus on other chemical topics, try to develop VR-environments or even include existing software into special learning situations to improve several competencies of chemistry education students and encourage our colleagues to do so, too. These approaches should also be a contribution for a modern chemistry teaching at school in the future.

References

[1] Hoffman, R. (2006). Elemente der Syntheseplanung. München. Elsevier

[2] Skoog, D., Holler, F., Crouch, S. (2013). Instrumentelle Analytik: Grundlagen - Geräte - Anwendungen. Berlin: Springer Spektrum.

[3] Hessisches Kultusministerium (2016). Kerncurriculum gymnasiale Oberstufe Chemie. Source: https://kultusministerium.hessen.de/sites/default/files/media/kcgo-ch.pdf download: 25.02.2019

[4] Schumacher, A. (2015). Paving the way towards “authentic chemistry teaching”: a contribution to teachers´professional development. Berlin: Logos Verlag.

[5] Bennet, J., Lubben, F. (2006). Context-based Chemistry: The Salters approach. In: International Journal of Science Education, 28 (9), 999-1015.

[6] Frevert, M. & Di Fuccia, D.S. (2017). Contemporary Science in Chemistry Education in Germany. In: The Clute Institute (Hrsg.), *International Science Education Conference Proceedings* (S. 147-1-147-10). Littleton: Clute.

[7] The Royal Society of Chemistry (2017). Chemistry to go boldly into virtual world. *https://www.chemistryworld.com/news/virtually-chemistry/3008119.article* (03.03.2018).

[8] Worsch, D., Weißbarth, K.-H., Aigner, A., Franke, J., Vögtle, F. (1986). Stereochemie in Stereobildern: Von Ringen zu Hohlräumen. *ChiuZ*, 20(1), 11-18.

[9] Smaldone, R. A. (2017): Teaching science through video games, Nature Chemistry, 9, 97-102.

[10] Bamford, A. (2011). LiFE: Learning in Future Education. Evaluation of innovation in learning using emerging technologies. *https://www.gaia3d.co.uk/wp-content/uploads/2012/11/Evaluation-of-Innovation-in-Learning-using-emerging-technologies-by-Prof-Anne-Bamford-2011.pdf* (08.01.2018)

[11] Frevert, M., Stein-Schomburg, D., Di Fuccia, D.-S. (2018). Virtual Reality in Chemistry Education and Research. Posterpresentation on 49th Australasian Science Education Research Association Conference (ASERA).

[12] Klafki, W. (1974). Didaktische Analyse als Kern der Unterrichtsvorbereitung. In Roth, Blumenthal (Ed.) Didaktische Analyse (pp. 5-34). Hannover: Schroedel.

[13] Reiners, C. 2017. Chemie vermitteln. Berlin. Springer Verlag.

[14] Shulman, L. S. (1986). Those who understand knowledge growth in teaching. Educational Researcher. Retrieved February 05, 2009 from http://er.aera.net.

[15] Mishra, P., Koehler, M. J. (2006). Technological Pedagogical Content Knowledge: A Framework for Teacher Knowledge. *Teachers College Record Volume* 108(6), 1017-1054.

[16] Friedrichsen P. J. et al. (2009). Does Teaching Experience Matter? Examining Biology Teachers´ Prior Knowledge for Teaching in an Alternative Certification Program, Journal of Research in Science Teaching, 46 (4/2009), 357-383.

[17] Mishra, P., Koehler, M. J. (2006). Technological Pedagogical Content Knowledge: A Framework for Teacher Knowledge. *Teachers College Record Volume* 108(6), 1017-1054.

[18] European Commission. 2018. Digitale Kompetenz Lehrender. https://ec.europa.eu/jrc/sites/jrcsh/files/digcompedu_leaflet_de-2018-09-21pdf.pdf. Download: 17.12.2018

[19] Mandl, H., Gruber, H., Renkl, A. (2002). Situiertes Lernen in multimedialen Lernumgebungen. In L. Issing P. Klisma (Hrsg.), *Information und Lernen mit Multimedia und Internet.* (139-148). Weinheim: Psychologie Verlags Union.

[20] https://nanome.ai/about/

[21] https://www.youtube.com/watch?v=2A4dAUYOpsI&feature=youtu.be.