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Peer-reviewed author version

BRASSINNE, Kristien; REYNDERS, Monique; CONINX, Karin & GUEDENS, Wanda (2020) Developing and Implementing GAPc, a Gamification Project in Chemistry, toward a Remote Active Student-Centered Chemistry Course Bridging the Gap between Precollege and Undergraduate Education. In: JOURNAL OF CHEMICAL EDUCATION, 97(8), p. 2147-2152.

DOI: 10.1021/acs.jchemed.9b00986
Handle: http://hdl.handle.net/1942/31303

Developing and Implementing GAP*c*, a GAmification Project in Chemistry, towards a Remote Active Student-Centered Chemistry course bridging the gap between precollege and undergraduate education

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ABSTRACT

This paper describes the development and implementation of GAP**c**, a Gamification Project in **c**hemistry. GAP**c** is an online active student-centered remedial teaching tool allowing prospective and enrolled students to electronically assess their knowledge of basic and advanced chemistry concepts via different game levels of expertise. This provides them with ways to correct potential shortcomings in view of an academic education. A large number of exercises with different degrees of difficulty, links to additional sources of information, automated feedback and the integrated grading center are key features of GAP**c**. Notwithstanding GAP**c** is conceived as a distance learning and self-learning tool, it works equally well in a classroom setting. Indeed, GAP**c** was initially meant as a trajectory for precollege students to remediate their acquainted knowledge of chemistry by an easy remote access. Today, on Hasselt University Campus, GAP**c** is used in the chemistry summer school for senior high school students, and in chemistry courses for freshmen and sophomores enrolled in curricula with a major chemistry component.

GRAPHICAL ABSTRACT

KEYWORDS

High School / Introductory Chemistry - First-Year Undergraduate / General - Inorganic Chemistry - Public Understanding / Outreach - Computer-Based Learning - Distance Learning / Self Instruction - Testing / Assessment - Aqueous Solution Chemistry - Acids / Bases - Electrochemistry

INTRODUCTION

The educational concept of Hasselt University is hallmarked by the key premise 'from guided self-study to autonomous learning'. A digital learning environment can be one of many suitable tools to increase student-centered self-learning processes by progressively decreasing teacher-centered learning.[1-4] Lecturers become coaches, and students have to take ownership of their studies. The presented GAmification Project in **c**hemistry, GAP**c**, developed by the chemistry department, is a proof-of-concept realization of such a learning environment offering students the opportunity to improve their skills and knowledge of basic concepts in general chemistry. The GAP**c** platform provides easy remote access to teaching material for a diverse audience in an entertaining but still scientific way. Immediate feedback on students' progress and recognition of completed tasks motivates, encourages and supports students in their learning process. The remedial teaching component of GAP**c** includes numerous exercises of different type with relevant feedback and links to additional sources of information. It is designed to detect and remedy knowledge gaps of basic and advanced general chemistry concepts among senior high school students, freshmen and sophomores at Hasselt University.

For chemistry students, an important aspect to consider is the variation in the individual student's processing time from learning basic chemistry concepts to mastering more challenging chemistry

problems. Stimulating learning environments with a strong emphasis on differentiated education methods and remote learning play a crucial role in this context. Indeed, these environments guarantee that the student is attributed the necessary time to learn autonomously within a flexible time frame.

This article first describes shortly the e-learning concepts of GAP**c**. The subsequent section introduces the reader to the virtual world and user experience. The results section offers feedback and insights from various user groups. Finally, some preliminary conclusions and suggestions for further development are presented.

The development of information and communication technologies have influenced the way students learn, as well as where they learn. Technological innovations enabled the creation of virtual environments for teaching chemistry.[5-11] GAP**c** is such a virtual environment, specifically aimed at teaching basic chemistry. GAP**c** is an electronic, location-independent (e-)learning and (e-)remediation platform that is available 24 hours a day, 7 days a week. Users benefit from the flexibility of e-learning, as the resources are available from anywhere and at any time. The system offers various resources: a glossary, a library and hundreds of exercises with instant assessment and corrections. From the start, GAP**c** has been designed to offer challenges that are adapted to the player's level of expertise.

Gamification is seen as a valuable tool to resolve some of the negative behaviors associated with learners in general and with the millennial generation in particular.[12-16] Multiple game design elements are implemented in GAP**c**: levels, achievements, badges and experience points. Every player starts at the first level. Each correct answer to an exercise will be rewarded with experience points. Achievements and badges are added as motivating elements. Students are awarded for completing the course, mastering a skill or gaining a level of experience. In the literature, several works report the use of games on specific topics as reinforcement in the chemistry classroom[17-29]. In contrast to most of the reported games, GAP**c** provides training materials on the full learning content of a chemistry curriculum at upper secondary education level in Flanders. The digital library within GAP**c** refers to supplementary supporting material, such as virtual labs[30-33], board games[34-36], card games[3è-39], etc. This material can be consulted for additional practice or gaining more in-depth insights in specific topics.

For chemistry students, GAP**c** adds an active student-oriented component to traditional class-room courses by offering students the opportunity to improve and deepen their understanding of general

chemistry concepts in an open virtual world where the pace, time and level of proficiency can be adapted by the student, thus empowering him to personalize his own learning path to gain exactly what he needs. By blending lectures, refresher sessions, practical hands-on training during laboratory assignments and e-learning, the different learning styles of students are taken into consideration[40-42]. University and secondary school students can make use of GAP**c** outside course schedule, but the academic staff and teachers can apply GAP**c** during course schedule as well. As Phipps too experiences[11], it is becoming increasingly important to adapt our traditional pedagogies to engage every student, whether it's about an introductory chemistry course or a remedial teaching course.

METHOD

User Requirements

At the start of the GAP**c** -project a number of requirements for the electronic platform were listed:

- Users should have free access to the online platform.
- The registration and sign in should be straightforward.
- The platform should provide support for creating, distributing, editing and managing courses from start to finish, regardless the type of content.
- The course creation tool should be easy to use.
- The platform should offer assessment tools like online quizzes and tests to help students pinpoint areas of improvement.
- The system should provide instant feedback to help students better understand their current assignments.
- Both students and teachers should be able to visualise progress.
- A grade book offers students at a glance an overview of their performances.

Platform

GAP**c** is built in OpenEducation powered by Blackboard. OpenEducation meets most of the requirements stated above. It offers the possibility to enroll an unlimited number of users, the use of different types of questions, includes a grading system, and ease use for organising a course with a multitude of pre-defined course structures. Blackboard also provides a range of additional resources: a glossary, a library, achievements, badges, etc. The GAP**c** homepage and the digital library are built in Google Sites.

Users can enroll in the course in two ways. Either he asks for a userID via the registration page on the GAP**c** homepage. Either he enrolls directly via the Openeducation-website after selecting the GAP**c**-course.

Course content

GAP**c** fully covers the contents of a chemistry curriculum at upper secondary education level in Flanders. The learning material is organized in nine chapters, with each chapter being divided in sections. The virtual world of Hasselt University is an 'open world': a GAP**c** player can roam freely without having to follow a specific path, and has the freedom to target various topics of his choice. This open character was deemed very important since the GAP**c** platform essentially aims at strengthening students' insights in chemistry concepts and offering remediation where needed. After the login users start on the welcome page, where a short introduction on the aim of the tool, some explanations about the virtual world, different levels of difficulty, etc. is presented. After selecting 'The virtual world of Hasselt University' in the menu, a map with several building (i.e. chapters) is shown.

In each chapter and section, the user can solve exercises with different degrees of difficulty: starter, advanced and expert. A correct answer is rewarded with experience points. An incorrect answer is followed by instantaneous feedback in various forms. Sometimes the fully detailed solution of the exercise is shown, another time, the student will be offered a step-by-step plan to solve the problem, or reference is made to the digital library in GAP**c**, where more information on that specific topic can be found. By varying the type of the feedback, the teacher-centered learning will decrease, while student-centered self-learning will progressively increase.

Navigating the Virtual world

In the virtual world of Hasselt University (see Figure 1), a GAP**c** player can explore eleven locations, buildings of Hasselt University and near-by public spaces. These locations correspond to the nine chapters in a typical general chemistry course, the library and a leisure area.

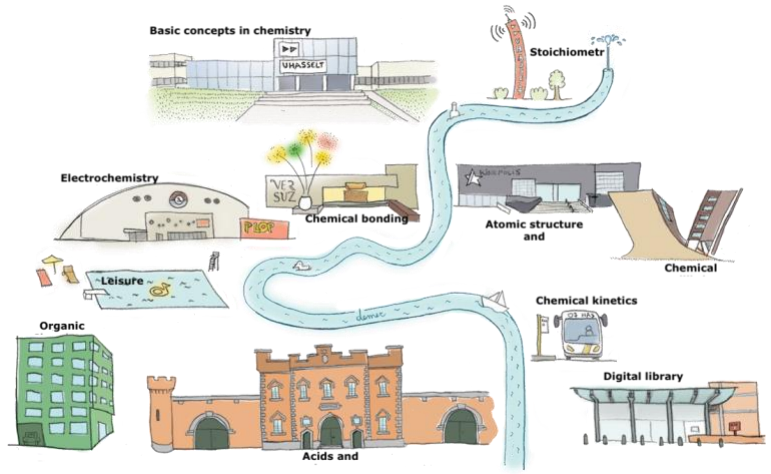
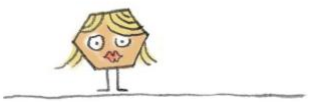
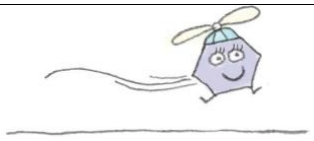
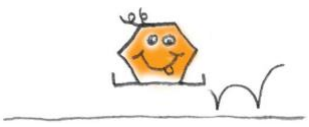


Figure 1: Map of the virtual Hasselt University world

After selecting a specific chapter on the map, a more detailed view of the building is shown, populated by hexagonal creatures (see Figure 2). These little characters represent the different topics that are covered in that specific chapter (see Figure 3).

Figure 2: Details of the chapter about acids and bases.

	Brønsted-Lowry theory of acids and bases		Acid-base indicators
	Self-ionisation of water		Calculation of pH and pOH

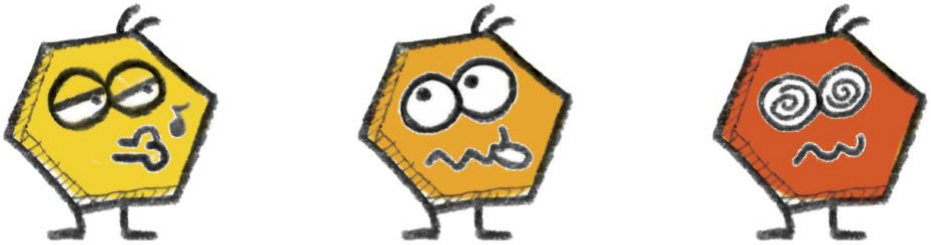
	Acid-base reactions in aqueous solution		Acid-base properties of salts
	Acid and base strength		Buffer solutions
	Relation between pH, pOH and Kw		Neutralisation reactions and Titration Curves

Figure 3 The topics of the chapter Acids and Bases

Clicking on a character provides access to exercises for that particular topic. The online platform automatically saves the answers, and after completing, the test can be submitted.

For each topic in a chapter several types of exercises are provided. We relied on the taxonomy of Romiszowski[43, 44] to vary the assignments to ensure that the user will have to apply things learned in different situations. Most taxonomies, such as Bloom[45] and De Block[46], but also for example the motoric taxonomy of Brion[47] and the affective taxonomy of Krathwohl[48], focuses on one skill domain: cognitive, psychomotor or affective. Romiszowski has, however, developed a taxonomy in which skills from each of these three domains can be placed on a reproductive and productive level. In addition, he has included a fourth domain, namely that of the interactive/social skills.

Inside the topic the GAP**c** user can choose exercises of various degrees of difficulty. Exercises for starters are depicted by a whistling character. More difficult exercises for the advanced users are represented by an attentive character. And finally, exercises for the expert users are linked with a pondering character (see Figure 4).



Starter level Advanced level Expert level

Figure 4: Symbols for various degrees of difficulty

The degree of difficulty of an exercise is assessed from our experience in teaching chemistry in various settings: secondary school classes, undergraduate programs at the university, exam committees… The time required to solve the exercise is also considered: the more effort and time it takes to find or calculate the answer, the more experience points are awarded. For GAP**c** we built tests per topic, chapter and level of difficulty. There are also tests of different degrees of difficulty for an entire chapter.

Ranking and badges

Being rewarded is a powerful extrinsic motivator. In gamified courses, badges and rankings are used to encourage behavior, recognize accomplishment and establish credibility. Badges are visual awards for the students, an online representation of a skill or achievement a student has earned (see Figure 5). The GAP**c** badge collection represents key learning milestones. In GAP**c** badges are earned by scoring 80% on a starter level test, 70% on a test for advanced users and 60% on a test for experts. Students are encouraged to collect all badges, but this is not required to be able to continue the game.

Figure 5: Badges for achieving a basic, advanced, resp. expert level test.

We intentionally chose to implement character ranking instead of experience levels. The ranking reflects the skill level of the user, but regardless the ranking, a player always has an unrestricted choice in the degree of difficulty of the exercises.

Eight echelons are incorporated in the remedial teaching course. Every player starts at the base level, called “pupil”. Each correct answer to a problem is rewarded experience points, the higher the complexity of the exercise, the higher the amount of experience points that can be gained. A proficient user can consecutively become a bachelor (undergraduate) student, a master (postgraduate) student,

and hold a PhD in science. At that point in the game the player chooses between an academic career or a career in the industry. The ultimate goal is to reach the highest level in the academic or industrial world. Table 1 describes the game ranks and the number of experience points one has to obtain to attain a higher level.

Table 1. Game ranks and experience points (XP)

Rank	+ XP	*Total XP*
Pupil	200	200
Bachelor student	200	400
Master student	400	800
Doctor in science	400	1200
Assistant Professor/Junior manager	400	1600
Associate Professor/Senior manager	400	2000
Professor/Top director	500	2500
Full Professor/Consultant	500	3000

RESULTS AND DISCUSSION

The GAP**c** platform was designed and developed in an iterative manner: prototypes were developed, evaluated by a test audience, and their feedback was taken into consideration for subsequent versions of the tool. In order to determine the added value of GAP**c** for different target user groups, and to collect a diversity of feedback on the gamification aspects, distinct stakeholder groups were involved in consecutive evaluation stages:

- In the first semester of the academic year 2017-2018 all first bachelor biology students were invited to participate in the test of the first GAP**c** prototype. Only six students participated effectively.
- A focus group consisting of 27 teachers of higher secondary education tested an improved version of the tool at the Congress of the Flemish Association of Science Teachers in November 2017.
- GAP**c** has been presented as case study at the 2018 Blackboard Teaching and Learning Conference, where the audience, consisting chiefly of 34 people with an IT background, was invited to comment on the tool.
- Finally, the first production-ready version of the chemistry remedial teaching course was integrated into the summer school for chemistry. Since the introduction of this course in 2018, 61 freshmen participated in this summer course.

The concept, the structure and the content of GAP**c** were reviewed and extensively discussed within each user group. Their experiences, considerations, frustrations and suggestions for improvement were recorded and analyzed.

The experiences and considerations of all stakeholder groups, except the technical audience, are summarized below in the topics “concepts”, “structure” and “content”. A full review of the questions concerning the various topics is given in the supplementary material.

The concept of GAPc

Most students (87%) would use the online remedial teaching course during their studies, to certain aspects of chemistry, as a means of remedial action or for self-assessments. They were positive about the degree of autonomy that the tool offered. They appreciate the possibility to work at their own pace and to determine the level of difficulty of the exercises themselves. They valued this step towards autonomous learning. Almost one third of the students (28%) missed fully developed solutions for the exercises in the feedback. They would feel more comfortable if they had direct access to the complete solutions. No student did consider GAP**c** to be a real game. If one has to practice anyway, the game design elements would make practicing more fun. The majority of the teachers (72%) did not consider the game design elements to be important.

The structure of GAPc

The full audience was delighted to discover the design of the virtual Hasselt University scenery with its humorous characters. They found it a great advantage that they could freely choose which chapter they practice at any time. Exercises with an equal degree of difficulty were not always perceived equally challenging, sometimes simply because one form of question is harder to answer than the other. The audience was very positive about the ability to choose the degree of difficulty of the exercises for each individual topic. 72 percent of the adults valued the ranking, the achievements and the badges as superfluous. This point of view is in high contrast to the views of the students. More than 80 percent of them felt motivated by their level, the achievements and the badges. There is clearly a discrepancy in students' and teachers' expectations of GAP**c**. Students want to catch up in an entertaining way with as little effort as possible. Teachers are mainly interested in the ability to differentiate and in the remedial student learning. They also appreciate the supply of lots of new

questions with feedback which they can use in their classroom. GAP**c** will not only bridge the gap between secondary education and higher education, GAP**c** apparently might also close the gap between pupils and teachers.

The content of GAPc

More than 90% of the stakeholders were excited about the full coverage of the remedial teaching course: a single registration for a single remediation tool, covering all global chemistry topics, a wide variety of types of questions, including many exercises at three difficulty levels, and on top of that instant feedback to help you when you don't find the correct answer.

Feedback on GAPc during the 2018 Blackboard Teaching and Learning Conference

According to the technical audience the game design elements currently available in OpenEducation and Blackboard were deployed efficiently, while the effort to write new application code was minimized. They considered that the strength of the platform was put to good use.

CONCLUSION AND FUTURE PERSPECTIVES

The active student-centered remedial chemistry teaching tool GAP**c** is developed to improve and facilitate the transition from secondary education to higher education, by including game design elements in the online course. The tool was iteratively presented to several test groups during and after its development. Overall, GAP**c** was positively received by the diverse test audience. Its major strengths are the adaptable use of the online platform, the possibility of personalizing your own learning path in an open world model, the mix of exercises of different degree of difficulty and the complete coverage of the contents of a chemistry curriculum at upper secondary education level in Flanders.

OpenEducation was chosen as environment for GAP**c** because it provides a stable platform with integrated tools for course development, assessment tools that offer the possibility to integrate feedback, a grading center and reporting tools. However, OpenEducation does not provide support for game-play scenarios or other game design elements. For this project, we feel the benefits of the platform far outnumber its shortcomings.

The actual game-play offered by the remediation tool is rather limited, but this is not seen as a problem by the test audience. While they appreciated the built-in game design elements, they found the ease of use, free navigation and scientific content to be more important.

Future improvements to the tool could include functions to allow for specialization, e.g., support for separate exercise sets for students of different academic educations. Future research should also focus on measuring the effectiveness of the remote remediation tool, when it is used by a larger number of students.

ASSOCIATED CONTENT

The Social-Societal Ethics Committee of Hasselt University agrees with the ethical principles and provisions which were used during the conduct of the research. This resulted in delivering an ex post facto positive advice.

The authors prepared an ex post facto public communication to provide transparent information on the use of personal data, which is approved by the legal Data Protection Officer of our university.

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.XXXXXXX. [ACS will fill this in.]

Detailed overview of the learning content covered by the GAP**c** environment (pdf)

Accessing the GAP**c** environment (pdf)

More details on the implementation in OpenEducation (pdf)

Example of a mixed assessment with exercises from different levels of difficulty (pdf)

More Graphics in GAP**c** (pdf)

Full review of the questions used during the interviews (pdf)

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ACKNOWLEDGMENTS

Authors thank Benny Daems (Expertise Center for Digital Media, Hasselt University) and Danny Lambrechts (Central Information Technology Service, Hasselt University) for the introduction to Blackboard and helping with the setup of the remedial course.

The authors wish to thank Karel Robert (Expertise Center for Digital Media, Hasselt University) for the marvelous cartoons concerning the virtual world of Hasselt University and its charming residents.

REFERENCES

1. Deci, E.L.; Ryan, R.M. The “what” and “why” of goal pursuits: Human needs and the self-determination of behavior. *Psychol. Inq.*, **2000**, 11 (4), 227-268. doi: 10.1207/s15327965PLI1104_01
2. Vansteenkiste, M.; Lens, W.; Deci, E.L. Intrinsic versus extrinsic goal contents in self-determination theory: Another look at the quality of academic motivation. *Educ. Psychol.*, **2006**, 41(1), 19-31. doi: 10.1207/s15326985ep4101_4x@
3. Vansteenkiste, M.; Sierens, E.; Soenens, B.; Luyckx, K.; Lens, W. Motivational profiles form a self-determination perspective: The quality of motivation matters. *Jpn. J. Educ. Psychol.*, **2009**, 101(3), 671-688. doi: 10.1037/a0015083
4. Boschmann, E. Teaching chemistry via distance education. *J. Chem. Educ.*, **2003**, 80(6), 704-708. doi: 10.1021/ed080p704
5. Barak, M. Transition from traditional to ICT-enhanced learning environments in undergraduate chemistry courses. *Comput. Educ.*, **2007**, *48* (1), 30-43. doi:10.1016/j.compedu.2004.11.004
6. Lovatt, J.; Finlayson, O.; James, P. Evaluation of student engagement with two learning supports in the teaching of 1st year undergraduate chemistry. *Chem. Educ. Res. Pract.*, **2007**, *8* (4), 390-402. doi:10.1039/B6RP90038K
7. Bell, P.; Volckmann, D. Knowledge surveys in general chemistry: confidence, overconfidence, and performance. *J. Chem. Educ.*, **2011**, *88* (11), 1469-1476. doi: 10.1021/ed100328c
8. Lau González, M.; Jáuregui Haza, U.; Pérez Gramagtes, A.; Fariñas León, G.; Le Bolay, N. Supporting students’ learning to learn in general chemistry using Moodle. *J. Chem. Educ.,* **2014**, *91* (11), 1823-1829. doi:10.1021/ed3007605
9. Casanova, R.S.; Civelli, J.L.; Kimbrough, D.R.; Heath, B.P.; Reeves, J.H. Distance learning: A viable alternative to the conventional lecture-lab format in general chemistry. *J. Chem. Educ.*, **2006**, *83* (3), 501-507. doi: 10.1021/ed083p501
10. Lagowski, J.J. The role of distance learning in chemical education, *Pure Appl. Chem.*, **1999**, 71(5), 845-850. doi: 10.1351/pac199971050845
11. Phipps, L.R. Creating and teaching a web-based, university-level introductory chemistry course that incorporates laboratory exercises and active learning pedagogies. *J. Chem. Educ.*, **2013**, 90 (5), 568-573. doi: 10.1021/ed200614r
12. Howe, N.; Strauss, W. *Millennials rising: the next generation*. Vintage Books, New York, **2000**.
13. Elam, C.; Stratton, T.; Gibson, D.D. Welcoming a new generation to college: The millennial students. *Journal of College Admission,* **2007**. Retrieved from: https://eric.ed.gov/?id=EJ783953 [Accessed 2020-05-14].
14. Vrellis, L.; Avouris, N.; Mikropoulos, T.A. Learning outcome, presence and satisfaction from a science activity in second life. Australas. *J. Educ. Tec.*, **2016**, 32(1), 59-77. doi: 10.14742/ajet.2164

15. Buckley, P.; Doyle, E. Individualising gamification: an investigation of the impact of learning styles and personality traits on the efficacy of gamification using a prediction market. *Comput. Educ.*, **2017**, *106*, 43-55. doi:10.1016/j.compedu.2016.11.009
16. Yildirim, I. The effects of gamification-based teaching practices on student achievement and students' attitudes toward lessons. *Internet High. Educ.*, **2017**, *33*, 86-92. doi:10.1016/j.iheduc.2017.02.002
17. Granath, P.L.; Russell, J.V. Using games to teach chemistry. 1. The old prof card game. *J. Chem. Educ.*, **1999**, 76 (4), 485-486. doi:10.1021/ed076p485
18. Nowosielski, D.A Use of a concentration game for environmental chemistry class review. *J. Chem. Educ.*, **2007**, 84 (2), 239-240. doi:10.1021/ed084p239
19. Capps, K. Chemistry Taboo: An active learning game for the general chemistry classroom. *J. Chem. Educ.*, **2008**, 85 (4), 518. doi:10.1021/ed085p518
20. Bayir, E. Developing and playing chemistry games to learn about elements, compounds and the periodic table: Elemental Periodica, Compoundica and Groupica. *J. Chem. Educ.*, **2014**, 91 (4), 531-535. doi:10.1021/ed4002249
21. Daubenfeld, T.; Zenker, D. A game-based approach to an entire physical chemistry course *J. Chem. Educ.*, **2015**, 92 (2), 269-277. doi:10.1021/ed5001697
22. Gonzalez-Gomez, D.; Rodriguez, D.A.; Canada-Canada, F.; Jeong, J.S. A comprehensive application to assist in acid-base titration self-learning: an approach for high school and undergraduate students. *J. Chem. Educ.*, **2015**, 92 (5), 855-863. doi:10.1021/ed5005646
23. Gorin, D.J.; Jamieson, E.R.; Queeney, K.T.; Shea, K.M.; Spray, C.G.R. The “pHunger Games”: manuscript review to assess graduating chemistry majors. *J. Chem. Educ.*, **2016**, 93 (12), 2058-2062. doi:10.1021/acs.jchemed.6b00179
24. Kurushkin, M.; Mikhaylenko, M. A guessing game to reinforce atomic structure. *J. Chem. Educ.*, **2016**, 93 (9), 1595-1598. doi:10.1021/acs.jchemed.6b00136
25. Lee, C.; Zhu, J. F.; Lin, T.; Ni, C.; Hong, C.P.; Huang, P.; Cunag, H.; Lin, S.; Ho, M. Using a table tennis game, “Elemental Knock-out”, to increase students’ familiarity with chemical elements, symbols and atomic numbers. *J. Chem. Educ.*, **2016**, 93 (10), 1744-1748. doi:10.1021/acs.jchemed.6b00341
26. Winter, J.; Wentzel, M.; Ahluwalia, S. Chairs!: a mobile game for organic chemistry students to learn the ring flip of cyclohexane. *J. Chem. Educ.*, **2016**, 93 (9), 1657-1659. doi:10.1021/acs.jchemed.5b00872
27. Da Silva junior, J.N.; Nobre, D.J.; do Nascimento, R.S.; Torres Jr, G.S.; Leite Jr, A.J.M.; Monteiro, A.J.; Alexandre, F.S.O.; Rodriguez, M.T.; Rojo, M.J. Interactive computer game that engages students in reviewing organic compound nomenclature. *J. Chem. Educ.*, **2018**, 95 (5), 899-902. doi:10.1021/acs.jchemed.7b00793

28. Hodges, G.W.; Wang, L.; Lee, J.; Cohen, A.; Jang, Y. An exploratory study of blending the virtual world and the laboratory experience in secondary chemistry classrooms. *Comput. Educ.*, **2018**, 122, 179-193. doi:10.1016/j.compedu.2018.03.003
29. Lima, M.A.S.; Monteiro, A.C.; Leite Jr, A.J.M.; de Andrade Matos, I.S.; Alexandre, F.S.O.; Nobre, D.J.; Monteiro, A.J.; Da Silva junior, J.N. Game-based application for helping students review chemical nomenclature in a fun way. *J. Chem. Educ.*, **2019**, 96 (4), 801-805. doi:10.1021/acs.jchemed.8b00540
30. Winkelman, K.; Keeney-Kennicutt, W.; Fowler D.; Macik, M. Development, implementation, and assessment of general chemistry lab experiments performed in the virtual world of second life. *J. Chem. Educ.*, **2017**, 94 (7), 849-858. doi:10.1021/acs.jchemed.6b00733
31. Davenport, J.L.; Rafferty, A.N.; Yaron D.J. Whether and how authentic contexts using a virtual chemistry lab support learning. *J. Chem. Educ.*, **2018**, 95 (8), 1250-1259. doi:10.1021/acs.jchemed.8b00048
32. Irby, S.M.; Borda, E.J.; Haupt, J. Effects of implementing a hybrid wet lab and online module lab curriculum into a general chemistry course: impacts on student performance and engagement with the chemistry triplet. *J. Chem. Educ.*, **2018**, 95 (2), 224-232. doi:10.1021/acs.jchemed.7b00642
33. Koh, S.B.K.; Fung, F.M. Applying a quiz-show style game to facilitate effective chemistry lexical communication. *J. Chem. Educ.*, **2018**, 95 (11), 1996-1999. doi:10.1021/acs.jchemed.7b00857
34. Kavak, N.; Yamak, H. PictureChem: playing a game to identify laboratory equipment items and describe their use. *J. Chem. Educ.*, **2016**, 93 (7), 1253-1255. doi:10.1021/acs.jchemed.5b00857
35. Triboni, E.; Weber, G. MOL: developing a European-style board game to teach organic chemistry. *J. Chem. Educ.*, **2018**, 95 (5), 791-803. doi:10.1021/acs.jchemed.7b00408
36. Kucukkal, T.; Kahveci, A. PChem challenge game: reinforcing learning in physical chemistry *J. Chem. Educ.*, **2019**, 96 (6), 1187-1193. doi:10.1021/acs.jchemed.8b00757
37. Alexander, S.V.; Sevcik, R.S.; Hicks, O.; Schultz, L.D. Elements – a card game of chemical names and symbols. *J. Chem. Educ.*, **2008**, 85 (4), 514. doi:10.1021/ed085p514
38. Franco-Mariscal, A.J.; Oliva-Martinez, J.M.; Blanco-Lopez, A.; Espana-Ramos, E. A game-based approach to learning the idea of chemical elements and their periodic classification. *J. Chem. Educ.*, **2016**, 93 (7), 1173-1190. doi:10.1021/acs.jchemed.5b00846
39. Gogal, K.; Heuett, W.; Jaber, D. CHEMcompete: an organic chemistry card game to differentiate between substitution and elimination reacties of alkyl halides. *J. Chem. Educ.*, **2017**, 94 (9), 1276-1279. doi:10.1021/acs.jchemed.6b00744
40. Graham, C.R. Blended learning systems: definition, current trends, and future directions. In C.J. Bonk & C.R. Graham (Eds.), *Handbook of blended learning: Global perspectives, local designs,* 3-21. San Francisco, CA: Pfeiffer Publishing, **2005**.

41. Williams, N.; Bland, W.; Christie, G. Improving student achievement and satisfaction by adopting a blended learning approach to inorganic chemistry. *Chem. Educ. Res. Pract.*, **2008**, *9* (1), 43-50. doi:10.1039/b801290n
42. DeLacey B.J.; Leonard D.A. Case study on technology and distance in education at the Harvard Business School, *Educ. Techno. Soc*, **2002**, *5*, 13-28.
43. Romiszowski, A. *Designing instructional systems: decision making in course planning and curriculum design*. Routledge, London, **1981**. Doi: 10.4324/9780203063446
44. Romiszowski, A. *Producing instructional systems: lesson planning for individualised and group learning activities*. Nichols Pub. Co., New York, **1984**.
45. Bloom, B.S.; Engelhart, M.D.; Furst E.J.; Hill, W.H., Krathwoll, D.R. *Taxonomy of educational objectives: The classification of educational goals. Handbook I: cognitive domain.* New York, David McKay, **1956**.
46. De Block, A.; Heene, J. *Inleiding tot de algemene didactiek.* 1e druk , 2e oplage Antwerpen: Standaard, **1992**.
47. Brion, W. Een taxonomie voor psychomotorische doelstellingen. *Impuls*, **1979**, 10(2), 67-74.
48. Krathwoll, D.R.; Bloom, B.S.; Masia, B.B. *Taxonomy of educational objectives: Handbook II: Affective domain.* New York, David McKay, **1964**.