An educational videogame to learn the periodic table: design rationale and lessons learned

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Abstract

The periodic table allows to easily understand the chemical elements and predict the behavior of theoretical yet undiscovered new elements. Many memorization techniques have been used for learning the periodic table, yet serious games (i.e. designed for a primary purpose other than pure entertainment) have been underexplored to complement or even replace such memorization techniques. Since ChemMend, an existing physical card-game, was found to assist learning the periodic table, we explore the potential of e-ChemMend, a digital version of the game as an aid to memorize the group and period numbers of the elements. e-ChemMend is a single-player serious game to explore the effect of four different game conditions involving two experimental factors that account for different educational scenarios. The first factor investigates the role of playing through levels of increasing difficulty versus playing with all elements from the very beginning. The second factor investigates the role of displaying the group and period numbers of the chemical element along with its symbol versus only displaying the element symbol. Preliminary results show that e-ChemMend is perceived as more enjoyable when the group and period numbers are displayed. In contrast, the game is found to better assist learning when this information is hidden and levels are shown. Taken together, our results suggest that a variety of educational purposes can be accommodated with a range of game settings. Ultimately, the design rationale and the lessons learned while testing e-ChemMend will be valuable for Chemistry instructors and education researchers. A desktop-based Windows executable version of the game is available at `http://www.chemmend.uji.es/game`.

Keywords

Humor / Puzzles / Games, Internet / Web-Based Learning, Multimedia-Based Learning, Computer-Based Learning, Periodicity / Periodic Table, Elementary / Middle School Science, High School / Introductory Chemistry, First-Year Undergraduate / General, Second-Year Undergraduate

Introduction

The group and period of the elements in the periodic table (PT) is vital to derive the electronic configuration of such elements and for understanding their properties.[1] Unfortunately, the association between elements and their group and period numbers, as well as other factual information, can hardly be reasoned and tends to be very arduous to memorize. To address this educational issue, mnemonics have been developed for recalling the elements per period.[2,3] Though helpful, the mnemonics presented so far are language-dependent, do not cover all periods, and typically disregard the group numbers, which are also important for defining chemical properties. Broadly speaking, traditional teaching methods focus on PT memorization, which results in a boring process to students.[4] Thus, there is a need to complement these approaches or devise new ones.

The PT itself is also proposed as a mnemonic tool for writing electronic configurations,[1] though very little can be found in the literature on how students can be assisted on the task of learning group and period numbers. Importantly, students approach introductory Chemistry courses with fear because others have stated it is a difficult subject or have had some negative experience.[5] Therefore, new teaching methodologies can help overcome this entry barrier.

There are diverse theories related to rote memorization.[4] In general, memorizing information is one of the fearful aspects in any subject and is usually an undervalued skill, as higher-level cognitive abilities and critical thinking are generally promoted.[6–8] Up to some degree, memorization is beneficial for a more fluent reasoning, as it brings intellectual benefits particularly helpful in the early stages of learning.[9] There is actually a continuum of learning from rote memorization to meaningful learning,[10] therefore it is important to find ways to support this task, particularly in the context of education.[11]

In Chemistry education, much work has been done regarding alternative memorization methods, including concepts and strategies such as "learning by playing",[12] "edutainment",[13] or "serious games";[14–18] i.e. games designed for a primary purpose other than pure entertainment. The games can be developed either in physical format,[18–26] digital format,[27,28] or both.[27] Some games are individual or competitive,[19] whereas others promote interactivity and let students ask either game characters or other players for help.[28] Most games take the form of puzzles,[29] quizzes or questions,[27,30] boards,[18,26] or cards.[5,18–21,23–25,31–33]

Different methodologies based on digital media have been used for teaching the symbol and atomic number of the elements, for example to visualize the shapes of molecules,[25] among many other tasks.[20,23,26,28,29,32–35] Online interactive animations[36] have facilitated the access to users worldwide.[27] Other applications for Chemistry students have been designed for touchscreen portable devices[30,34,35,37] and augmented reality games.[38,39]

A key aspect in serious games is to measure their effectivity and utility, usually in terms of improving students' knowledge by just playing.[21,25,39,40] The assessment is based on feedback from students and teachers after playing the game.[18,22,23,26,27,30,34] Generally, students perceive serious games as useful.[41]

A plethora of games based on the PT have been developed, most of them focusing on a particular pedagogy concept. For example, the *People Periodic Table*[40] is a classroom activity where each student represents one element, and the interactions with the neighbors is intended to learn the regular properties present in the PT. The card game *Elemental Periodica* allows learning the location of elements in the s and p blocks and common elements in the d block.[18] In the card-based game *ChemPoker*,[31] the players can learn the name and symbol of elements, periodic trends, and to identify groups and periods in the PT. In a similar fashion, ChemMend[21] is aimed at learning the period and group number of elements.

ChemMend showed benefits in learning the PT with a significant potential of use in several Chemistry levels, however this aspect was not investigated.[21] Fine-tuning the design of ChemMend would support specific needs of each particular Chemistry course. In fact, the design of serious games is of utmost importance for the pedagogical effectiveness and student's experience as a player.[42,43] Despite such a key importance, it has not been explored in games that support learning of the PT. Towards filling this gap and addressing other interesting research questions, we have developed e-ChemMend, an electronic counterpart of ChemMend. e-ChemMend includes four different game conditions corresponding to whether difficulty levels, group, and period numbers are displayed in the chemical cards. This work reports on the design rationale of e-ChemMend and the insights learned from its evaluation on a user study. We believe these contributions can be highly valuable both for researchers and practitioners. A desktop-based Windows executable is currently offered for research purposes at `http://www.chemmend.uji.es/game`. Unlike ChemMend, e-ChemMend can be played at anytime, supports several playing modes, and facilitates both self-assessment and progression monitoring.

Game design

The e-ChemMend game builds on ChemMend,[21] and is conceived as a research prototype of a single-player serious game, aimed at further exploring the possibilities of ChemMend. e-ChemMend was initially deployed as an online web-based game for reaching a large audience. Online tools are always valuable to complement in-person instruction, and they are particularly useful under remote learning scenarios.[44] This section provides an overview of the game and the design rationale. Further details are discussed in *Detailed design* of the Supporting Information document.

Cards and piles

e-ChemMend has chemical cards and wild cards (Fig. 1a). Chemical cards have the symbol of the chemical element, whereas wild cards are not based on any chemical element, but they have some specific purpose, as described below. During the gameplay, the cards can be in three different card piles (Fig. 1a): 'draw', 'discard', and 'player' piles. Cards in the draw pile are front-side down; cards in the discard pile are front-side up with only the card at the top being visible; and cards in the player pile are all front-side up.

Gameplay

The goal is to transfer all cards from the draw pile to the discard pile, using the player pile as an intermediate pile that allows the player to select the card to play. A card in the player pile is playable if the group or period match those of the top card in the discard pile. Score increases when a card is correctly played and decreases if the player attempts to play a card incorrectly. In any moment, a wild card can be played, which is especially useful for

(a) Main game display in game condition C_3 $\langle \ell-, d+ \rangle$ (b) Levels indication

Figure 1: Screenshot of E-CHEMMEND's main screen, with its three piles (a) and the difficulty levels (b). Here the draw pile has 7 cards, the discard pile has 35 cards, and the player pile has 8 cards. We refer to the difficulty levels according to the two experimental conditions $\ell+$ of our user study (C_1 and C_2).

situations where the player does not have any chemical playable card, or just for strategic purposes. After using a wild card, the player must answer the corresponding card question that will be shown on the screen (Fig. 2) for a maximum of 5–10 seconds, depending on the game condition. The player has to guess correctly the group and period from one of the elements from cards from the discard pile, i.e. already played cards.

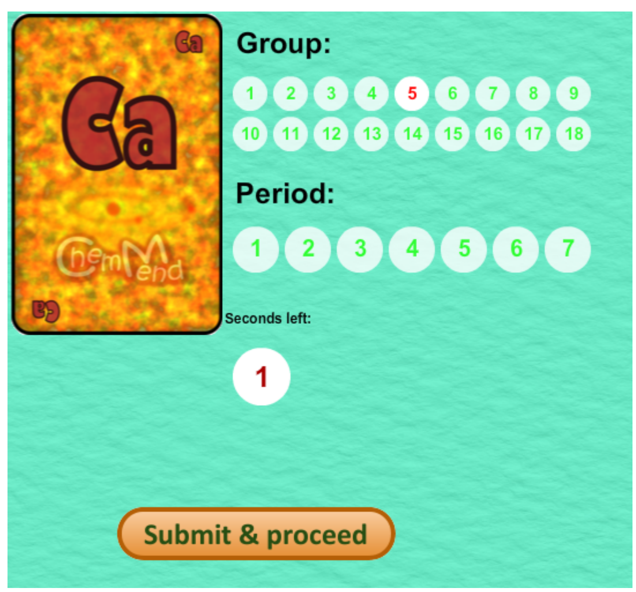

Figure 2: Example of a card question associated to the use of a wild card. In this case, there is one second left and the player has already selected the group number (5) but not yet the period number.

We also introduced a self-assessment quick test to evaluate the knowledge of the player, aimed at making the gameplay less linear and more entertaining. Users need to complete a quick test that consists of 6 questions (two questions of each of three different question types, as shown in Table 1) that needs to be completed in a limited time. See Supporting Information for more details. By being timed, the game is expected to be more entertaining and to foster its learning goals. The player has to answer correctly 3 quick tests distributed at different levels in order to complete the game. Fig. 3 shows an example of question where the player has to answer the correct group and period of a given element. See E-GP question in Table 1 for more details.

Table 1: Types of questions in the quick test. g and p are group and period number, respectively, e is a chemical element (without g and p displayed), and s is a set of elements like e. In this work, s has 4 elements.

		Player info	
No.	Type	Given	Asked
1	GP-GP	g, p, s	e of given set s that has the same g (or p)
2	E-GP	e	g and p of given e
3	GP-E	g, p, s	e of given set s that has both g and p given

Game conditions

The learning and gameplay implications of two independent variables have been considered. These variables act as experimental factors and result in four game conditions (see Table 2). The first variable introduces levels of difficulty that regroup the elements in 10 different groups (see Table 3). The progressively more challenging levels should result in a scaffolding approach to learning[45] and provide the player with a sense of progression.[47] This not only allows a gradual increase in the difficulty, from level 1 with elements of groups 1 and 2, to level 10 with transition metals, but also motivates the students to progress through the game. The second variable is the addition of the group and period number of each element on the game cards. This may facilitate the gameplay for beginners or students who are less familiar with the PT. Although the effect of these variables can be somehow speculated, its impact on the actual learning and playful aspects is still unknown and worth studying.

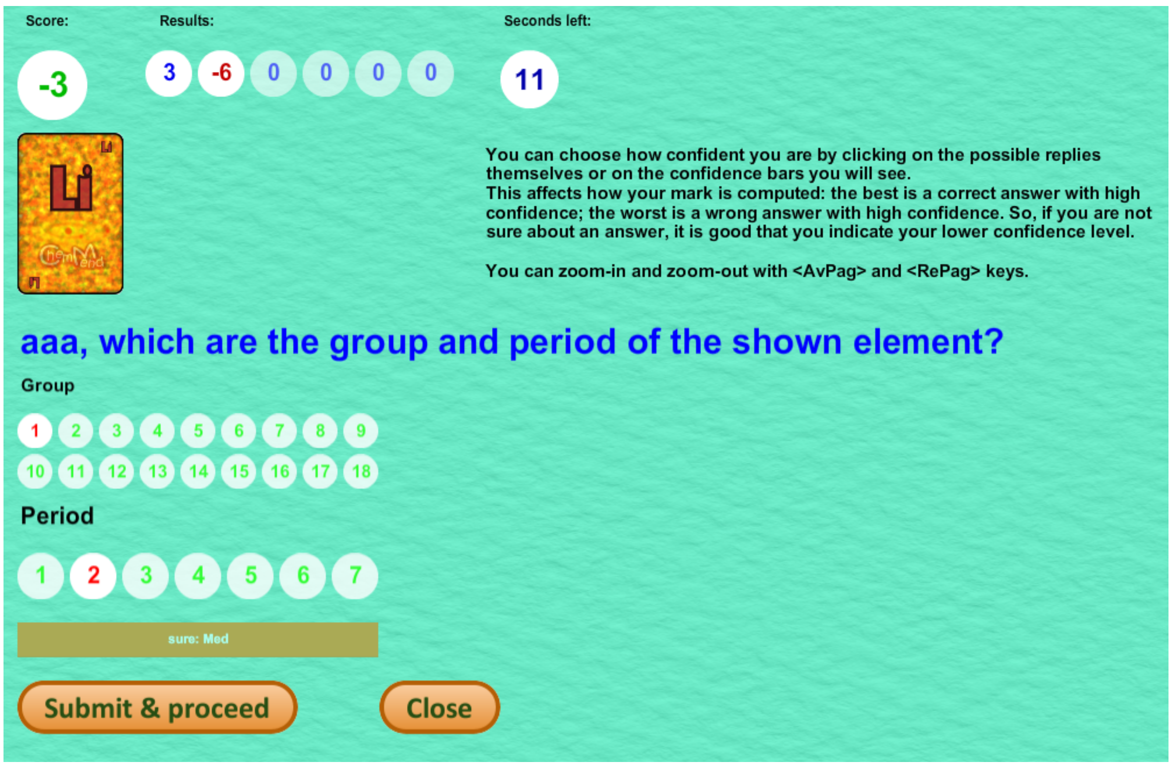

Figure 3: Quick test. The player (user name aaa) has already replied the first two questions, the first one correctly and the second one incorrectly. For the current (third) question, which happens to be of type E-GP (Table 1), the player has selected $\mathsf{g} = 1$ and $\mathsf{p} = 2$. There are three other questions and 11 seconds left to complete the quick test.

Table 2: Four game conditions emerged from our two-factor independent variables: Levels ($\ell+$, $\ell-$) and Display Info ($d+$, $d-$).

With levels?	Displayed group and period? Yes ($d+$)	No ($d-$)
Yes ($\ell+$)	C_1 $\langle \ell+, d+ \rangle$	C_2 $\langle \ell+, d- \rangle$
No ($\ell-$)	C_3 $\langle \ell-, d+ \rangle$	C_4 $\langle \ell-, d- \rangle$

Table 3: Distribution of chemical elements per game level.

Level	Groups	Periods	New elements per level	Elements
1	1–2	1–5	9	H, Li, Be, Na, Mg, K, Ca, Rb, Sr
2	13	2–5	4	B, Al, Ga, In
3	14	2–5	4	C, Si, Ge, Sn
4	15	2–5	4	N, P, As, Sb
5	16	2–5	4	O, S, Se, Te
6	17	2–5	4	F, Cl, Br, I
7	18	1–5	5	He, Ne, Ar, Kr, Xe
8	3–7	4	5	Sc, Ti, V, Cr, Mn
9	8–12	4	5	Fe, Co, Ni, Cu, Zn
10	10–12, 14	5–6, 6	7	Pd, Ag, Cd, Pt, Au, Hg, Pb
		Total	51	

Game implementation and user study

We developed a web-based prototype to test the game with as many users as possible. A pilot study was conducted prior to the actual user study, as described in the Supporting Information. For implementation convenience, the game was developed with ActionScript 3.0 for the Flash platform. Since Flash is currently unsupported by web browser vendors, a standalone desktop-based Windows executable is provided at `http://www.chemmend.uji.es/game`, for testing and research purposes. Accordingly, the game allows the user to select one out of four game conditions C_1–C_4 and start playing after at a particular completion level. This desktop version neither performs user logging nor requires an Internet connection.

Registration and assignment of game conditions

Although the main target audience were students in secondary education or in early higher education, we were open to a variety of possible users, including other stakeholders such as educators. For this, we included text fields for age range, expectation, and study level in the registration form. Users were asked about their expectations towards the game, with four possible answers: fun, learn, review, or other. To analyze the effect of the four game conditions, each user was assigned to one condition at random upon registration. Users could only play the game in the assigned game condition. Details for all the information requested at registration time are provided in Table S5 of the Supporting Information. Calls for participation were made through local press, social media, and mailing lists. Incentives to get users involved to complete the game and surveys were offered through weekly raffles of 10 EUR gift vouchers.

Standard tests, user feedback, and statistical analysis

The evaluation of the effectiveness of serious games can be achieved through different tests answered by the users after playing the game.[48] In our research, we have used Task Load Index (TLX),[49] System Usability Scale (SUS)[50] and qualitative questions. Please, refer to the Supporting Information for more details. The description of the statistical tests and their results can also be found in the Supporting Information.

Results

The game was live-tested for four months, during which we collected gameplay data from the different registered users. Most participants had Chemistry studies at secondary or university levels (see Table 4), and their ages roughly correlate according to this level (the higher the age, the higher the education level). Three hundred users registered but only about 15% of them fully completed the game at least once, which suggests that most of the users were casual players who mainly registered to test the game. Certainly, about one fourth of the registered users reported to have other expectations towards the game. The users who completed the game were typically those studying Chemistry in high-school, and therefore had either intrinsic or extrinsic motivations to actually learn the PT; e.g. because of the weekly gift vouchers and/or prompts from their teachers. Most of the users who did not complete the game played up to about 20% of game completion. The number of registrations and game completions were similar among the game conditions; see Table 5.

Table 4: Distribution of number of participants and ages (mean and standard deviation) per education level.

		Education level related to Chemistry				
		None	Primary	Secondary	University	PhD
	count	4	30	224	149	52
age	mean	31.3	21.1	21.0	39.3	42.4
	std. dev.	12.3	12.8	13.6	11.7	12.2

Table 5: Number of users who registered and completed the game at least once per game condition.

Condition	Registered	Completed
C_1	76	8
C_2	75	7
C_3	72	11
C_4	77	10
Total	300	36

We found the youngest students to be mostly interested in learning the PT, as they would be in high school and probably with ongoing Chemistry courses. Indeed, the distribution of expectations per studies (Fig. 4) confirms this notion: those in primary and secondary school are mostly interested in learning (either learn or review). Many graduates and PhDs just want to review, and most of them report other as their main purpose. From the emails we received, we speculate that, besides curiosity, most of the participants who reported other purposes had an exploratory goal in mind. In fact, those participants were either teachers or parents who wanted to try the game themselves to decide if the game would be suitable for their students or children.

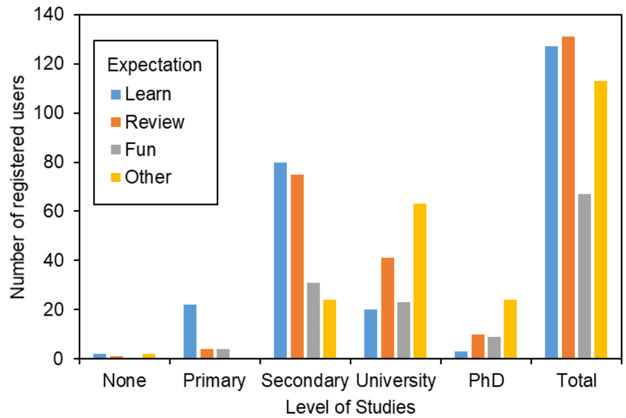

Figure 4: Expectations of the registered participants grouped by education level.

In-game feedback

Statistical analysis of the results in the quick tests and game scores, coming from gameplay data logs, are included in the Supporting Information. We also offer insights and performance correlates with players' motivations.

General feedback

This section summarizes the feedback from users from both the in-game and after-game questionnaires, as well as complementary questions. The analysis of the responses to the SUS and TLX questions can be found in the Supporting Information.

Regarding reasons for recommending the game or not (Table S18), most of the negative reasons are related to issues at registration time ("Registration is complicated"), the implementation platform ("It requires Flash"), or some occasional malfunctioning experience ("It freezes sometimes"), but, interestingly, have little to do with the core idea of the game or the gameplay. This is encouraging given that, as a research prototype, some interface details need further polishing, but the core idea is generally valued. Similarly, some users did not find the game entertaining or disliked the aesthetics (e.g. "I don't like the design"), the later being a debatable but important cosmetic issue. The reasons rarely relate to the specific game condition, an interesting exception being a user in C_3 (i.e. one $d+$ condition) who rightfully wondered how one may learn the group and period of elements if they simply focus on matching numbers. In a similar vein, among the most interesting and constructive comments we can mention those which actually challenge the learning utility of the game. Although the views are very diverse, many of them align with by the comment by one user who would recommend the game because "It is useful if it is well explained and played repeatedly". After all, regular repetition is one key ingredient in many learning tasks,[51] particularly in memorization tasks. As a quantitative evidence, the user who played the most (up to six times), managed to progressively improve their final game scores, as follows: 23, 27, 27, 31, 34, and 38. There are two likely reasons for this good progression. On the one hand, the game condition randomly assigned to this user was C_2 $\langle \ell+, d- \rangle$, i.e. with levels and without the visual aid, which can be seen as a convenient learning scenario, as found in the context of our study. On the other hand, this user self-imposed a learning strategy that resembles one that would be followed under the controlled conditions of classroom-based, instructor-guided educational settings, and this proved effective for them, as confirmed by their commitment and spirit of achievement, expressed during their interview (see *Participant interview* in the Supporting Information document). Thus, eventually, a game like e-ChemMend can support and alleviate the more tedious parts of this memorization process. Among the reason for recommending the game, the innovative, entertaining, and utility aspects were mentioned (e.g. "It is useful and more entertaining for learning").

Regarding further user preferences (Table S19), one of the aspects people liked the least was related to the timing, either because of the stress they felt when playing under time pressure, or because they found the game too long to complete. However, both the dynamic and quick pace were also liked the most by other users. Some users seemed to miss more explanations of some aspects of the game, either because they were not aware of the existing help or they felt that it should be more explicit or comprehensive ("A tutorial is required"). However, not only other users found it easy, but also even users who demanded more explanations, at the same time they recognized it was easy to play ("It doesn't say much at the beginning about how to play, but is easy to learn"). This implies that, although a minor issue, we should consider further improvements in providing help.

Some of the most sensible users provided useful and constructive criticism. For example, one user missed more strategic gameplay but liked the game idea, while another user felt the game was too long but also appreciated the essence of the game. Overall, most users liked the most that one can learn (and revise) the PT interactively and dynamically in an entertaining way (e.g. "The alternative offered to learn the PT without having to learn the elements by heart").

Finally, when invited to write free-form comments (Tables S20 and S21), some users pointed back to the physical/mental effort demanded by the game (e.g. "I got tired and there is too little time to think. I also got very stressed"), the perceived utility (e.g. "It is quite difficult to learn the [periodic] table but this game makes it a quick and easy task"), or indicate a useful use case ("I would recommend the game to prepare a Chemistry exam"). Some suggestions for improvement include increasing more gameplay variants; e.g. more types of cards or tests. Some advanced users (teachers, university-level students) suggested including more learning components, such as oxidation elements or atomic numbers. While interesting, this may deviate from the main target group of the game (high-school students). As a user mentioned, "it encourages us to learn the PT that so many people are afraid of".

User observations

A group of about twenty high-school students (14–15 years old) was screened while using e-ChemMend in a computer lab in their school. They had already been playing e-ChemMend during some weeks, either at school or at home. At the beginning of the class, the teacher handed a printed PT to help students play fluently. Scoring higher than their classmates was found to motivate them a lot, even more than completing the game itself. One student asked us whether their score (about 78 points) was "good enough". This suggests that some kind of performance feedback or a reference they can quickly compare with, such as a leaderboard, might guide and motivate them over time.

Their interest to obtain high scores led some of the students to develop a form of strategic playing: even when some cards in the player pile were playable, one student chose the wild card and failed on purpose the card question to get more cards from the discard pile to the draw pile, as more cards have potential for higher scoring. This situation should probably be addressed similarly as when we freeze the score if a quick test is not passed, as discussed in the Supporting Information document. One possibility would be to decrease the score for each card that is moved from the discard pile to the draw pile. However, besides redesigning the game to prevent these situations, the main lesson learned here is that, since at least for this age group the score is very important, the game should build upon this fact to improve its didactic and playful aspects.

Interestingly, some students pointed out that they liked to play in couples, because they found it much more fun, as one student can play while the other looks at the PT. This suggests that even being a single-player game, new usage scenarios are possible to make the most of the sharing and collaborative willingness of students. Thus, the didactic implications of pair playing, which may intriguingly remind us of the pair programming paradigm[52] might also be investigated in future work.

Some teachers also provided feedback and noted that, traditionally, memorization is carried out by *per-group* lists, not by *per-period* number. As a consequence, a significantly additional cognitive challenge is posed, even for teachers, as e-ChemMend involves both the period and group of PT elements. One teacher suggested a usage scenario which aligns very well with our own view that, on the one hand, the game should be viewed as a complementary tool, not as a replacement of other methodologies; and, on the other hand, that the game can be useful at different moments during the learning process or education levels, with different purposes and educational objectives.

Discussion

Here we provide ideas and recommendations for usage, comments on limitations of our study, further software developments, and research possibilities.

Usage suggestions

An important lesson learned is the fact that the way the game is used is as important as the game design itself. This calls for a revision of the usage guidelines, either as a part of the game, or provided by the instructors in a classroom setting. Generally speaking, one could start playing with the support of a physical PT. Then, after several teething sessions, the use of the table should be reduced progressively. Similarly, since the display of the group and period number simplifies the gameplay and thus introduces a bigger entertaining component, this choice may be more adequate for introductory academic levels or for sporadic leisure.

Although the web-based version used in our user study considered separately the four game conditions using two levels of two factors each (levels vs no-levels and display vs no-display), the provided desktop version offers these playing modes to be user-controlled, thus offering the opportunity to play differently at different moments. For example, priming a fun gameplay (e.g. with the group and period numbers displayed, trying to compete with friends and get an score as high as possible), or more focused towards learning (e.g. without these numbers displayed).

Some other useful usage hints were revealed under naturalistic observations (*User observations*), which reinforces how useful this feedback can be for participatory design in terms of both redesigning instructional activities,[53] and games themselves.[54] Based on the feedback obtained from our users and our own experience throughout the process, we summarize in Table 6 the usage suggestions, recommendations, and possible improvements to e-ChemMend.

Table 6: Summary of key insights of the study.

Recommendations
• Used repeatedly and regularly, it can help memorize the group and period numbers
• Better used as a complementary tool to other learning mechanisms
• Under supervision, the quick tests can be helpful in formative and summative assessment
• An auxiliary periodic table might be used, but its consultation progressively reduced
• Using levels and not displaying the group and period number is generally preferable
• Playable individually, cooperatively, and competitively at instructor's discretion
Possible improvements
• Additional explanations of the gameplay and usage guidance
• Customization options for levels' contents, timings, etc.
• Alternative aesthetics and color themes, e.g. for background and cards
• Richer gameplay, e.g. additional wildcards, or levels for atomic and oxidation numbers

Limitations of the study

Our findings suggest preliminary empirical evidence on the usefulness of e-ChemMend in assisting students' learning of the PT. However, we believe that its effectiveness is highly dependent on the attitude, motivation, and expectations of the user towards the game. We observed that students truly interested in learning (i.e. those who need to master the PT for their studies) managed to make the most of the game. Naturally, this somehow conditions the role that the game may have as a learning tool to a proper attitude and usage, which were factors essentially out of our control in the study, since it was conducted "in the wild", with a wide range of players' ages, profiles, and motivations. For an in-depth understanding and assessment of the long-term impact of e-ChemMend, further studies under more controlled conditions are needed. Furthermore, the need of repetitive and spaced playing should not be underestimated to promote long-term learning benefits.

Further developments

It may be very interesting to consider two different user profiles: end-users (e.g. students) and superusers (e.g. educators). Superusers would be in charge of configuring different gameplay options for a set of end-users. Similar to the usage guidelines, educators may set up the game for their students to play only the game under the superuser-chosen options. The superusers might also have access to aggregate usage statistics to supervise the learning process. Similarly, groups of end-users could be defined and the superuser would configure the conditions (times, scoring, etc.) for those specific groups. Then, each group would share an individual leaderboard. This would be appropriate in classroom settings and would motivate competitive students to play against their peers, not against others who might be much more or less qualified.

Although we proposed a series of game levels, each with a limited set of new elements, it is clearly desirable that players (end-users or superusers) could choose customized sets of elements to practice, depending on their particular teaching or learning needs.

In terms of development technology, a HTML5 version of the game would be desirable, building on all the gained experience that we report in this work. A number of users suggested that a mobile app would be appreciated. Their usage habits and the ubiquitous presence of these devices would facilitate accessing and using the game, thus increasing the learning opportunities.

Research possibilities

How much and when the group and period numbers are displayed may help in both regulating learning progress, and accommodating a range of user experiences. e-ChemMend includes many other aspects (in-game tests, confidence-based marking, scaffolding levels, time-paced activities) whose customization, possibly at the instructor's discretion, would contribute to modulate a desirable difficulty level by combining intrinsic skills (e.g. under an unlimited amount of time) and stress.[55] All these possibilities open the door to a variety of didactic and playful goals, as well as further educational research opportunities. Another interesting study would be to compare the relative benefits of e-ChemMend over ChemMend.

According to the feedback provided by one teacher who tested the game with their students, it might be useful to have a game mode that can be played jointly by teams of students, possibly co-located and guided by the instructor, so that in-classroom contests can be facilitated, with functionality similar to generic game-based learning platforms.[56,57] We believe this is an interesting possibility, although studies of its potential and limitations should be carefully conducted for this particular memorization task.

Making games enjoyable can be generally advisable, however it should not be always an easy goal, particularly for serious games, whose primary purpose is not simply entertainment. The right balance between the learning goal and enjoyment is essentially an open issue.[58,59] In e-ChemMend not only it is the educational goal a hard memorization task, but it also builds on the physical counterpart.[21] Consequently, although some entertainment components were included, future research should look into how to further elicit particular user experiences such as immersion or fun *while* being equally or more effective learning-wise.

Conclusion

We have developed e-ChemMend, a single-player serious game to assist students in learning the group and period numbers of chemical elements, a basic need yet largely overlooked in the literature of Chemistry education. Overall, students appreciated the main idea of the game, and the more conscientious ones stated that it helps them to memorize or revise the group and period numbers of the elements in the periodic table. Regarding the didactic implications of the four game conditions considered, there is evidence that displaying the group and period does not benefit memorization, but it seems that this can make the game less challenging and more entertaining. On the other hand, having difficulty levels is perceived to have a positive learning effect, but possibly less relevant than the display factor. Given the diversity of user profiles and interests, making the game customisable seems a proper direction to accommodate a variety of goals. Ultimately, our findings can inform the design of other future Chemistry tools aimed at supporting not only the learning of the group and period numbers, but also other memorization tasks.

Associated content

Supporting Information

The Supporting Information is available at [URL]

> Additional information regarding the rationale behind game design and decisions, specific details on forms and questionnaires, and further results on the user study. [PDF]

Desktop game

> A desktop-based Windows executable is available at `http://www.chemmend.uji.es/game`

Acknowledgments

We are grateful to all users who have participated in the study; to the high-school teachers Desideria Almela, Manuela Segura, and Rosa Salvador; and others who tested the game with their students, and the financial support from the Institute of New Imaging Technologies at Universitat Jaume I for conducting the pilot study. V.M.-C thanks the financial support from Generalitat Valenciana (CIDEGENT/2020/031).

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