Assessment of the ability of game-based science learning to enhance genetic understanding

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Abstract

Background: Game-based science learning (GBSL) provide an alternative route for learning genetics, but its effects on students' conceptual learning is contested. In this paper we assess the utility, in primary teacher education, of Recal: a game designed to promote participants' learning of key genetic concepts through acting as detectives investigating a case.

Purpose: The purpose of the study was to analyse and compare teacher students' learning of genetics through the game, and both their attitudes towards and experiences of it. Tests were conducted in Spanish and Swedish contexts to assess its potential utility in contrasting cultural and educational contexts to obtain indications of the potential breadth of its application.

Samples: Participants included 120 pre-service teacher students from a university in north-eastern Spain and 51 from a university in western Sweden.

Design and methods: The research involved an intervention, in which students played the game, and assessment of its efficacy by questionnaires designed to investigate students' knowledge of genetics before and after the game, their expectations and experience of it, and their satisfaction with it. The results were analysed statistically.

Results: The game appeared to enhance both Spanish and Swedish participants' knowledge of genetics, and they reportedly found it both educationally beneficial and

engaging. It was also assessed in terms of the following characteristics of GBSL, based on experiential data: contextualisation, authenticity, collaboration, problem-solving, guided paths and competition.

Conclusion: The results clearly indicate that the game has utility in different countries and educational contexts. The article discusses how the six characteristics of GBSL facilitate or hinder learning, and implications (for educational professionals and researchers) of the findings.

Keywords

Conceptual knowledge, Game-based science learning (GBSL), Game-based learning (GBL), Genetic education, Pre-service teacher training, Serious educational games (SEG)

Introduction

In recent decades there has been a revolution in biological and genetic research leading to exponential increases in knowledge and new technological applications (Chen, Chu, Lin and Chiang 2016). The rapid consequent development of modern biotechnology and genetic engineering has led to huge gaps between the scientific community's and general public's understanding of the risks and benefits of using the new technologies (Boerwinkel, Yarden and Waarlo 2017). However, in order to involve society in

formulation of policies about scientific matters, we need well-informed citizens who can make rational decisions based on scientific knowledge and understanding of associated ethical and moral issues. Thus, a primary goal for science education is to help students develop the knowledge, skills and epistemologies required to deal with contemporary real-world scientific issues (Barab and Dede 2007).

For citizens to be biotechnologically literate they clearly require adequate knowledge of fundamental biology, including genetics (Stern and Kampourakis 2017). However, most members of society receive information about scientific developments in genetics through mass media, which may lead to lack of understanding (Kılıç and Sağlam 2014). To address these problems there is a clear need (corroborated by a Delphi-study involving international experts on genetic education and outreach) for education systems to enhance future citizens' genetic literacy (Boerwinkel, Yarden and Waarlo 2017). Moreover, such development should begin in primary education, as outlined by the US National Research Council (NRC 2012). To meet that goal, new teaching materials must be developed that enable teachers with little training in genetics to participate in enhancement of their pupils' understanding (Marbach-Ad et al. 2008). Game-based learning has been identified as a powerful approach to promote learning of content knowledge, according to several reviews (e.g. Chen et al. 2018; Hussein et al. 2019; Spires et al. 2019). However, few games have been developed to facilitate genetics education, there have been few studies on their potential utility, and they have provided conflicting results. Anetta et al. (2009)

detected no effects of game-based learning on genetic knowledge, Kim et al. (2015) detected some minor impact, and Rachmatullah (2021) recently found it can have significant effects on students' conceptual understanding of genetics. These discrepancies clearly indicate that there are poorly understood influential factors that may help or hinder game-based learning in genetics. These issues are explored here in an analysis of responses to, and effects of, features of a game called Recal that is intended to foster understanding of key genetic concepts.

Background

Describing Game-based Science Learning

Recal combines game characteristics such as problem-solving and authenticity for the purpose of engaging students in learning genetics. Game-based teaching specifically focused on science education has been called Game-Based Science Learning (GBSL) (Chen, Lui and Shou 2018; Li and Tsai 2013), and as we focus on genetics education in this article we use the term GBSL hereafter.

Although games can support learning in various ways, there is little consensus regarding the definition of a game, nor GBSL (Liu et al. 2014). Related terms (such as games, computer games, and video games) have often been used interchangeably (O'Neil, Wainess and Baker 2005; Liu et al. 2014). In a seminal work, James Gee (2008) describes

games as tools for "deep learning" through creation of "virtual experiences centered on problem solving [that] recruit learning and mastery as a form of pleasure" (p. 36). Hence, games can provide students with opportunities for experiential, authentic learning (Gee 2003), and Gee (2008, p. 36) further argues that games can promote acquisition of knowledge within specific contexts by relating the language used in them to "actual experiences, actions, functions, and problem solving".

In the literature GBSL is often described as facilitating learning by guiding learners through a path of events and into a way of thinking. GBSL may have several characteristics that foster learning, including collaboration between multiple players, problem-solving and competition (Chen, Lui and Shou 2018). Another characteristic of games applied in Science Education is that they are often designed to encourage students to create identities and play roles of authentic professionals, such as scientists (Van der Wal et al. 2016). According to GBSL theory, learning occurs when the relationship between actions of a player and outcomes of the system in a game are discernable and integrated into the game's larger context (Rachmatullah et al. 2021). This prompts students to acquire information from many sources and make decisions quickly, deduce a game's obstacle, understand complex systems through experimentation, and collaborate with others (Chen, Lui and Shou 2018).

Theoretically, a game applied in GBSL should also ideally involve multiple tools and resources. These resources may establish certain aspects of the game, such as the goal, the

virtual setting, rules, clues, and cycles of choices that allow players to interact with the environment (Liu et al. 2014). Moreover, the resources of educational games may include newspaper articles, videos, multi-media documents, websites, manuals, encyclopedias and even books for players to read in order to gain more background information and richer contexts for play (Cheng et al. 2015; Solé-Llussà et al. 2018). Most GBSL games available today, and discussed in the literature, are largely or entirely digital (e.g. Chen, Wang, Kirschner & Tsai, 2018; Hussein et al., 2019). However, this study is based on a physical game including real artefacts and paper-and-pencil tasks, thus it could potentially provide additional insights that may not be afforded by further analysis of digital games.

Evaluating Game-based Science Learning

According to a systematic review by Hussein et al. (2019) most evaluations of serious educational games (SEGs, i.e. games that are explicitly used as teaching and learning tools; Annetta 2008) have assessed cognitive gains, such as content knowledge or skills, and attitudinal outcomes (towards the games or game environments). The overall idea is that GBSL provides a motivational edge in comparison to traditional teaching, and the game will lead to an immersive experience, what Cheng, She and Annetta (2014) describe as an "immersive state, whereby players become cognitively and emotionally absorbed" (p. 248). This immersive state is then supposed to promote better learning of curriculum knowledge included in the serious game than traditional teaching. If so, when assessing the effect of a SEG it is important to evaluate not only the cognitive gain (in this case

genetics knowledge) but also its affective effects. However, according to Cheng, She and Annetta (2014, p. 233) "most of the past research generally examines the issue of what are the cognitive and affective consequences of using SEGs. Yet, there is still a lack of research attempting to delve into the questions about how players feel and what they experience through playing SEGs." Their point is that the assessment instruments should be adapted to the game evaluated, and general attitudinal instruments decoupled from the game should be avoided. Thus, in the study presented here, we have used both closed and open-ended questions to investigate players' experiences of the Recal game, in addition to their content knowledge of genetics before and after playing it.

It is also important to recognize that the support for theoretical advantages of game-based learning claimed in some empirical studies has been questioned. For example, Kirschner and Van Merrienboer (2013) have asked whether learners using games really know what is most beneficial for their learning, and (for example) the true value of positive experiences. Several systematic reviews provide some illumination regarding this issue. In a quantitative meta-analysis of 32 articles by Vogel et al. (2006) it is concluded that learners who used digital learning games obtained greater cognitive gains and demonstrated better attitudinal outcomes, on average, than students who learned via a traditional teaching method. Similarly, in other systematic reviews Connolly et al. (2012) and Boyle et al. (2016) concluded that SEGs promote students' content learning. However, in a synthesis of 39 studies, Wouters et al. (2013) found no evidence that SEGs

were more motivational than traditional teaching methods. More recently, a systematic review by Hussein et al. (2019) concluded that digital GBSL shows "promising potential…particularly in the area of content understanding", but "the findings…also suggest that there is a need to provide additional research in order to gain a more comprehensive picture of the educational effectiveness" (Hussein et al. 2019, p. 62465) of GBSL. In this study we address this need by investigating if (and if so how) a specific SEG intended to facilitate genetics education that promotes content learning, fosters positive experiences and thus creates a pedagogically valuable environment.

A new educational game for genetics education

Genetic literacy is recognized as crucial for the ability to take personal decisions and participate in democratic decision-making at socio-political levels regarding issues such as genetically modified organisms, genetic testing, and personal genomics (Boerwinkel, Yarden and Waarlo 2017). However, research has consistently shown that genetics is difficult to understand, and there are many misconceptions, as previously reviewed (Authors 2014). Genetics has also been identified by biology teachers as the most difficult topic to teach and learn in biology education (Bahar, Johnstone, and Hansell 1999). For example, Marbach-Ad and Stavy (2000) found that pre-service teachers clearly compartmentalized genetic concepts, and lacked coherent understanding. Another study found that pre-service teachers are aware of some applications of biotechnology but lack knowledge of basic genetic concepts (Authors 2015a). For example, students participating

in the cited study had difficulties understanding the difference between genetic information and genetic material, and that the same genetic information is present in all cells of a living organism. Moreover, these (and other) misconceptions seem to be widely shared by students in many countries (Authors 2014). Hence, teachers seem to have difficulties in equipping students with adequate genetic knowledge. There are several possible reasons for this. One is the dominance of traditional teaching methods focusing on obsolete Mendelian concepts in genetics education (Dougherty et al. 2011; Authors 2014; Authors 2015b). Another is that teachers might not have enough knowledge to teach the content, especially primary teachers in elementary school. This is important because teachers' fundamental genetic knowledge is positively correlated with their self-confidence to teach the subject and ability to answer pupils' questions correctly (Stern and Kampourakis 2017).

Learning games have been proposed as means to overcome these teaching and learning difficulties in genetics education (Marbach-Ad, Rotbain & Stavy, 2008). However, few games have specifically targeted genetics education, there have been few studies of GBSL's ability to promote genetic knowledge and literacy, and those studies have provided conflicting results. ~~Anetta et al. (2009) detected no effects of game-based learning on genetic knowledge, Kim et al. (2015) detected some impact, and Rachmatullah (2021) recently identified significant effects on students' conceptual understanding of genetics.~~ Thus, there is a paucity of studies exploring the role of games

in genetics education. Moreover, the few studies that have been published have focused on digital games, while this study addresses a physical game. Hence, this study fills important gaps in previous research.

Based on the above arguments, an educational game (Recal) was developed to help students to encounter and acquire understanding of key genetic concepts in contemporary contexts underpinned by GBSL theory (Authors 2017). The Recal game has been designed as a collaborative activity in which students work in groups of three or four for 90-120 minutes (depending on the students' problem-solving skills) as police detectives investigating a criminal case. The main goal of the game is for students to acquire, understand and apply evidence and clues obtained in the investigation to enable them to complete tasks that require application of genetic knowledge. In that manner, the game is intended to facilitate the players' learning of genetics while not requiring any pre-knowledge.

The aim of the Recal game is to foster *contextualized* understanding of contemporary genetics concepts by immersing students in an *authentic* scientific-based scenario in which they play the role of a scientific assessor. They must develop and use scientific reasoning and evidence-based decision-making in a *collaborative* way to *solve problems* they encounter as the game progresses (Authors 2017). The game involves four phases, in each of which the participants receive information on specific cards about concepts involved in the application of forensic evidence as a *path or guiding tool*. In each phase

they must then answer a multiple-choice questionnaire before trying to solve a puzzle to acquire evidence (clues) collected from the scene of a robbery and results of laboratory tests, which helps them to eliminate some suspects (Figure 1). *Competition* to get the highest marks on the questionnaires also provides a motivational target for the groups. As can be seen from this short overview, the Recal game is designed to include the GBSL characteristics of contextualisation, authenticity, collaboration, problem-solving, guided paths and competition. For a more detailed description of the game, see Authors (2017).

[Insert Figure 1 about here]

The comparative perspective - The Spanish and Swedish contexts

The utility of the Recal game was assessed by inviting both Spanish and Swedish elementary pre-service teachers with little experience and training in biology to play the game and evaluating (through questionnaires) their expectations and experiences of it, and their satisfaction with it. The educational outcome was also assessed to compare its learning potential in the two contrasting educational and cultural settings. The reason for testing the game in two different contexts is that students' understanding of educational games and their learning effects may depend on both educational and cultural contexts (Hussein et al. 2019). Therefore, in this study the game was assessed in two contrasting contexts: primary school teachers' educational settings in Spain and Sweden to obtain at least preliminary indications of the game's efficacy in multiple contexts.

Spain and Sweden are representatives of northern and southern European countries, respectively, with substantial differences in knowledge related to genetics issues. Spain is reportedly in the bottom four and Sweden in the top three European countries in terms of shares of citizens who are well informed about biotechnological applications of genetics, respectively, according to the latest available comparative data (European Commission 2010). Further, teachers' perception of teaching differ between the two contexts (Loinaz 2019), and a recent study found differences in biotechnological literacy between pre-service teachers of the two contexts (Author, 2021). Hence, we regarded these contexts as good settings for testing the Recal game's efficacy.

Aim

The aim of the study was to assess the Recal game's utility for improving pre-service teachers' understanding of genetics and their attitudes towards it in two contrasting (Spanish and Swedish) cultural and educational settings. The study was guided by the following research questions:

1) Does participation in the Recal game promote learning of genetics?
2) What GBSL characteristics of the learning game promote and hinder learning according to the participants?
3) Are there any differences in learning outcomes and experiences between Spanish and Swedish participants?

Materials and methods

Research design

The Recal game and associated factors were evaluated in an intervention study with a mixed methods approach designed to enable capture of both general comparative insights and more detailed and nuanced perspectives (Creswell 2014). The study combined acquisition and analysis of quantitative Likert-scale data on genetic knowledge and attitudinal experiences of the game with qualitative data obtained from an open-ended questionnaire on students' experiences of, and satisfaction with, the game.

During the intervention the students played the game, and its efficacy was assessed by questionnaires designed to acquire socio-demographic data and students' knowledge of genetics before and after the game, their expectations and experience of it, and their satisfaction with it **(**Figure 2). The pre-intervention questionnaire (which was manually distributed to the groups of participants by the first author) included questions on the students' socio-demographic status, genetic knowledge, and expectations regarding the learning game. After an intentional 2-week delay, the first author conducted the intervention (Recal game) with the student groups during time scheduled for a course that was not related to genetics or the game. In each case the intervention took 90-120 minutes. The post-intervention questionnaire (manually distributed to the groups of participants by the first author two weeks after the intervention) included the same socio-demographic questions and genetics questions as in the first questionnaire. It also included questions about the pre-service teachers' experience of, and satisfaction with, the game. The delay between the intervention and post-testing was deliberately included to test the GBSL activity's persistent, rather than immediate, effects (Figure 2).

[Insert Figure 2 about here]

Participants

Two samples of pre-service primary teachers were recruited for the study, because they had limited pre-knowledge of genetics but would have responsibility for teaching children biology, including genetics, in the future. Thus, they were typical target groups for the Recal game. The first sample consisted of 120 pre-service teacher students (four classes of 20-30 students) from a university in north-eastern Spain. The students were taking an experimental science course that was part of their second level primary school teacher education program. The second sample consisted of 51 pre-service teachers (two classes of 20-30 students) from a university in western Sweden. Students were taking a general science course that was part of their primary teacher education program. It should be noted that the Spanish and Swedish curricula for primary teacher education do not include specific university courses in biology, but biology content is included in the abovementioned science courses.

The study followed the local ethical guidelines in both countries, *inter alia* the respondents were fully informed about the content of the study that participation was voluntary, and they could withdraw at any time. Consent was collected from the participants, and all acquired data have been treated with confidentiality and solely for research purposes.

Instruments

The questionnaires used in the study included five instruments. First, a set of socio-economic questions to acquire background information about the participants. Second, 10 items designed to measure genetic knowledge before and after the intervention, thereby addressing the first research question. The other three were reflective attitudinal instruments developed from the literature to assess the students' expectations of the game pre-intervention and both their experiences of and satisfaction with its post-intervention, thereby addressing the second research question. These instruments are described in the following sections.

- Socio-demographic data

These items consisted of one question for coding the participant, and three regarding socio-demographic variables (their age, gender and parents' educational level), as shown in Table 1. These three items were only included in the pre-intervention questionnaire. Sociodemographic data were collected to characterize both samples of students, and thus assess their comparability.

- Genetic knowledge test

Ten multiple-choice (True, False or Do not know) questions were designed to test participants' basic knowledge of genetics, matching specific intended learning outcomes

from the Recal game intervention. These items were included in both the pre- and post-intervention questionnaires (Tables 2 and 3) and were collected from author (2015b).

- Expectation questions

Three attitudinal questions regarding the participants' perceptions and expectations before participating in the Recal game were developed (Table 4) and included solely in the pre-intervention questionnaire.

- Experiences of and satisfaction with the game – part 1

A new instrument was developed to measure the students' experiences of and satisfaction with the game based on an instrument developed by Garrido (2005). This consists of 29 closed questions inviting Likert-type responses (strongly agree, agree, disagree, or strongly disagree) regarding five aspects of the intervention (organization and structure of the game, group working environment, motivation, student assessment, and future applications). These items (which were only included in the pre-intervention questionnaire) and associated aspects are presented in Table 5.

- Experiences of and satisfaction with the game – part 2

To further investigate the students' experiences of and satisfaction with the game an open-ended questionnaire adapted from Biasutti (2011) was included. This invites participants to note, in writing, three aspects of the Recal game that they would like to

keep, three they would like to eliminate and three they would like to change. These items (presented in Tables 6 and 7) were only included in the post-intervention questionnaire.

Statistical analysis

First the reliability of the instruments was assessed by calculating Cronbach's alpha coefficients. We then calculated descriptive statistics for participants' responses to the three questionnaire scales with closed questions and assessed the significance of between-group differences in responses using paired-sample t tests and repeated-measures Analysis of Variance (ANOVA) with a General Linear Model (GLM).

Analysis of responses to the open questions

An inductive approach was employed to analyse and categorize responses to the three open questions in the last section of the post-intervention questionnaire, based on the following five phases of the 'constant comparative method' (Strauss and Corbin 1998). First, immersion, in which all the discernibly different answers are recognized. Second, categorization, in which 'categories' are identified in the discernibly different answers. Third, phenomenological reduction, in which 'themes' emerge from the 'categories'. Fourth, triangulation, in which supplementary aspects are used to corroborate, amend and/or refine researchers' interpretations. Finally, in interpretation, a complete explanation of outcomes is sought based on the interpretations in conjunction with previous research and/or models. The coding of the open questions was subsequently

validated by an independent researcher who separately checked the data coding. The first author and the independent researcher addressed any disagreements regarding their coding and through a process of negotiation reached 100% agreement.

Finally, categories were weighted by frequencies of responses in which they appeared of participants of each group from each country.

Results

In this section we first present demographic data on our samples of Spanish and Swedish pre-service teacher students. These are means and standard deviations (in x ± y format) or frequencies of the students' age, gender, and parents' educational level.

[Insert Table 1 about here]

As shown in Table 1, the Spanish students were younger on average than the Swedish students (21.1 ± 3.53 and 28.3 ± 7.99 years, respectively). Hence, the Swedish students may have had more professional or academic experience before they entered teacher training. There were higher shares of females than males in both the Spanish and Swedish groups (79 and 91%, respectively), reflecting the dominance of women in primary teacher education in both countries. The Swedish students generally had more highly educated parents than the Spanish students. In summary, the demographic data indicate that the Swedish students may generally have had higher educational levels, and potentially more

pre-intervention knowledge of genetics and/or relevant contexts than the Spanish students.

Cronbach's alpha coefficients, calculated to assess the instruments' reliability, ranged between .89 and .96, indicating good reliability. In the following sections we present the results pertaining to each of the research questions addressed in the study.

***Does participation in the Recal game promote learning of genetics*?**

To assess the game's ability to promote students' learning of genetics, we compared total pre- and post-intervention scores (obtained by assigning one point for each correct answer to the genetic knowledge questions and summing scores for all students of both countries). The post-intervention scores were significantly higher, by more than two points, on average, than the pre-intervention scores: 6.09 ± .87 and 3.87 ± 2.03, respectively; $t(126) = 11.35$, $p < 0.001$. Furthermore, there were significant ($p < 0.05$) improvements in scores for all questions (Table 2), except question 3, for which there was a marginally significant improvement ($p = 0.07$).

[Insert Table 2 about here]

The next step was to investigate variations in the improvement in genetic knowledge. The Spanish students' post-intervention scores were 2.66 points higher than their pre-intervention scores on average (6.12 ± 1.90 and 3.46 ± 1.90, respectively). The Swedish students had higher pre-intervention scores on average (5.03 ± 1.93) than the Spanish

students, but there was just a one-point increase in their scores (to 6.03 ± 1.81) following the intervention. The significance of the differences between pre- and post-intervention scores between the two samples was confirmed by 2x2 repeated measures analysis, including time (pre- and post-intervention) and sample (Spanish and Swedish) factors.

In addition, between-sample differences in pre- and post-intervention scores for each question were examined. The results are presented in Table 3 and summarized here. In the pre-intervention test, only two questions were correctly answered by more than 50% of the Spanish teacher students (questions 2 and 9, which were correctly answered by 79 and 82% of the students, respectively). Three questions were correctly answered by more than 50% of the Swedish students (questions 2, 9 and 10, by 91, 88 and 70% of the students, respectively). Moreover, higher shares of the Swedish students than the Spanish students correctly answered nine of the 10 questions. In contrast, higher percentages of the Spanish students gave 'Do not Know' answers in the pre-intervention test, indicating awareness of their ignorance of corresponding genetic concepts. In the post-intervention test, seven and six of the questions were correctly answered by more than 50% of the Spanish and Swedish students, respectively. In addition, in the post-intervention test the Spanish students correctly answered the questions that elicited 'Do not Know' answers from them in the pre-intervention test.

Although the increase in the Spanish students' correct answers was significant for all questions (see Figure 3A), more than half still wrongly answered three of them (3, 4 and

8) in the post-intervention test. In contrast, the increases in correct responses by the Swedish participants to specific items were not significant, except for questions 5 and 6 (Figure 3B**)**. Similarly, less than half of them did not correctly answer four questions (3, 4, 5 and 8), three of which were in the corresponding set for Spanish students. Two of these items, questions 3 and 4 (inviting responses to the statements *DNA molecules are the same in all living beings* and *Chromosomes are made up of cells*, respectively) refer to genetic concepts concerning DNA structure and cell management of genetic information.

[Insert Table 3 about here]

[Insert Figure 3 about here]

Participants' experience of aspects of the game that promoted and hindered learning

The attitudes of students towards the Recal game before the activity were assessed using three expectation items in the pre-intervention test. The results indicate that, in both countries, 79% of students had great expectations about the activity and 85% expected it to be dynamic and motivating (Table 4). In addition, 88 and 91% of the Swedish and Spanish students agreed or strongly agreed that the activity would help to improve their knowledge. Thus, the students had high expectations before participating in the game.

Students' self-evaluated satisfaction with the game was quantitatively evaluated by 29 items in the post-intervention test covering five aspects of the game: *its organization & structure, group working environment, motivation, student assessment of the activity* and

future applications of the activity (Table 5). Both the Spanish and Swedish participants expressed positive responses to all five of the mentioned aspects, as illustrated by the following examples. More than 80 and 70% of the Spanish and Swedish students, respectively, agreed that the main goals of the activity were comprehensible and that its pacing and police case topic were appropriate and interesting. Around 90% of participants in both countries agreed that the game was motivating, dynamic, clear and well organized. Most participants of both countries also agreed that the educational material was helpful and that the group working atmosphere was satisfactory. They also expressed a preference for teamwork and indicated that they had learned from other team members.

The pre-service teachers also assessed the activity from a learning perspective. Most of the Spanish and Swedish students declared that the GBSL activity was a good way to learn and acquire new knowledge and that they would like to engage in such activities more often. More than 90 and 73% of them, respectively, declared that the Recal game had met their expectations. Similarly, around 90% of both samples stated that they would recommend the activity to other students.

[Insert Table 4 about here]

[Insert Table 5 about here]

The last part of the post-intervention questionnaire invited students to suggest sets of three aspects of the game that they would keep, change, and eliminate. The responses

were counted, and the most frequent suggestions are presented, with percentages of the Spanish and Swedish students who made them, in Tables 6 and 7, respectively.

[Insert Table 6 about here]

[Insert Table 7 about here]

Aspects of the Recal game that the highest shares of Spanish and Swedish teacher students would reportedly keep were the same: "teamwork" (25 and 26%, respectively) followed by 'police case' (17 and 15%, respectively) and 'use of additional information cards' (12 and 13%, respectively). However, there were some substantial variations in the two samples' responses. Most prominently, 12% of the Swedish students (but none of the Spanish students) highlighted the motivational quality of the GBSL activity. In contrast, 11% of the Spanish students (but none of the Swedish students) approvingly mentioned the Recal game's structure.

Regarding aspects that students thought should be changed, nearly a fifth of the Swedish students (19%) stated that the instructions should be clearer at the start of the game. A similar share of the Spanish students (16%) advocated inclusion of more supplementary information cards and more information on each card to help participants solve the case. A substantial share of the Spanish students (12%) also raised timing issues. However, some recommended provision of more time for the tasks, while others said that they had to wait too long for other groups to complete assignments. This discrepancy might be associated with differences in students' levels of prior understanding and suggests that

allowing groups to work at their own pace may be beneficial. Several suggestions were assigned to 'Teacher' and 'Information' categories, especially by Spanish students who recommended introduction of genetic contents before participation in the activity or provision of more information during the game.

Finally, regarding aspects of the Recal game that students would eliminate, 21% of the Swedish students recommended re-organization of the game, and reduction of the confusing number of worksheets. A substantial share 25% of the Spanish students also stated that they would eliminate some worksheets. In addition, around a quarter of the Swedish students stated that the content was too difficult and recommended reduction of the information, and 15% of the Spanish students recommended simplification of the game by reducing the number of activities. A general conclusion is that the Spanish students would have preferred a lower workload during the activity, while the Swedish students advocated re-organization of the materials.

In summary, a large majority of the Spanish and Swedish students agreed that the topic based on a police case is interesting and maintains the participants' engagement in the activity. They also preferred working in groups to working individually. They found the supplementary information cards helpful for solving the police case, but substantial shares indicated that there is too much information to learn in a two-hour session. Thus, dividing the activity into two sessions or providing more time, if necessary, for groups to read and assimilate the information may also be helpful.

Discussion

Recals' ability to promote learning of genetics

Presented results of the pre- and post-intervention tests of genetic knowledge show that the Recal game can improve the genetic knowledge of participating students. Responses of the Spanish and Swedish students to the intervention were very similar, indicating that the Recal game can be used in various contexts with similar results. The knowledge gain between the pre- and post-tests was slightly greater in Spain, but this might be due to 'ceiling effects' associated with Swedish pre-service teacher students' higher pre-intervention knowledge and pre-intervention test scores. Thus, there was less scope for the activity to improve their scores.

Results of these tests support previous findings that use of gaming methodologies in genetics teaching can provide better learning outcomes than traditional approaches (Kim et al., 2015; Rachmatullah et al. 2021; Solé-Llussà et al. 2018), but conflict with findings by Anetta et al. (2009) that GBSL has no significant effects on learning outcomes in genetics. It should be noted that our results also extend the previous findings as they are based on studies of digital gaming, while we investigated a physical game and its effects.

However, our results are not unambiguous. Participation in the Recal game substantially enhanced the students' understanding of 'transfer of information between generations', and 'differences in karyotypes between species and between males and females. In contrast, it provided limited improvement in understanding of the nature of genetic

information, and there was considerable confusion—as often found in previous studies (Annetta et al. 2009; Rachmatullah et al. 2021)—about basic biological structures (chromosomes, cells, and genes) before and after the intervention. Nevertheless, the detected effects of the Recal game on genetic understanding are encouraging, particularly given the short duration of the intervention. However, these effects are largely restricted to concepts that are mostly strongly targeted in the game, and to teach a broader web of genetic concepts the game must be complemented with other games, teaching aids or traditional instruction.

Characteristics of GBSL that facilitate or hinder learning

We discuss here results regarding attitudinal aspects: expectations of and satisfaction with the game, and their relations to designed characteristics of the GBSL framework (contextualisation, authenticity, collaboration, competition, problem-solving and guided paths). Overall, the teacher students' experiences were generally positive, and similar in both countries, indicating that the Recal game has both utility and validity. The game was new to the students, and the intervention was conducted as an event outside their ordinary teaching practice. This might have promoted a positive response due to the specific attention it received (Cook 1962) and/or power relations (Cohen, Manion and Morrison 2011), so the results should be interpreted with caution. However, the open-ended qualitative responses provide indications of the students' reasons for their positive response, which corroborate the robustness of the results, and the conclusion that the

reported positive experience was due to participation in the game rather than the attention it received or power relations.

The *contextualization* of genetics by using a forensic case as well as the *authenticity* through identity-making by providing different roles in the police case was highly appreciated by the students, as shown in the questionnaire responses. The students claimed this increased their motivation to learn more about biotechnological applications of genetic knowledge. Van der Wal et al. (2016) argued that role assignment in games might be important for social learning. This is because it can putatively improve the quality of solutions by including relevant non-scientific sources of knowledge and experience, and by enhancing solutions' relevance and legitimacy through associated provision of diverse perspectives. The findings of this study support these arguments. Although the use of forensic cases in genetic games is not novel, it was novel to most of the participants in our study, which might partly explain the positive experiences. Hence, a novelty effect cannot be excluded as a possible explanation for these positive experiences.

The presence and importance of the *collaborative* characteristic in the Recal game were acknowledged in the students' responses to part 1 of the experiences of and satisfaction questionnaire, which clearly indicated that they felt there was a good working atmosphere during the gaming. Moreover, in responses to the open-ended questions students from both countries stated that the most appreciated characteristic of the activity was working

in groups, as shown in the 'team work' category. Hence, most students, from both countries, felt comfortable engaging in the activity in groups, corroborating previous findings that collaboration is an important success factor in GBSL design (Chen, Liu and Shou 2018; Chen et al., 2018). Interestingly, however, the students provided little support for the notion that the *competitive* aspect of the game was important. This is consistent with findings in a recent study that students who engaged in a ~~competitive~~ intervention performed significantly better on a learning achievement test than peers who had engaged in a competitive, but otherwise identical, intervention (Chen, Liu & Shou 2018). The results of our study give some support for those findings. Thus, the importance and effects of competition clearly warrant further investigation and consideration in the further development of GBSL.

Almost all the participating Spanish and Swedish pre-service teacher students also agreed that the *problem-based learning* approach incorporated in the activity was a beneficial way to learn. The vast majority of both sets said that they would like to engage in such activities more often in their education. This is consistent with underlying theories of gaming as suggested by Gee (2008), and empirical findings as reviewed by Chen, Lui and Shou (2018) that problem-based activities in GBSL have motivational features.

Regarding the last characteristic, the *guided paths* provided by the game, our results indicate that most of the pre-service teachers from both countries thought that the main goals of the Recal game were understandable and clear. However, many students

suggested that additional information cards and more instructions could improve the game, clearly indicating that some students wanted more guidance or scaffolding. This could be at least partly due to most students in both countries having little experience of learning through this kind of game activity, and limited pre-knowledge of genetics. In future development of the Recal game, more scaffolding should be considered. However, if the degree of scaffolding is increased, the level of problem-based learning is decreased, and the optimal trade-off between the two goals must be considered. This may be an important finding to consider in the future development of SEGs for players with limited pre-knowledge and gaming skills to use in GBSL activities.

To conclude, most of the design characteristics of GBSL used to develop the Recal game seem to function as intended, but the competition and guided paths characteristics showed less alignment with intended goals for the game. Consideration of these findings might be useful in efforts to design, research and develop SEGs for use in future GBSL.

Implications for the use and further studies of the Recal game

The results of this study indicate that the Recal game has the potential to promote genetics learning via a GBSL approach. The results show that participation in the game increased the pre-service teachers' knowledge and understanding of some central ideas of genetics. Hence, the game can enhance the genetics literacy of an important target group who generally have limited educational background in genetics but will be responsible for teaching children about the subject in the future, as called for in the literature

(Boerwinkel, Yarden and Waarlo 2017). Moreover, the attitudinal and experienced based results show that the students had very positive experiences during their participation. This is encouraging as attitudinal aspects are suggested to be very important for engaging in a game and hence learning from it (Cheng, She and Annetta 2014).

As the results in the two different educational and cultural contexts of Spain and Sweden were very similar it seems likely that the game would have similar benefits in other countries and educational systems. Thus, we advocate its use in other countries and educational contexts. However, it is also important to recognize that a rigorous experimental design was not applied in this study, and more evaluations of the games' effects are required, including comparisons with a control group. Comparisons of this physical game with other interventions based on digital games designed to foster learning of genetics would also be valuable. One interesting possibility would be to digitalize the Recal game then compare effects of the digital and physical versions.

References

Authors (2014).

Authors (2015a).

Authors (2015b).

Authors (2017).

Authors (2021).

Annetta, L. A. (2008). *Serious educational games*. The Netherlands: Sense Publishers.

Annetta, L. A., Minogue, J., Holmes, S. Y., & Cheng, M. T. (2009). Investigating the impact of video games on high school students' engagement and learning about genetics. *Computers & Education*, 53(1), 74-85. https://doi.org/10.1016/j.compedu.2008.12.020

Bahar, M., Johnstone, A.H., & Hansell, M.H. (1999). Revisiting learning difficulties in biology. *Journal of Biological Education*, 33(2), 84-86. https://doi.org/10.1080/00219266.1999.9655648

Barab, S.A., & Dede, C. (2007). Games and immersive participatory simulations for science education: An emerging type of curricula. *Journal of Science Education and Technology*, *16* (1), 1–3. https://doi.org/10.1007/s10956-007-9043-9

Biasutti, M. (2011). The student experience of a collaborative e-learning university module. *Computers & Education*, *57*(3), 1865-1875. https://doi.org/10.1016/j.compedu.2011.04.006

Boerwinkel, D.J., Yarden, A, & Waarlo, A. (2017). Reaching a consensus on the definition of genetic literacy that is required from a twenty-first-century citizen. *Science & Education*, 26(10),1087–1114.

Boyle, E. A., Hainey, T., Connolly, T. M., Gray, G., Earp, J., Ott, M., et al. (2016). An update to the systematic literature review of empirical evidence of the impacts and outcomes of computer games and serious games. *Computers & Education*, 94, 178-192. https://doi.org/10.1016/j.compedu.2015.11.003

Chen, S. Y., Chu, Y. R., Lin, C. Y., & Chiang, T. Y. (2016). Students' knowledge of, and attitudes towards biotechnology revisited, 1995–2014: Changes in agriculture biotechnology but not in medical biotechnology. *Biochemistry and Molecular Biology Education*, *44*(5), 475-491.

Chen, C. H., Liu, J. H., & Shou, W. C. (2018). How competition in a game-based science learning environment influences students' learning achievement, flow experience, and learning behavioral patterns. *Journal of Educational Technology & Society*, 21(2), 164-176. http://www.jstor.org/stable/26388392

Cheng, M.-T., Lin, Y.-W., She, H. C., & Kuo, P. C. (2016). Is immersion of any value? Whether, and to what extent, game immersion experience during serious gaming effects science learning. *British Journal of Educational Technology*, 48(2), 246-263. https://doi.org/10.1111/bjet.12386

Chen, J., Wang, M., Kirschner, P. A., & Tsai, C. C. (2018). The role of collaboration, computer use, learning environments, and supporting Strategies in CSCL: A meta-

analysis. *Review of Educational Research*. 88(6), 799-843. https://doi.org/10.3102/0034654318791584

Cheng, M. T., She, H. C., & Annetta, L. A. (2015). Game immersion experience: its hierarchical structure and impact on game-based science learning. *Journal of Computer assisted Learning,* 31(3), 232-253. https://doi.org/10.1111/jcal.12066

Cohen, L., Manion, L., & Morrison, K. (2011). *Research methods in education* (7th ed.). Abingdon: Routledge.

Connolly, T. M., Boyle, E. A., MacArthur, E., Hainey, T., & Boyle, J. M. (2014). A systematic literature review of empirical evidence on computer games and serious games. *Computer Education*, 59(2), 661-686. https://doi.org/10.1016/j.compedu.2012.03.004

Cook, D. L. (1962). The Hawthorne effect in educational research. *Phi Delta Kappan*, 44, 116-22.

Creswell, J. W. (2014). A concise introduction to mixed methods research. SAGE publications.

Dougherty, M. J., Pleasants, C., Solow, L., Wong, A., & Zhang, H. (2011). A comprehensive analysis of high school genetics standards: Are states keeping pace with modern genetics? *CBE-Life Sciences Education*, 10, 318–327. https://doi.org/10.1187/cbe.10-09-0122

European Commission (2010). Special Eurobarometer 341. *Biotechnology*. Brussels (Belgium): Directorate General Research, EU. Retrieved from: http://ec.europa.eu/public_opinion/archives/ebs/ebs_341_en.pdf

Garrido, M. F. (2005). Formación basada en las Tecnologías de la Información y Comunicación: análisis didáctico del proceso de enseñanza-aprendizaje (Doctoral disertation, Universitat Rovira i Virgili).

Gee, J. P. (2003). *What video games have to teach us about learning and literacy*. New York, NY: Palgrave Macmillan.

Gee, J. P. (2008). Learning and games. In K. Salen (Ed.), *The ecology of games: Connecting youth, games, and learning* (pp. 21–40). Cambridge, MA: MIT Press.

Hussein, M.H., Ow, S.H., Cheong, L.S., Thong, M., & Ale Ebrahim, N., (2019). Effects of digital game-based learning on elementary science learning: A systematic review. *IEEE Access*, 7, 62465-62478. doi: 10.1109/ACCESS.2019.2916324

IBM Corp. 2016. *IBM SPSS Statistics for Windows*, Version 24.0. Armonk, New York: IBM Corp.

Kılıç, D., & Sağlam, N. (2014). Students' understanding of genetics concepts: The effect of reasoning ability and learning approaches. *Journal of Biological Education*, *48*(2), 63-70.

Kim, B., Pathak, S. A., Jacobson, M. J., Zhang, B., & Gobert, J. D. (2015). Cycles of exploration, reflection, and consolidation in model-based learning of genetics. *Journal of Science Education and Technology*, 24(6), 789-802. https://doi.org/10.1007/s10956-015-9564-6

Kirschner, P.A. & Van Merrienboer, J. J. G. (2013) Do learners really know best? Urban legends in education. *Educational Psychologist*, 48(3), 169-183. https://doi.org/10.1080/00461520.2013.804395

Li, M. C., and C. C. Tsai. (2013). Game-based Learning in science education: A review of relevant research. *Journal of Science Education and Technology,* 22 (6): 877–898. doi:10.1007/s10956-013-9436-x.

Liu, M., Rosenblum, J. A., Horton, L., & Kang, J. (2014). Designing science learning with game-based approaches. *Computers in the Schools*, 31(1-2), 84-102. https://doi.org/10.1080/07380569.2014.879776

Loinaz, E. S. (2019). Teachers' perceptions and practice of social and emotional education in Greece, Spain, Sweden and the United Kingdom. *International Journal of Emotional Education*. 11, 31–48.

Marbach-Ad, G., Rotbain, Y., & Stavy, R. (2008). Using computer animation and illustration activities to improve high school students' achievement in molecular

genetics. *Journal of Research in Science Teaching*, *45*(3), 273-292. https://doi.org/10.1002/tea.20222

Marbach-Ad, G., & Stavy, R. (2000). Students' cellular and molecular explanations of genetic phenomena. *Journal of Biological Education*, 34(4), 200-205. https://doi.org/10.1080/00219266.2000.9655718

National Research Council [NRC]. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, D.C: The National Academies Press.

O'Neil, H. F., Wainess, R., & Baker, E. L. (2005). Classification of learning outcomes: Evidence from the computer games literature. *The Curriculum Journal*, *16*, 455–474, doi: 10.1080/09585170500384529

Rachmatullah, A., Reichsman, F., Lord, T., Dorsey, C., Mott, B., Lester, J., & Wiebe, E. (2021). Modeling secondary students' genetics learning in a game-based environment: Integrating the expectancy-value theory of achievement motivation and flow theory. *Journal of Science Education and Technology*, 1-18. https://doi.org/10.1007/s10956-020-09896-8

Solé-Llussà, A., Casanoves, M., Salvadó, Z., Garcia-Vallve, S., Valls, C., & Novo, M. (2018). Annapurna expedition game: Applying molecular biology tools to learn

genetics. *Journal of Biological Education*, *53*(5), 516-523. https://doi.org/10.1080/00219266.2018.1501409

Spires, H. A., Nesbitt, K. T., Paul, C. M., & Lester, J. C. (2019). Game-based literacies and learning: Towards a transactional theoretical perspective. *ValpoScholar*, 20(4), 81.

Stern, F., & Kampourakis, K. (2017). Teaching for genetics literacy in the post-genomic era. *Studies in Science Education*, 53(2), 193-225. https://doi.org/10.1080/03057267.2017.1392731

Strauss, A., & Corbin, J. (1998). *Basics of qualitative research: Grounded theory procedures and techniques* (2nd ed.). Thousand Oaks, CA: Sage.

Van der Wal, M. M., De Kraker, J., Kroeze, C., Kirschner, P. A., & Valkering, P. (2016). Can computer models be used for social learning? A serious game in water management. *Environmental modelling & software*, 75, 119-132. https://doi.org/10.1016/j.envsoft.2015.10.008

Vogel, J. J., Vogel, D. S., Cannon-Bowers, J., Bowers, C. A., Muse, K., & Wright, M. (2006). Computer gaming and interactive simulations for learning: A meta-analysis. *Journal of Educational Computing Research*, 34(3), 229-243. https://doi.org/10.2190/FLHV-K4WA-WPVQ-H0YM

Wouters, P., Van Nimwegen, C., Van Oostendorp, H., & Van Der Spek, E. D. (2013). A meta-analysis of the cognitive and motivational effects of serious games. *Journal of Educational Psychology,* 105(2), 249-265. https://doi.org/10.1037/a0031311

Figures and Tables

Table 1

Socio-demographic data on the Spanish and Swedish participants.

	Variable	Spanish	Swedish
Age	Age in years	21.15±3.53	28.27±7.99
Sex	Female	79%	91%
	Male	21%	9%
Parents' educational level	Elementary school certificate	31%	12%
	High school certificate	44%	46%
	University degree	25%	42%

Table 2

Total scores for each genetic knowledge question in the pre- and post-intervention tests.

Question	Pre-test	Post-test	*t*	*p*
1. The phenotype is independent of genetic information.	2.76	5.76	5.67	< .001
2. All living organisms have the same number of chromosomes.	8.27	9.84	4.36	< .001

3. DNA molecules are the same in all living beings.	2.44	3.39	1.83	.070
4. Chromosomes are composed of cells.	2.05	2.83	1.98	.049
5. We can distinguish two women by the information that we get from karyotypes.	0.79	4.72	8.50	< .001
6. We can obtain information about species, gender and some genetic diseases from a karyotype.	3.7	7.95	7.68	< .001
7. Human beings have more DNA because they are more evolved.	3.78	7.01	5.91	< .001
8. A son looks more like his father when he receives a higher percentage of genetic information from him.	2.13	3.7	3.04	.003
9. Men have one chromosome that is the same as in women and another that is different.	8.43	9.21	2.16	.032
10. A boy has 23 pairs of chromosomes. His father transmits to him one chromosome of each pair and his mother the other.	4.33	6.54	4.80	< .001

Table 3

Percentages of Spanish and Swedish students' correct and wrong answers for each genetic knowledge question in the pre- and post-intervention tests.

		Spanish						Swedish					
		Pre-test			Post-test			Pre-test			Post-test		
	Correct answer	Correct	Wrong	D.K.	Correct	Wrong	D.K.	Correct	Wrong	D.K.	Correct	Wrong	D.K.
1. The phenotype is independent of genetic information.	F	22	11	67	60	17	23	42	15	42	52	21	27
2. All living beings have the same number of	F	79	4	16	99	0	1	91	6	3	97	0	3

chromosomes.													
3. DNA molecules are the same in all living beings.	T	22	53	24	39	50	11	30	64	6	18	73	9
4. Chromosomes are composed of cells.	F	12	41	47	22	52	26	45	45	9	45	45	9
5. We can distinguish two women by the information that we get from karyotypes.	F	7	22	70	52	34	14	9	24	67	33	52	15
6. We can obtain information about species, gender and some genetic diseases from a karyotype.	T	37	3	60	78	10	13	36	9	55	85	9	6
7. Human beings have more DNA because they are more evolved.	F	29	18	53	70	12	18	64	15	21	70	15	15
8. A son looks more like his father when he receives a higher percentage of genetic information from him.	F	19	71	10	38	57	4	27	55	18	33	55	12
9. Men have one chromosome that is the same as in	T	82	3	14	94	3	3	88	9	3	88	6	6

women and another that is different.													
10. A boy has 23 pairs of chromosomes. His father													
transmits to him one chromosome of each pair and his	T	33	13	53	60	16	24	70	15	15	82	9	9
mother the other.													

Table 4

Students' pre-test expectations about the Recal game (percentages of indicated responses).

	Spain				Sweden			
	Strongly disagree	Disagree	Agree	Strongly agree	Strongly disagree	Disagree	Agree	Strongly agree

I have great expectations about this new activity.	1	20	68	11	3	18	58	21
I think that this activity is going to improve my knowledge.	0	3	54	43	0	12	67	21
I think that this activity is going to be dynamic and motivating.	0	15	73	12	0	15	70	15

Table 5

Percentages of indicated responses to the satisfaction and usability questions (in percentages) regarding: organization and structure of the game , group work environment, motivation, student assessment of the activity and future applications of the activity.

	Spanish students				Swedish students			
organization and structure of the game (timing, cards, teacher...):	Strongly disagree	Disagree	Agree	Strongly agree	Strongly disagree	Disagree	Agree	Strongly agree
The activity's main goals were understandable and simple.	0	5	76	19	0	21	73	6
The activity's pacing was appropriate and maintained	1	10	53	36	0	3	73	24

interest.								
The police case topic used was appropriate.	0	5	50	45	0	0	76	24
Wordings were clear and I could understand that was required.	0	7	64	29	3	36	42	18
I understood all the questions at the end of each stage.	1	6	60	33	3	27	39	30
The activity was clear and well-organised.	0	13	42	45	3	27	48	21
The teacher / professor was a good guide during the activity.	0	6	44	50	0	15	45	39
I had enough time to finish the activity.	2	9	32	57	3	3	58	36
We had enough resources during the activity to solve the police case.	1	18	53	28	0	3	58	39
I think that all the educational materials were useful.	0	15	58	27	3	21	48	27

I used the educational material at the right moments.	0	8	61	31	0	30	42	27
I could obtain all the information that I didn't know from the additional information cards	0	5	53	42	0	15	61	24
The additional information cards motivated me to continue solving the police case.	1	15	62	22	3	15	58	24

	Spanish students				Swedish students			
Group working environment:	Strongly disagree	Disagree	Agree	Strongly agree	Strongly disagree	Disagree	Agree	Strongly agree
The group working atmosphere was satisfactory.	0	1	24	75	0	6	45	48
I would have preferred to do the activity on my own.	80	13	4	3	42	36	15	6
I had some problems with other team members to solve	81	16	1	2	67	21	6	6

the activity.								
I learned from other members of the team when I had doubts.	3	9	52	36	3	18	55	24

Motivation:	Strongly disagree	Disagree	Agree	Strongly agree	Strongly disagree	Disagree	Agree	Strongly agree
This activity has increased my interest in genetics and biotechnology.	9	54	35	2	15	39	45	0
This police case has motivated me to increase my knowledge about scientific topics.	15	47	37	1	18	55	27	0
I think that this activity is motivating and dynamic.	0	9	60	31	3	9	73	15
Student assessment of the activity:	Strongly				Strongly		Agree	

	disagree	Disagree	Agree	Strongly agree	disagree	Disagree		Strongly agree
I think that this kind of problem-based learning activity is a good way to learn.	0	5	61	34	0	3	70	27
The research that we did to solve the police case was useful for gaining knowledge.	0	18	58	24	0	6	76	18
This activity made me learn new knowledge.	1	14	63	22	0	12	73	15
It was difficult to solve all parts of this case.	17	66	16	1	9	36	48	6
I would like to do activities of this kind more often.	1	6	48	45	3	12	61	24
Future applications of the activity:	Strongly disagree	Disagree	Agree	Strongly agree	Strongly disagree	Disagree	Agree	Strongly agree

My expectations of this new activity were met.	0	9	81	10	3	24	70	3
I think that I have improved my knowledge.	0	38	54	8	0	24	70	6
I am going to recommend this activity to other students.	0	6	62	32	0	12	58	30
I think that I could apply all acquired knowledge in the future.	1	41	52	6	0	33	55	12

Table 6

Sets of three aspects that Spanish students would like to keep, change and eliminate from the Recal game.

	Keep			Change			Eliminate		
	Themes	Categories	Percentage (%)	Themes	Categories	Percentage (%)	Themes	Categories	Percentage (%)
Spain	Methodology	Game	11.17	Methodology	Police case	3.20	Methodology	Evaluation	17.40
		Practical	1.06		Game	1.60		Competitively	4.35
		Police case	14.89		Flipped class	0.80		Timing	13.04
		Organization	3.72		Organization	2.40	Material	Number of activities	15.22
		Timing	2.66		Timing	12.00		Difficulty	4.35
		Guided	2.13		Evaluation	4.80		Extra info cards	10.87
		Evaluation	4.79		Team work	3.20		Clarity	2.17
		Competitively	3.72		Motivation	4.00		Design	15.22
		Class	3.72	Material	Activities	5.60		Resources	13.04
		Team work	26.06		Difficulty	3.20	Contents	Previous knowledge	2.17
		Team environment	0.53		Worksheets	4.80		Difficulty	2.17
	Material	Worksheets	6.38		Extra info cards	16.25			
		Extra info cards	13.30		Clues	2.40			
		Clues	2.13		Resources	3.20			
		Resources	3.72		Design	2.40			
					Prize	2.40			
				Contents	Teacher	8.80			
					Goals	1.60			
					Previous knowledge	6.40			
					Information	12.00			
					Summary	4.80			

Table 7

Sets of three aspects that Sweden students would like to keep, change and eliminate from the Recal game.

	Keep			Change			Eliminate		
	Themes	Categories	Percentage (%)	Themes	Categories	Percentage (%)	Themes	Categories	Percentage (%)
Sweden	Methodology	Organization	7.69	Methodology	Instructions	18.92	Methodology	Police case	5.26
		Timing	5.77		Order	2.70		Autonomous	5.26
		Set-up	1.92		Timing	8.11		Competition	5.26
		No guided activity	1.92		Chronogram	5.41		Evaluation	5.26
		Police case	17.31		Work environment	5.41	Material	Organization	21.05
		Innovation	1.92		Team work	5.41		Clues	5.26
		Motivation	11.54		Competition	2.70	Contents	Instructions	10.53
		Team work	25.00		Evaluation	2.70		Teacher	5.26
		Competition	3.85	Material	Worksheets	8.11		Difficulty	26.32
	Material	Clues	5.77		Info cards	8.11		Knowledge	10.53
		Extra info cards	11.54		Translations	5.41			
	Contents	Educational	3.85		Organization	2.70			
		Knowledge	1.92		Difficulty	5.41			
					Simplicity	10.81			
				Contents	Previous knowledge	8.11			

Figure 1. *Workflow of the Recal game.*

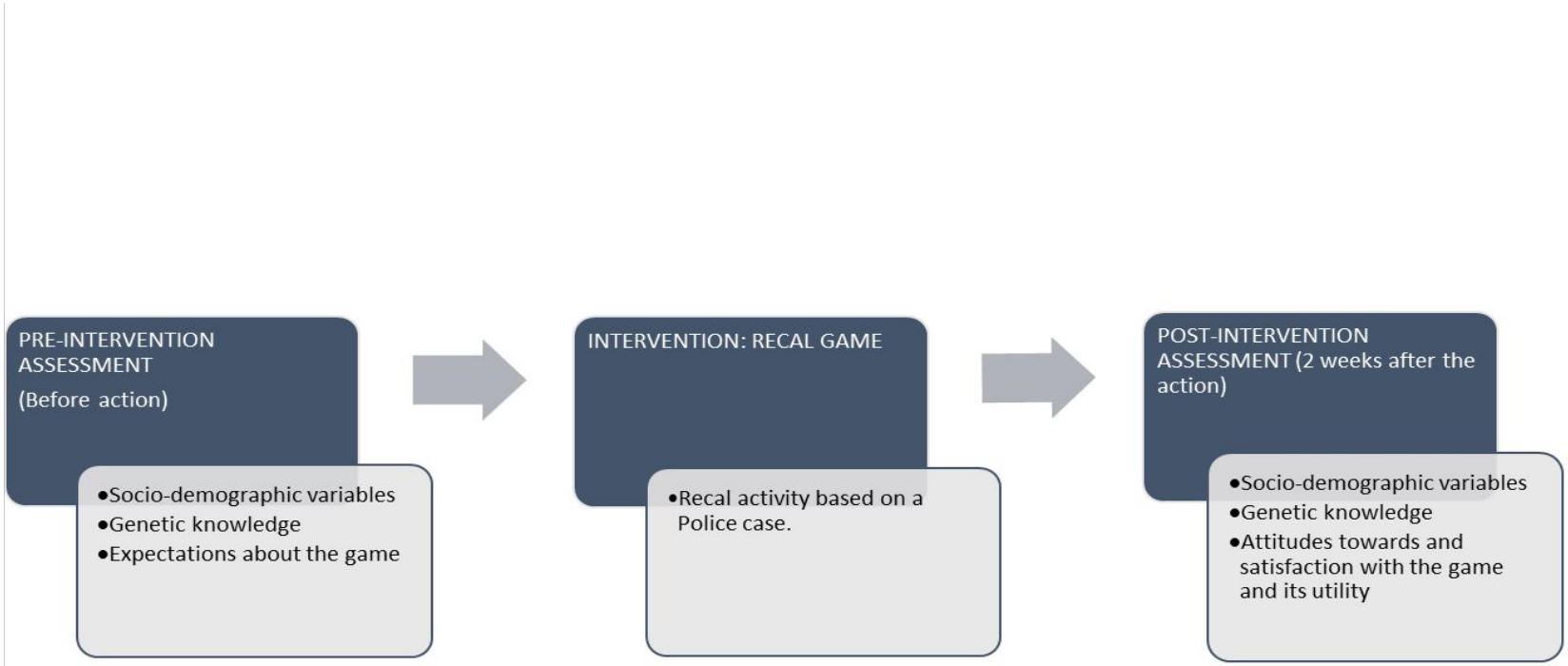

Figure 2. *Phases and schedule of the intervention and assessments.*

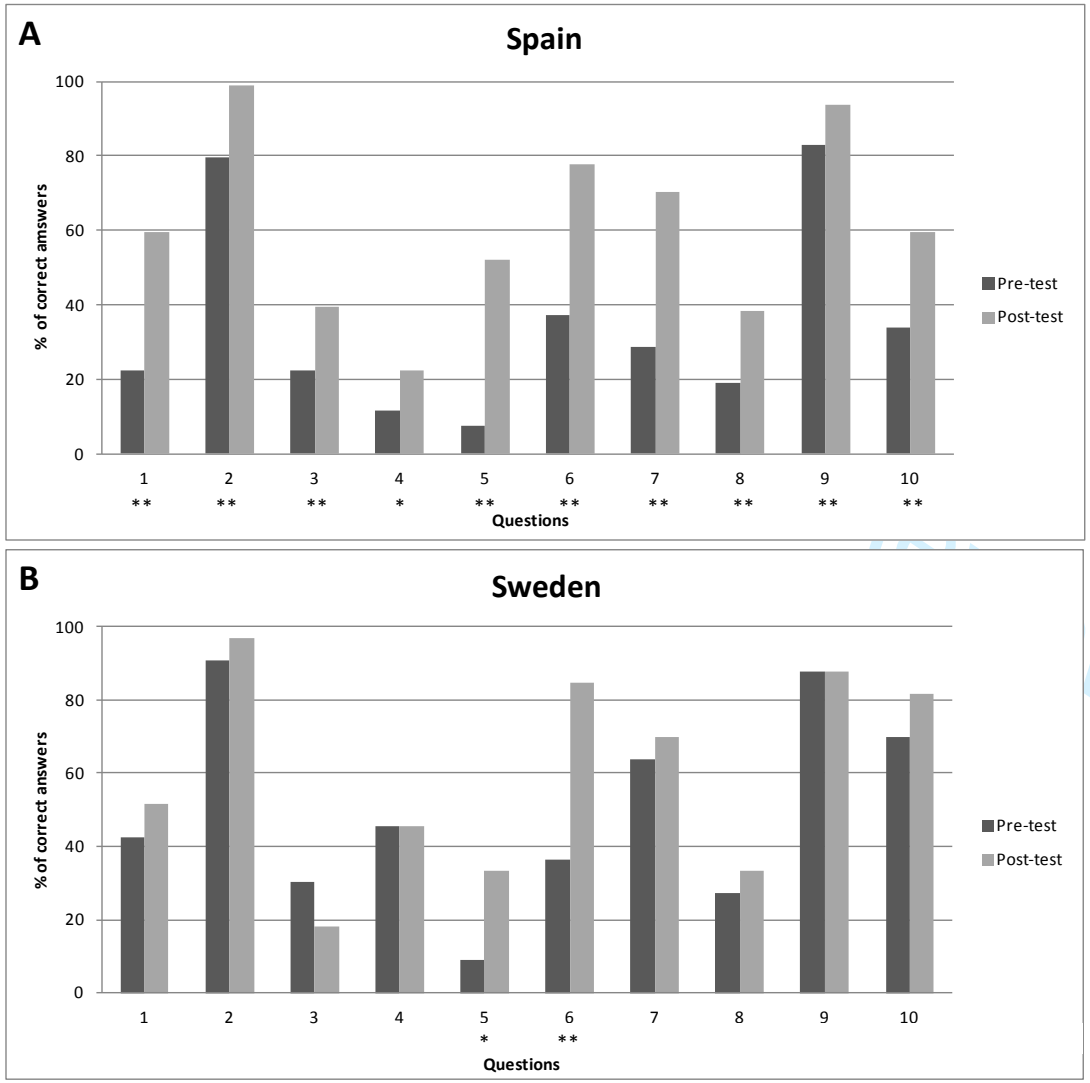

Figure 3

*Percentages of correct answers for all questions in the pre- and post-intervention tests in Spain (A) and Sweden (B). Asterisks indicate the significance of differences between pre- and post-intervention scores: **p<.01 and *p<.05.*

	Variable	Spanish	Swedish
Age	Age in years	21.15±3.53	28.27±7.99
Sex	Female	79%	91%
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Correct answer	Correct	Wrong	D.K.	Correct	Wrong	D.K.	Correct	Wrong	D.K.	Correct	Wrong	D.K.
1. The phenotype is independent of genetic information. F	22	11	67	60	17	23	42	15	42	52	21	27

2. All living beings have the same number of chromosomes.	F	79	4	16	99	0	1	91	6	3	97	0	3
3. DNA molecules are the same in all living beings.	T	22	53	24	39	50	11	30	64	6	18	73	9
4. Chromosomes are composed of cells.	F	12	41	47	22	52	26	45	45	9	45	45	9
5. We can distinguish two women by the information that we get from karyotypes.	F	7	22	70	52	34	14	9	24	67	33	52	15
6. We can obtain information about species, gender and some genetic diseases from a karyotype.	T	37	3	60	78	10	13	36	9	55	85	9	6
7. Human beings have more DNA because they are more evolved.	F	29	18	53	70	12	18	64	15	21	70	15	15
8. A son looks more like his father when he receives a higher percentage of genetic information from him.	F	19	71	10	38	57	4	27	55	18	33	55	12

9. Men have one chromosome that is the same as in women and another that is different.	T	82	3	14	94	3	3	88	9	3	88	6	6
10. A boy has 23 pairs of chromosomes. His father transmits to him one chromosome of each pair and his mother the other.	T	33	13	53	60	16	24	70	15	15	82	9	9

Table 4

Students' pre-test expectations about the Recal game (percentages of indicated responses).

	Spain				Sweden			
	Strongly disagree	Disagree	Agree	Strongly agree	Strongly disagree	Disagree	Agree	Strongly agree
I have great expectations about this new activity.	1	20	68	11	3	18	58	21
I think that this activity is going to improve my knowledge.	0	3	54	43	0	12	67	21
I think that this activity is going to be dynamic and motivating.	0	15	73	12	0	15	70	15

Table 5

Percentages of indicated responses to the satisfaction and usability questions (in percentages) regarding: organization and structure of the game , group work environment, motivation, student assessment of the activity and future applications of the activity.

	Spanish students				Swedish students			
organization and structure of the game (timing, cards, teacher...):	Strongly disagree	Disagree	Agree	Strongly agree	Strongly disagree	Disagree	Agree	Strongly agree

The activity's main goals were understandable and simple.	0	5	76	19	0	21	73	6
The activity's pacing was appropriate and maintained interest.	1	10	53	36	0	3	73	24
The police case topic used was appropriate.	0	5	50	45	0	0	76	24
Wordings were clear and I could understand that was required.	0	7	64	29	3	36	42	18
I understood all the questions at the end of each stage.	1	6	60	33	3	27	39	30
The activity was clear and well-organised.	0	13	42	45	3	27	48	21
The teacher / professor was a good guide during the activity.	0	6	44	50	0	15	45	39
I had enough time to finish the activity.	2	9	32	57	3	3	58	36

We had enough resources during the activity to solve the police case.	1	18	53	28	0	3	58	39
I think that all the educational materials were useful.	0	15	58	27	3	21	48	27
I used the educational material at the right moments.	0	8	61	31	0	30	42	27
I could obtain all the information that I didn't know from the additional information cards	0	5	53	42	0	15	61	24
The additional information cards motivated me to continue solving the police case.	1	15	62	22	3	15	58	24

	Spanish students				Swedish students			
Group working environment:	Strongly disagree	Disagree	Agree	Strongly agree	Strongly disagree	Disagree	Agree	Strongly agree

The group working atmosphere was satisfactory.	0	1	24	75	0	6	45	48
I would have preferred to do the activity on my own.	80	13	4	3	42	36	15	6
I had some problems with other team members to solve the activity.	81	16	1	2	67	21	6	6
I learned from other members of the team when I had doubts.	3	9	52	36	3	18	55	24

Motivation:	Strongly disagree	Disagree	Agree	Strongly agree	Strongly disagree	Disagree	Agree	Strongly agree
This activity has increased my interest in genetics and biotechnology.	9	54	35	2	15	39	45	0

This police case has motivated me to increase my knowledge about scientific topics.	15	47	37	1	18	55	27	0
I think that this activity is motivating and dynamic.	0	9	60	31	3	9	73	15

Student assessment of the activity:	Strongly disagree	Disagree	Agree	Strongly agree	Strongly disagree	Disagree	Agree	Strongly agree
I think that this kind of problem-based learning activity is a good way to learn.	0	5	61	34	0	3	70	27
The research that we did to solve the police case was useful for gaining knowledge.	0	18	58	24	0	6	76	18
This activity made me learn new knowledge.	1	14	63	22	0	12	73	15
It was difficult to solve all parts of this case.	17	66	16	1	9	36	48	6

I would like to do activities of this kind more often.	1	6	48	45	3	12	61	24

Future applications of the activity:	Strongly disagree	Disagree	Agree	Strongly agree	Strongly disagree	Disagree	Agree	Strongly agree
My expectations of this new activity were met.	0	9	81	10	3	24	70	3
I think that I have improved my knowledge.	0	38	54	8	0	24	70	6
I am going to recommend this activity to other students.	0	6	62	32	0	12	58	30
I think that I could apply all acquired knowledge in the future.	1	41	52	6	0	33	55	12

Table 6

Sets of three aspects that Spanish students would like to keep, change and eliminate from the Recal game.

	Keep			Change			Eliminate		
	Themes	Categories	Percentage (%)	Themes	Categories	Percentage (%)	Themes	Categories	Percentage (%)
Spain	Methodology	Game	11.17	Methodology	Police case	3.20	Methodology	Evaluation	17.40
		Practical	1.06		Game	1.60		Competitively	4.35
		Police case	14.89		Flipped class	0.80		Timing	13.04
		Organization	3.72		Organization	2.40	Material	Number of activities	15.22
		Timing	2.66		Timing	12.00		Difficulty	4.35
		Guided	2.13		Evaluation	4.80		Extra info cards	10.87
		Evaluation	4.79		Team work	3.20		Clarity	2.17
		Competitively	3.72		Motivation	4.00		Design	15.22
		Class	3.72	Material	Activities	5.60		Resources	13.04
		Team work	26.06		Difficulty	3.20	Contents	Previous knowledge	2.17
		Team environment	0.53		Worksheets	4.80		Difficulty	2.17
	Material	Worksheets	6.38		Extra info cards	16.25			
		Extra info cards	13.30		Clues	2.40			
		Clues	2.13		Resources	3.20			
		Resources	3.72		Design	2.40			
					Prize	2.40			
				Contents	Teacher	8.80			
					Goals	1.60			
					Previous knowledge	6.40			
					Information	12.00			
					Summary	4.80			

Table 7

Sets of three aspects that Sweden students would like to keep, change and eliminate from the Recal game.

	Keep			Change			Eliminate		
	Themes	Categories	Percentage (%)	Themes	Categories	Percentage (%)	Themes	Categories	Percentage (%)
Sweden	Methodology	Organization	7.69	Methodology	Instructions	18.92	Methodology	Police case	5.26
		Timing	5.77		Order	2.70		Autonomous	5.26
		Set-up	1.92		Timing	8.11		Competition	5.26
		No guided activity	1.92		Chronogram	5.41		Evaluation	5.26
		Police case	17.31		Work environment	5.41	Material	Organization	21.05
		Innovation	1.92		Team work	5.41		Clues	5.26
		Motivation	11.54		Competition	2.70	Contents	Instructions	10.53
		Team work	25.00		Evaluation	2.70		Teacher	5.26
		Competition	3.85	Material	Worksheets	8.11		Difficulty	26.32
	Material	Clues	5.77		Info cards	8.11		Knowledge	10.53
		Extra info cards	11.54		Translations	5.41			
	Contents	Educational	3.85		Organization	2.70			
		Knowledge	1.92		Difficulty	5.41			
					Simplicity	10.81			
				Contents	Previous knowledge	8.11			

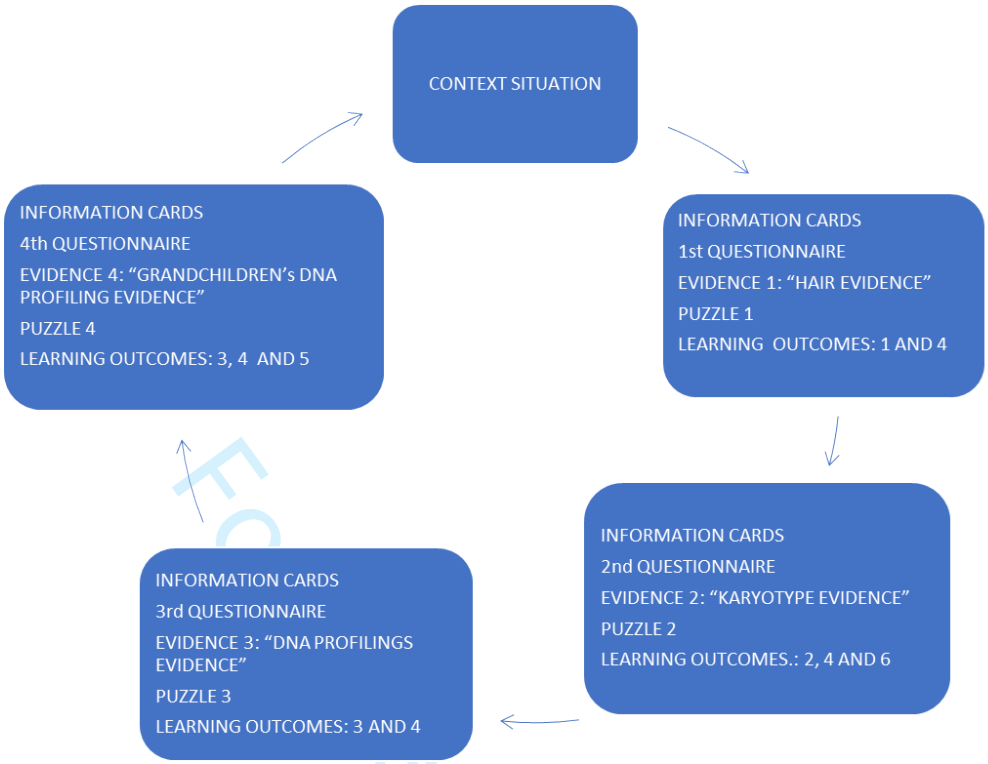
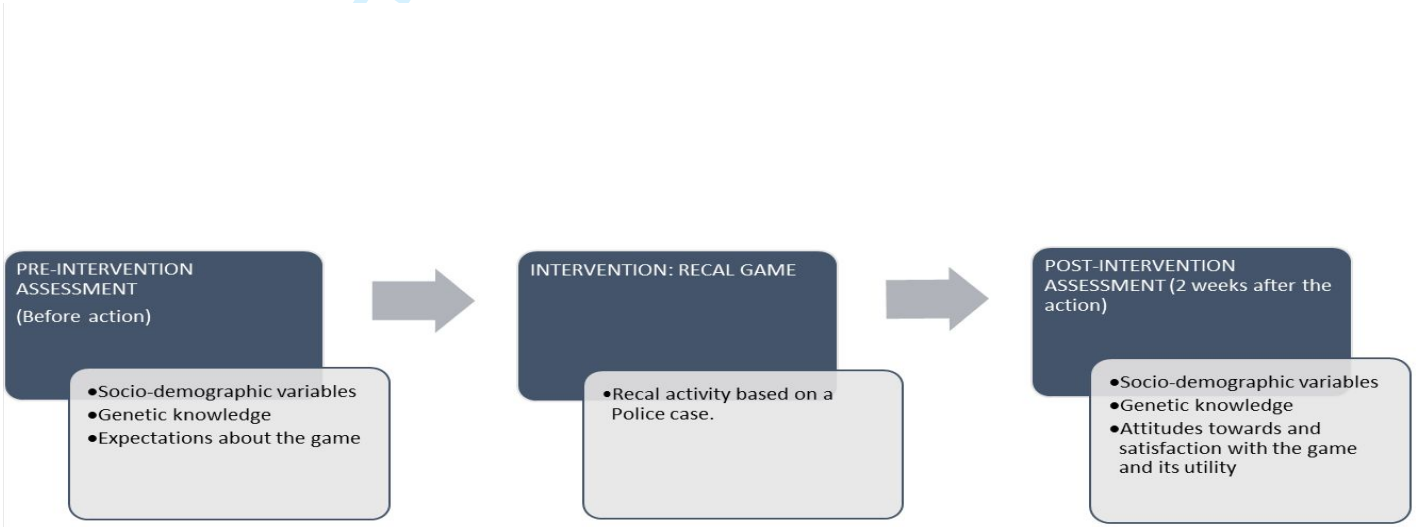


Figure 1. *Workflow of the Recal game.*

Figure 2. *Phases and schedule of the intervention and assessments.*



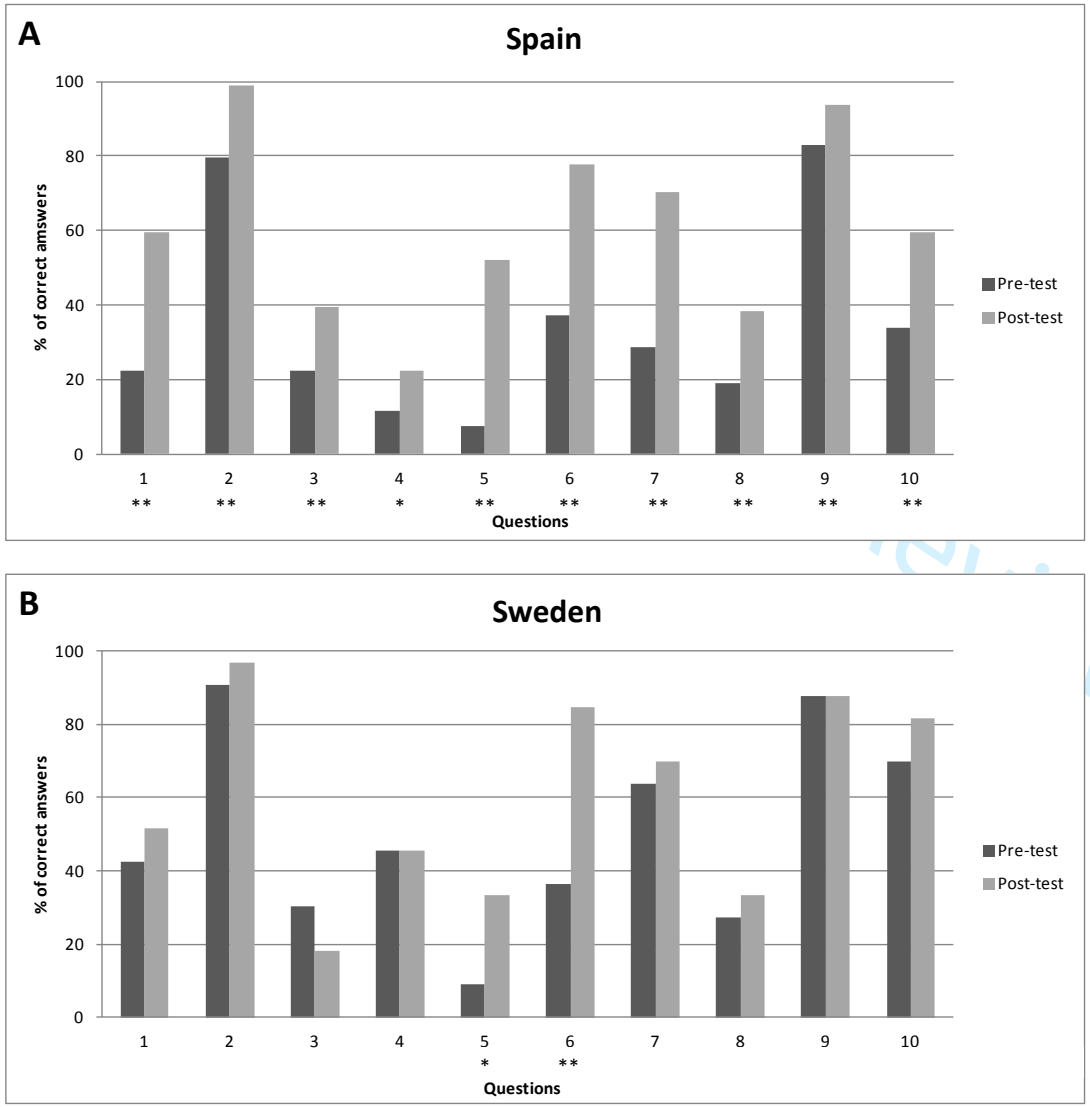


Figure 3

*Percentages of correct answers for all questions in the pre- and post-intervention tests in Spain (A) and Sweden (B). Asterisks indicate the significance of differences between pre- and post-intervention scores: **p<.01 and *p<.05.*