Can the implementation of an interdisciplinary retrieval practice in science facilitate students' motivation and perception about cross-curricular concepts?

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A Research & Development Project

Submitted for the MSc Learning & Teaching 2022

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Abstract

This study explores the effects on online educational games as a retrieval practice on students' retention and understanding of the cross curricular concepts between sciences and between sciences and mathematics. The implementation of an online cross-science retrieval practice was introduced to investigate whether it can facilitate students' understanding of the interrelation of sciences and mathematics, as well as students' motivation/ participation. It also aimed to explore teachers' perspectives on a cross-science retrieval approach. Questionnaires were completed before and after the implementation of the intervention with 43 KS4 students and 5 science teachers participating. Based on the findings of this study, it could be suggested that there is evidence, although not at a statistically significant level, to support that applying retrieval practice with online educational games could improve students' motivation and perception about cross-curricular concepts.

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Introduction

Teachers around the world seek methods to transfer the knowledge effectively to their students. However, judging by the outcome, this is not always the case, since many students underachieve in their exams for various reasons, such as lack of motivation, appropriate time management or other skills (Balduf, 2009). But even a well-motivated diligent student may struggle to retain the vast amount of information they have to study for their GCSE exams. Hence, a lot of teachers usually wonder why the students do not remember the new knowledge taught extensively during the lessons. One should seek the answer to this problem into the fundamentals of the education systems, the teaching itself and the purpose of the school.

Many students and parents believe that teaching results in learning, but this is a misconception (Larsen, 2018). Mere teaching is not enough unless it is followed by various methods to support the long retention of the information.

In addition to this, the purpose of the school has evolved from what was two generations ago to prepare the students for their life as adults in a democratic society, who are able to think critically and solve their everyday problems (Roosevelt, 2008). Science could be regarded as one of the school subjects that serve this purpose. Yet the students in a secondary school in UK might not be well prepared for their testing window in GCSE in science. As Ofsted reported, 'for pupils to achieve well in science, they must not only acquire the necessary knowledge, but also understand its value, enjoy the experience of working.' (Ofsted, 2013).

Some researchers are claiming that it is inherited in the method that the schools are applying to deliver the lessons and they are proposing frequent tests

(Larsen et al., 2013), retrieval practice (Agarwal et al., 2021), concept maps (Berry & Chew, 2008; Hay, 2007), or even to allow time for the students to forget and remember the knowledge using the so-called spacing effect (Vlach, 2014).

On the other hand, there are some researchers who are proposing that it is the lack of literacy skills to blame for the low scores of the students in their exams. The students need to understand at least 95% of the words in a question to be able to answer it (Schmitt et al., 2011). For example, some years ago I had a student who did not know the expression of expanding the brackets in mathematics and during the lesson he outstretched the brackets, rather than solving the expression (a+b). Similarly, a student who may not have visual experience of a topic, may miss the correct link to properly answer the question (Stokes, 2002).

In the meantime, it is understandable that in a lockdown, many people may have found it difficult to get used to work from home including students participating in online lessons (Putri et al., 2020). This situation may have detrimentally affected the students' learning.

Therefore, the aims of this study are two. The first aim is to investigate if the online educational games could change the students' perception of the cross links between sciences as well as between sciences and mathematics. The second target is to examine the effects of online cross-science retrieval practice on students' motivation and participation.

A significant number of researchers claim that the retrieval practice questions could increase students' retention and achievement (Agarwal et al., 2021; Karpicke, 2012; Rowley & McCrudden, 2020). Therefore, this study will investigate the interconnection between the use of retrieval practice cross-curricular questions in the

form of online educational games and the students' perception on cross links in science. For the purpose of this study, the terms interdisciplinary and cross-curricular are used interchangeably.

Also, the same online game-based learning will be assessed on its effectiveness for increasing students' motivation and participation in science. These online games will be specially designed and consistently applied for this purpose. The assessment will be based on students and teachers' responses alike.

Furthermore, the level of understanding that the science and mathematics are cross linked and the level of participation and motivation of the students might be directly proportional. However, the null hypothesis of this study is that the retrieval practice has not got any effect either in changing the students' perception about cross-curricular concepts in sciences or on their motivation and participation in these subjects.

Hence, the purpose of this study is to investigate the following questions:

1. Can the implementation of a cross-science retrieval practice facilitate students' understanding of the interrelation of sciences and mathematics?
2. Can the implementation of an online cross-science retrieval practice facilitate students' motivation/ participation?
3. What are teachers' perspectives on a cross-science retrieval approach?

With regard to the school, in which the study is based, there are many students who are low attaining high achievers based on their term tests and hence, the implementation of this intervention could investigate whether the online retrieval practice may potentially increase their tests scores as well as their motivation. (Agarwal et al., 2021).. Furthermore, the students have access to Ipads, which may

facilitate the implementation of this intervention. Additionally, the senior management of the school is open to different teaching approaches to enhance the science capital of the students, especially for the pupil premium and the SEN students, and on these grounds I have been asked and given permission to create and implement this intervention for the benefit of our students, my colleagues and myself. This study could be a valuable experience for my professional development as a teacher, for better supporting my students and for collaborating with my colleagues and exchanging ideas.

Literature Review

In this section, there will be a critical review of the literature to seek the benefits and the challenges of cross-curricular teaching. Then, there will be an attempt to investigate how the retrieval practice and especially the gamification is applied in the cross-curricular teaching. Finally, a relevant literature referring to students' motivation using online games for retrieval practice will be presented.

Cross-curriculum benefits

Students' interest

Many students could easily participate and succeed in specific subject content. However, there are also those students who are under achieving in the core subjects: English, Mathematics and Science. In such a case, a cross-curricular teaching approach might be beneficial for those underachievers because, it could increase their retention (Rowley & McCrudden, 2020), and it could motivate and help them being creative (J. Barnes, 2018). In the meantime, the lack of students' interest on sciences could be rather challenging, and hence the addition of topics, which are

interesting to the students, with cross-curricular links could potentially tackle this issue (Djudin, 2018). It seems that there is a correlation and interaction between cross-curricular teaching and prior knowledge as well as science capital, which may have an impact on the learning outcomes (Neuenhaus et al., 201; DeWitt et al., 2016).

Application in the exams

Furthermore, nowadays it seems that many past papers questions have cross science questions across different exam boards. Such questions require advanced metacognitive skills and ability to retrieve knowledge from different subjects, which in turn are important for the scientific literacy of the students (Avargil et al., 2018). Again, the cross-curriculum teaching could become useful insofar as it helps students reach their zone of proximal development (Andreassen et al., 2019; Silalahi, 2019). This will follow the students' natural progression and developing maturity (Reiners & Wood, 2015).

In order for the students to develop the necessary skills to address the new type of cross-linked questions, many theories have been proposed. For example, based on Bloom's taxonomy (Bloom, 1956), there is a system of six categories of thought, and hence the development of teacher's questioning skills is crucial, since the students may know more things that they are able to tell (Polanyi & Sen, 2009). According to Bloom and his partners, most of the teachers at the time were asking low level questions during the lessons. Low level questions about recalling/ remembering facts and explaining/ understanding ideas could be well used to subject based teaching and learning. However, higher level questions, even if they could still be orientated towards a specific subject only, could give further

opportunities for cross-curricular links. Such questions could focus to apply, analyse, evaluate, and create based on revised Bloom's taxonomy (Anderson & Krathwohl, 2001). These additional challenge questions could motivate further the students (Ward-Penny, 2010).

Development of reading skills

Furthermore, according to another study, the application of critical reading of scientific articles in English or science lessons could potentially develop the reading skills of the learners, as well as facilitate their understanding of cross-curricular connections with other subjects, and how to answer relevant questions (McClune et al., 2012). However, many teachers may express resistance to such literacy skill development methods that takes time away from their content and adds to the workload (Kirsten, 2019).

Links between science and mathematics

It appears that the application of various theories to cross link science and mathematics is promising. According to a recent study with the intention to connect mathematics and physics, the outcomes were rather encouraging. During a cross-curricular experiment that has taken place in a Japanese College, the students were more engaged and motivated to study science and mathematics as a team. They were also able to answer higher level questions connecting these two subjects (Saeki et al., 2001). Furthermore, according to another study, the use of laptops for cross-curricular in mathematics and science, may not improve the results in a test, yet they may improve the learning process with a variety of tools and resources for cognitively advanced tasks (Perrucci et al., 2012).

Students' future employability and awareness

Apart from teaching the students how to approach the new type of GCSE questions, motivate them and develop their reading skills, the development and delivery of a cross-curricular teaching has other benefits too. Nowadays the students are aware of how to use online resources, and therefore the role of the teacher has evolved to a facilitator, who could inspire students' innovation and creativity; skills that most companies are seeking for in their employees (Harms & Hastings, 2016). In the same context, the science curriculum should integrate more vocational relevance, such as health education and industrial case studies (Eizagirre Sagardia et al., 2018; Safta, 2015; Stuckey et al., 2013), undervalued competencies, such as environmental awareness and ethical commitment (Mateo et al., 2010), as well as humanities and social science. Thus, the science curriculum could work as an intervention vehicle for career orientation and increased employability degree for the learners (Belova et al., 2017). Likewise, many students are not intrinsically motivated by science (Hofstein et al., 2011; Ogborn, 2004), and thus a cross-curriculum approach in science, that integrates a broaden approach in various fields, or even away from the classroom for participating in nonstandard learning field trips, could be beneficial for the learners and raise their interest for participating in science lessons. Many studies have also referred to this widen approach of teaching science with a problem-solving skills perspective as the societal dimension of science curriculum (Crippen & Antonenko, 2018; Sjöström & Eilks, 2018; Stuckey et al., 2013), or teaching cross-curricular skills through project based learning and other applied work (Viro et al., 2020). Furthermore, science learning and achievement could be further developed by engagement in social activities beyond the learner's mental procedures (Buchinger & da Silva Hounsell, 2018).

In light of this, since there is a lack of scientists and engineers, there is also a necessity to develop cross-curricular activities in STEM related lessons, so the learners are familiar with the benefits of STEM at an early stage (Wilkinson, 2018), and they could self-determine themselves in the world by being able to solve problems and participate in it (Hofstein et al., 2011). If the students are trained to transfer knowledge from theorical subjects to practical applications, they could improve their academic performance and probably follow a STEM career (Kezerashvili et al., 2007; Nakakoji & Wilson, 2018). Serving this purpose, cross-curricular activities could be used to motivate the students to see how a concept learnt at school is used in other subjects, and how they could possibly apply the knowledge learnt in their own lives, such as reading scales on kitchen measurement instruments and understand the ingredients of a product (Ward-Penny, 2010). Furthermore, based on the same study, a cross-curricular approach in teaching helps the students to develop metacognitive skills and become more creative.

Opportunities and obstacles in delivering cross-curricular teaching

Students' and teachers' previous knowledge

As far as the application of the cross-curriculum teaching, there are some conditions, such as the students' previous knowledge, that could facilitate the process, whereas other circumstances could hinder it. Sometimes the cross-curricular application requires the use of knowledge acquired in a subject as a tool for establishing a concept in another discipline, for example, mathematic calculations for explaining physics concepts. A cross-curricular activity could also use a known model of a subject, as a flexible knowledge, to explain and develop a concept on another subject, or transfer it to out-of-school environments, through discussions and

questioning until the students may reach an accurate and authentic conclusion (Gobert et al., 2011; Michelsen, 1998). It seems that the students may not be well trained to apply ideas and concept out of the box, to solve tasks and answer questions that they have not been explicitly taught. In other words, they may not see different ways to operate a model they are familiar with (Cobb, 1986; Schwarz et al., 2007; Schwarz & Gwekwerere, 2007). However, a recent study has shown that the use of a guided model with ICT as a teaching tool seems to improve students' science skills (Gunawan et al., 2019). On the other hand, the teachers may not be ready to shift their teaching from a memorisation procedure to a structured method of target-orientated question answered (Richland et al., 2012), or they may not feel confident in teaching outside of their specialism (Avramides et al., 2015). After all, the teachers are the main factor for developing and applying cross-curricular practices in their lessons and this application depends on their professional profiles, the students' ability in their class and the culture of their school (Eizagirre Sagardia et al., 2018).

Teachers' traditions and implications

Another issue that should be mentioned as an obstacle for applying cross-curricular methods is the different teaching traditions of the teachers, namely the fact-based, the normative and the pluralistic traditions (Sandell et all, 2005). For example, if teachers of different disciplines teach with a cross-curricular approach the same topic, their students might be confused if one teacher emphasise facts, while other colleagues focus on the development of abilities (Sund et al., 2020).

Hence, the alignment of common teaching practices appears to be a critical factor for maximising the effect of a cross-curricular teaching. It is argued that the

teachers' professional practices could change through professional learning. According to a recent study (Lillejord & Børte, 2016), these changes could happen if the teachers were exposed to different types of knowledge and co-construct new lessons in collaboration with other teachers (van Schaik et al., 2019). The existence of professional communities in some schools could further support the change of the teachers' professional practice (Goodyear & Casey, 2015).

Teacher's perspectives on cross-curricular approach

In the meantime, teachers may have various approaches with regard to cross-curricular teaching. There is a tradition in many schools where teachers are specialised in one subject only (Niemelä & Tirri, 2018). This could possibly affect the teachers' understanding of the interdisciplinary connections in science, and in turn, their students may miss the opportunity to create connections between different sciences, develop a holistic approach of sciences, and as a result they may have a poor academic performance (You, 2017). Many teachers may feel less confident to integrate the sciences and mathematics together and deliver interdisciplinary teaching (Bartels et al., 2019), or they may see the knowledge as a static structure to be learned, and therefore they may avoid a creative cross-curricular approach for fear of failing (Harris & de Bruin, 2018). A cross-curricular approach of a topic could also have low priority by the teachers delivering the lessons as per a recent study on sustainability (M. Barnes et al., 2019). To increase teacher's confidence in cross-curricular teaching, relevant pedagogical strategies should explicitly be delivered and modelled to teachers. Also, the teachers should be encouraged to collaborate with other colleagues in multidisciplinary methods of learning (Margot & Kettler, 2019; Veishene & Dsouza, 2022). Furthermore, the implementation of cross-curricular

teaching could increase the teacher's perception of individual autonomy (Elo & Nygren-Landgärds, 2021).

On the other hand, there are cases in which the teachers of conventionally dissimilar subjects, such as sciences and religious education, have limited chances to express the arguments of their subjects with regard to the other subjects, although both sides do not necessarily see that their subjects are in disagreement (Guilfoyle et al., 2021); Additionally, both sides understand argumentation as an important aspect of their discipline, although there are differences on how the teachers apply argumentation in the class (Erduran et al., 2020). On a recent study, secondary school teachers from different disciplines delivered general cross-curricular arguments during their lessons and the students' cognitive skills have been improved (Rapanta, 2021), while a similar study with primary school teachers had similar results too (Kiely et al., 2021). However, the implementation of a more combined curriculum depends on teachers' ability and perception to merge the knowledge appropriately, so the students are able to make fruitful correlations between the different subjects (Heywood et al., 2012).

Different approaches for the same topic subject dependent

Even if all these steps for overcoming different teachers' traditions and approaches are to be implemented, undoubtedly some topics might appear challenging. For example, the creation and the evolution of humanity could generate some theological discussions in the science lessons and vice versa. The teachers could adapt a median position and understand how to handle similar questions by the introduction and integration of the epistemic insight during their professional development (Konnemann et al., 2018), since learning should be complimented by

epistemic and transformative teaching elements (Sterling, 2011). Yet, the transformative learning, namely the idea that the students could adjust their thinking based on the new information could be a rather challenging method. Not only it challenges dominant perceptions for teaching and learning, but also the students may not be prepared for this type of learning (Moore, 2005). A possible solution to this might be found in sharing different tasks among subjects. For instance, while science would provide the facts and explain what is happening in life, other social science subjects could provide an answer to why and how something is happening. In this way, many subjects could become complementary to each other and provide a multidimensional teaching through a collaborative cross-curricular development (Sund & Gericke, 2020).

Transferability of different disciplinary knowledge among subjects

Apart from the teachers' practices that might be aligned through collaboration, it seems that there is another issue in the core of some subjects that needs to be tackled. Based on a recent study, which has focus on transferability of knowledge between mathematics and physics, it was proposed that the problem of transferring knowledge may not lie on students' incapacity to apply the knowledge in different disciplines, or on teacher's practices, but on the way that the physics concepts, and its equations are represented. A possible explanation given is that the physics laws, and consequently the physics formulas, have been developed well before the application of mathematical functions, and hence the students many times find difficulty in perceiving the physics equations as functions of one variable (Sokolowski, 2021). Similar inability to transfer knowledge has been located between chemistry and mathematics with regard to the graphical skills of the students (Potgieter et al., 2008). A possible remedy proposed is the introduction of

regular teaching graphical skills in both subjects to support the understanding of the concepts. For instance, the line of best fit is a common idea in science and mathematics at GCSE, but the curve of best fit appears mainly in sciences GCSE (Ward-Penny, 2010). Also, the students could develop a dislike in mathematics formulas or the equivalent equations in physics (Robert Goldstone et al., 2005; Zhao & Schuchardt, 2021), if they have been taught shortcuts, such as formula triangles, in a way that eventually bypass their understanding. For example, the student could learn the method of a mathematical triangle, but they are not confident to confirm if their answer is correct or not (Southall, 2016; Foster, 2021).

However, the students' abilities should be considered in any attempt to tackle the transfer of knowledge from one subject to another, since it may not apply to the same degree to students with different abilities. In an experiment measuring the transferability of mathematics components to science questions with a formal assessment, students who had a low score in mathematics, had a lower percentage of successfully transferring the mathematical concepts in the different context comparing to the achievers of an excellent score in mathematics (Britton et al., 2005).

Challenges in cross-curricular teaching

Overall, many studies have proven the difficulty of understanding specific concepts across all sciences, such as the concepts of energy transfer and energy conservation in electromagnetism, in waves and in the atomic structure (Neumann et al., 2013; Park & Liu, 2019). It appears that each concept in science has an inherited difficulty level, and the students should master the simpler concepts prior to the more complex concepts, otherwise the misconceptions in science will remain (Soeharto &

Csapó, 2021; Steedle & Shavelson, 2009). In some cases, as it is suggested, there must be a bottom-up approach in which the first order elements are delivered and then the second order more complex relationships could be attended, so the students are able to understand problems and analogies accurately (Chi & VanLehn, 2012). For example, in the concept of diffusion of ink in water (chemistry concept), the collision of molecules is concept of first order, whereas the fact that this collision of the molecules could happen simultaneously and independently is a second order concept (Chi et al., 2012). That being said, according to another study, even if the students have mastered a science concept, as the aforementioned diffusion on ink in water, they may find it difficult to transfer the knowledge to another science subject and understand for example that oxygen and carbon dioxide diffuse in the lungs (biology application), unless their teachers provide the learning context to facilitate the connections as well as collaborate across sciences for long term targets (Bertrand & Namukasa, 2020; Herfeld & Lisciandra, 2019; Kohn et al., 2018).

Cross- curricular teaching as a retrieval practice

One way to implement cross-curricular teaching and allow the students to connect the same concept in the context of all three sciences as a general concept (for example the concept of energy) is with retrieval practice, since it could bridge the gaps in knowledge bringing specific notions together and create concept maps about science topics in a more effective way comparing to elaborative studying (Karpicke & Blunt, 2011).

Research has developed over years to assess the effectiveness of different methods to retrieval practice and its relationship with students' motivation. According to a study (Kang & Pashler, 2014), retrieval practice could be beneficial for the

students regardless of motivation, although it cannot be regarded as universal formula for low motivation, whereas based on another study (Abel & Bäuml, 2020), the retrieval practice in conjunction with feedback could trigger students' attention and intrinsic motivation to carry on studying.

Retrieval practice with testing

One way of applying retrieval practice is by testing. There is a general assumption in education that testing is given only to assess the learner's knowledge, not to alter it. However, there is plenty of literature that claims that tests not only assess memory, but also changes it, often in a positive way (Abel & Roediger, 2017).

Thus, it has been claimed that taking a test helps the retention of the information in the long-term memory of the students (McDaniel et al., 2012). The testing outcome is usually referred in the literature, as the advantage of the retrieval practice (Carpenter, 2012; Koh et al., 2018; Rawson & Dunlosky, 2012; Roediger & Butler, 2011). In other words, the testing effect claims that applying retrieval practice on previously taught subjects can enhance memory and boost long-term retention for the tested subject comparing to learners who have not being exposed to such methods (Abel & Roediger, 2017). Besides, it is regarded easy to make retrieval practice tests, especially with online platforms, which means it is an effective learning tool, especially in the absence of up-to-date resources (Rowley & McCrudden, 2020). Also, retrieval practice questions that are based on the aforementioned Bloom's taxonomy with a variety of recalling facts to higher order questions have yield a great performance score for the students, comparing to retrieval practice based only on fact recalls (Agarwal, 2019).

However, there might be some drawbacks too. Based on (Hinze & Rapp, 2014; Petrovic-Dzerdz, 2019), regular testing for practicing retrieval it may increase the pressure and anxiety on the students, and hence to reduce the benefits of retrieval practice. On the other hand, the retrieval practice could protect the memory against stress and anxiety much better than restudying the content (A. M. Smith et al., 2016).

Spaced testing for retrieval practice

High retention could be enhanced by frequent intervals following each test attempt and feedback afterwards (Roediger & Butler, 2011). On another study, it is proposed that pretesting, namely assessment prior of the delivery of the knowledge to be learnt, could be as much beneficial as the post-testing retrieval practice (Pan & Sana, 2021). In the same context, based on a recent study (Gopalan et al., 2020), the teachers could assign a content to be prepared by the learners before the lesson together with an online quiz. Based on the same study, the application of flipped learning following by an online quiz three times per week could be too much, whereas another study, that supports spaced learning, proposed that test spacing may have positive effects on long term retention of the knowledge (Kelley & Whatson, 2013). The important factor that enhances the long-term memory may be a delayed initial retrieval practice after the new knowledge has been delivered, as per the equally spaced retrieval, rather than the expansion of intervals between further retrievals, according to a study (Karpicke & Roediger, 2007). Therefore, the timing and the frequency of the tests for practicing the retrieval might be a controversial point among different researchers.

Retrieval practice for independent learning

The retrieval practice could be used as a tool for independent learning too. In particular, according to Koh (Koh et al., 2018), to maximise the retrieval benefit the learners should be given specific learning instructions prior to retrieval practice so that the students are aware of how to use the retrieval practice resources for their own benefit, either in classroom or during their independent study strategy to increase retention of the knowledge and avoid retroactive interference (Abel & Roediger, 2017; Agarwal et al., 2012; Roediger et al., 2011). However, relative few students engage in retrieval practice or self-testing at home, while most of them repeatedly study their notes or textbooks, which may not be an effective strategy (Badali et al., 2022; Karpicke et al., 2009). Although there are many data to support the effectiveness of retrieval, most of the students do not prefer it for their revision and are ignorant of its benefits (Karpicke, 2012; Petrovic-Dzerdz, 2019). Relatedly, with the use of multimedia, the students could revise and repeat any learning objective until they understand it naturally (Gunawan et al., 2019; Muslem & Abbas, 2017). On the other hand, many researchers propose that merely copying notes and rereading of a topic may not have such a powerful effect in the learning process comparing to regular testing, not only as assessment tools but also in the context of a learning tool (Petrovic-Dzerdz, 2019; Rowley & McCrudden, 2020).

Nonetheless, many students, not aware of the mnemonic effect of retrieval practice, assume that if they can remember a concept, they have mastered it, and therefore they do not apply retrieval practice when revising (van Peppen et al., 2021; Karpicke & Roediger, 2008). This exclusion of freshly-recall-topics from repeated retrieval practice decreases their long-term retention (Karpicke & Roediger, 2008). Furthermore, the learning and retention were both improved with additional retrieval

practice tasks comparing to simple more study after previous successful retrieval practice (Leonard et al., 2020). Even if students are practising covert retrieval by self-testing without producing responses, this could be an equally beneficial method comparing to the overt retrieval with regard to long-term memory as well as a better learning method comparing to restudying (M. A. Smith et al., 2013).

Equally, the retrieval practice could be also beneficial to the forward testing effect, which refers to the finding that retrieval practice of previously studied information supports understanding, learning and long-term retention of new information to be studied later on (Pastötter & Bäuml, 2014; Pastötter & Frings, 2019).

Gamification as a retrieval practice

One out of many ways to practice retrieval in the school environment is with gamification. Sometimes the students may have problem understanding the lesson, and thus the teacher tends to adapt their teaching, change the curriculum and alter the presentation of the content by introducing games to engage the students (Ikwumelu et al., 2015; Mostafa et al., 2018). The term gamification refers to '' the application of game features and game mechanics in a non-game context'' (Becker & Nicholson, 2016), but it does not include actual games (Schrier, 2016). The basic idea behind gamification is to find and encourage the desirable behaviours and to assign positive points for such behaviours (Zichermann & Cunningham, 2011). Also, the gamification could help the students in becoming independent learners (Pinchuk et al., 2019; Kapp, 2013; Hamari et al., 2014; McKain, 2019).

A common misconception is the confusion of gamification with related terms, such as just-for-fun games and game-based learning. The teacher should ensure to

integrate gamification into teaching and learning applying appropriate strategy and explaining the reasons for this approach to maximise the positive effect and minimise possible countereffects (Kapp, 2013). For example, the use of nicknames that the teacher cannot link to the students' real names might reduce effective feedback.

Positive engagement of the students could be due to various factors one of which is the students' motivation. Motivation may be described as a state which starts and preserves the learner's target orientated attitude (Kang & Pashler, 2014). It is regarded that there is a strong link between learning, motivation and academic success (Steinmayr et al., 2019). Motivation is believed to improve the learning in many ways, such as facilitating the attention of the learners and the application of various learning encoding strategies (Kang & Pashler, 2014).

Motivation using online games for retrieval practice

Regarding motivation, based on a recent study, it was found that there is a positive correlation between an online game score visualisation and motivation of the learners and a positive effect between students' motivation and learning outcomes (Scholten, 2020). It is also argued that the digital game-based way of learning could promote the students' critical thinking (Hussein et al., 2019), although the repeated retrieval practice may not have a significant effect on the students' critical thinking skills, based on another study (van Peppen et al., 2021).

According to a recent study, the implementation of gamification for pedagogical reasons has neither improved nor worsen the students' academic results and by no means should substitute the common paper assessments in schools (Hernández-Fernández et al., 2020), or replace the design of good teaching and learning (Glover, 2013). Furthermore, game based educational tools cannot

substitute the teachers in their differentiation and diversification for students with different abilities, and needs (Pei Hwa, 2018). On the other hand, based on the outcome of another study (Ku et al., 2014), 'the interaction with digital educational games offers better results comparing to the paper-based tasks in both students' performance and confidence. The same study has also reported that both higher and lower ability learners has shown better confidence and achievement in mathematics, while working on online educational game platforms, compared to students who are engaged in traditional approaches with pen and paper. In accordance with the previous research, a meta-analysis has concluded that games could outperform the conventional teaching methods of simple instructions, such as reading a book (Wouters et al., 2013; Reiners & Wood, 2015).

In the meantime, one possible factor that hinders students' progress in science may be the application of mathematical equations as tools in science (Baxter et al., 2014; Pang & Good, 2000; Zakaria & Iksan, 2007; Westwood, 2006). Based on some studies on students studying mathematics, all participants using game-based learning applications showed learning progress. Especially the lower motivated students, who are usually disruptive in a regular classroom, participated in the online games and had the highest percentage score in the games' outcome (Papp, 2017). Additionally, low attaining students that engaged in game-based learning applications get better scores in mathematics tests, comparing to the students who worked on paper-based revision. (Ku et al., 2014) Those students working on paper-based revision did not show any improvement in their confidence, and therefore they could not improve their performance. Concordantly with these results, another study suggests that game based educational platforms could provide a better learning experience and subsequently improved performance compared to

traditional educational methods (Knight et al., 2010). On the contrary, according to Lister and others (Lister, 2015; Looyestyn et al., 2017), the application of online educational games in classroom does not make the students' understanding better or worse, although it creates a positive climate in the classroom and improves students' motivation to learn based on the number of contributions that the students made, and the time spent on the software. In such a way the engagement could be quantifiable. However, the positive effect of online games wears off after some time, and hence it is advisable to be used for a short period over time to maximise their effectiveness (Looyestyn et al., 2017).

Some study has proposed with regard to the level of motivation the weaker students may be more motivated on game-based activities comparing to the more able students (Charles et al., 2011), and the less able students may also benefit from these games the most (Miller & Robertson, 2011), whereas, if the educational games are competitive, they may discourage from engaging the less competitive students, based on Glover (Glover, 2013). According to the same study, there could be many reasons that make the students to be demotivated, such as the easiness or difficulty of an activity or even the students cannot understand the relevance of the content. In such cases, the issue will not be solved by the application of online games but by a better learning design, quality of materials and activities, although the behaviour of the classroom could be improved straightaway. Furthermore, the application of gamification requires attention to ensure that the correct course content is used in the appropriate timing and context and immediate feedback is provided to the students (Ku et al., 2014; Villagrasa & Duran, 2013). Moreover, the creation of good question banks for such a vast content, as the school curriculum, could be a deterrent factor to the teachers. Yet the online games could offer the

option of sharing question banks among different schools, even if the questions are taken from textbooks and transferred unaltered to the online application. Therefore, the teachers may have readily available plenty of online retrieval practice question banks to use frequently during the lessons (Petrovic-Dzerdz, 2019). Based on another study by Soderstrom and Bjork (Soderstrom & Bjork, 2014), frequent retrieval practice questions could inform the students about their strengths and weaknesses. The students in turn could adjust their future revision schedule accordingly.

Design of the online games for increased motivation

It is the appearance of the Leader boards during the game and the winners of the game, that motivate a lot the students to participate alone or as a team to win over their opponents, until they reach the top of the leader board, which leads to low or no motivation to continue playing (Glover, 2013).

Apart from the leader boards, the whole design of online games is made on the concept of capturing the students' attention. Even the selection of the avatars that exist in a virtual environment could be adopted by the student user and lead the latter to make informed choices and explore their course of study by dwelling an avatar (Charles et al., 2011), or even the option for the student to use the winning game points to acquire a rare avatar for the next game. In the same context, the game-based learning applications offer various levels for challenge, which facilitates students with different level of ability to access the correct challenge (Ku et al., 2014). On the other hand, the use of a point system on an educational game could increase the speed of the participants but not the accuracy (Attali & Arieli-Attali, 2015), while based on another study, the point-based games that give rewards for

quick answers may lead to lower learning results generally compared to a poll-based game (Koppitsch & Meyer, 2021; Wang & Tahir, 2020). Besides, some students may not be ready for a fair game and may want to win at all costs, which downplays the whole learning process (Reiners & Wood, 2015)

Online learning platforms allow the educators to monitor in real-time how learners engaged and answer the questions and enhance the competition that motivates the students to win (Bratel, Kostiuk, Bratel, Okhrimenko, et al., 2021; Pei Hwa, 2018). This collaboration through peer competition might be more beneficial in terms of conceptual knowledge and structure for the students comparing to those who are playing in a solitary mode (Chen, 2019; Richland et al., 2012). Concurrently, another study suggests that participants in group educational games, regardless the competition nature of the game, had higher scores comparing to those who were playing in solo mode (Chen, 2019). Furthermore, the most effective way to solve problems related to science may happen when students work together in competition mode (Bornstein et al., 2002; Zhu et al., 2016). As Kapp states, ‘‘just because a person sits in front of a computer or staring straight ahead at an instructor and answers every question, it does not mean he or she is actually learning. To learn, a person needs to be engaged’’ (Kapp, 2013, p.46).

Concurrently, the design of the games could be explained as an extrinsic motivation factor, which in turn could increase the time on task spend by the students. Had the students spend more time on tasks, the countereffect of negative attitudes on test results could be alleviated (Carroll, 1963; Kupiainen et al., 2014). Also, the design of games could be well based on Papert’s constructionism (Harel & Papert, 1991) and Bloom’s revised taxonomy (Anderson & Krathwohl, 2001). In a recent experiment, students have been asked to create some e-artifacts based on

literature to improve digital literacy and skills in English. The results have revealed that many students showed increased classroom participation, self-efficacy, and motivation. (Walton et al., 2019), although, this approach was less effective to students, who are weak in language skills.

On the other hand, the involvement of the students to retrieval practice activities and online educational games, could keep them for a long time engaged, and therefore, the teacher could have more time for supporting the weakest students. Several studies have shown that the students who regard their teacher as supportive tend to be more motivated in academic tasks (Ricard & Pelletier, 2016). This has an outcome that the students may pay more attention and are preparing for lessons, and it relates to increased intrinsic motivation (Federici & Skaalvik, 2014; Klem & Connell, 2004).

While the efficacy of games is hard to measure, the use of games as learning tools seem to increase students' motivation and participation in the lessons and could be related with change in the behaviour (De Freitas, 2018; Plass et al., 2013). Many studies have shown that the students have shown more engagement on online games compared to traditional lectures (Knight et al., 2010; Koppitsch & Meyer, 2021; Miller & Robertson, 2011). Furthermore, learners, who participate in an online educational game in collaboration with their peers, have shown a higher value of the lesson, higher interest in learning and better behaviour comparing to those who were playing in solo mode (Chen, 2019).

Besides, game-based learning could engage and motivate students in physics and increase their knowledge based on pre-test and post-test outcomes and the gender appears to have no effect on the learning outcome at all. However, it is

important to understand what motivates the students and include this into the game development. (Cardinot & Fairfield, 2019).

Last but not least, the implementation of online educational games could engage the majority of the class, leaving more time for the teacher to further support the borderline students with the online activity and potentially increase their motivation resilience (Pitzer & Skinner, 2017).

Spaced time for online games

A lot of study has shown that teenagers spend a lot of time in digital games, and therefore the educational games should engage students without being addictive and causing a sedentary behaviour (Straker et al., 2013). After all, it seems that there is a shift to digitilised the education (Luckin et all, 2012; Dillenbourg, 2016). This could be achieved by limiting the time of student's exposure to the game and by having regular switching between completing the educational tasks and actively engaged with the game (Toh & Lim, 2021). Online methods for retrieval practice could apply in a specific time frame as mini quizzes and incorporate old and new knowledge alike, applying the principles of spaced learning and creating long term memories of a subject (Kelley & Whatson, 2013).

Feedback and assessment with online retrieval practice

Another reason that online educational games could be a useful ally to the students and teachers alike, is that the students applying retrieval practice need to get feedback in a timely manner and hence, the gamification of the retrieval practice with auto scoring could be a proper solution to this issue, especially for course heavy in content (Petrovic-Dzerdz, 2019). The immediate feedback could play a significant

role, especially to the lower ability students since they can understand straightforward their mistake, correct it and move forward (Ku et al., 2014; Wild, 2007).

There is a variety of online games that can be used for teaching purposes. According to a recent study (Bratel, Kostiuk, Bratel, & Okhrimenko, 2021), some of them (for example, Google form and Socrative) are better for summative assessment since they do not have elements to distract the students, while others, such as Quizlet, Kahoot and Blooket, are better for formative assessment. The graphics, sounds and gamified environment of the latter could be beneficial to reduce students' anxiety or develop their cross functional skills such as respect, cooperation, team spirit, memorising etc (Safta, 2015). There are also some games which are suitable for both forms of assessment like Quizziz.

Digital literacy with online retrieval practice

Relatedly, for the students to maximise their potential, the use of digital means is an essential factor and therefore, it is argued that a revision of the computer curricula should be implemented to promote the digital literacy as a cross-curricular lesson (Polizzi, 2020). If the students become computer literate, they could potentially get involved in designing their own educational games collaborating with other students (Wake et al., 2018). This approach could support a shift of the learning process towards an increased student's ownership and participation (Ko & Krist, 2019), although the game design activity has some inherited challenges, for example creating a game with the appropriate level of difficulty for the participants (Tekinbas & Zimmerman, 2003). Based on another study on learning chemistry through designing online games, the participation of the learners as a game creator

may increase their scores as well as their motivation (Lay & Osman, 2018). After all, a successful game-based learning should be students' informed choice to provide learning autonomy and self-paced experience (Reiners & Wood, 2015).

In the meantime, to maximise the effects of the digital educational games, there should be continuous professional development offered to the teachers focusing on cultivating such educational methods (Hébert & Jenson, 2019).

To sum up, the literature review indicates that a retrieval practice with cross-curricular concepts might facilitate the students to understand the interrelation of sciences and mathematics by overcoming disengagement, providing timely online feedback, helping the retention of complex notions by repetition, and enabling fair play. Furthermore, with regard to the school that the intervention is taking place, the low attainers high achiever students may become more motivated and engaged in science lessons by the implementation of a game-based cross-curriculum intervention since it may help them to understand better difficult concepts across the boards, using their iPads.

Furthermore, after the intervention, the comparison of participating teachers' perspectives on cross-curricular approaches with the theory discussed above would be useful to draw some conclusions and decide further steps.

Based on my experience as a teacher in the school and after discussions with colleagues, the students seem to enjoy participating in online educational games, and thus in the science department we have started to include such games in the lesson plans and share across the department. Hence, this intervention could be beneficial by seeking methods that will maximise the impact of the online retrieval practice for cross-curricular notions in our lessons.

Intervention

Design and implementation of a cross-curricular intervention

Students of different year groups (9, 10 and 11) participated in a variety of physics, chemistry and biology lessons using cross-curricular online retrieval practice. The lessons were selected either because specific ideas could be combined together, or because these topics have cross-curricular ideas. For example, punnet squares (biology) were combined with vectors (physics), electricity (physics) was reintroduced in the biology topic of the electrical signals of the nerve cells and lenses (physics) were connected with the human eye topic in biology. Furthermore, both the ideas of energy and atoms were introduced as cross-curricular concepts in energy resources topic (physics), and atomic structure (chemistry). In the meantime, five science teachers answered qualitative questions and applied parts of the intervention adapting it to best fit in their classes.

More precisely, the steps for the intervention are outlined in the table 1 below. The intervention was completed in eight non-consecutive lessons following the same steps each time.

Teacher's actions (see Appendix item 1 for each of the items below)	Students' actions	Resources
Starter activity (5min)	Students answer questions on concepts from previous lessons. Either in their books or	Cross-curriculum material from previous courses. Either on paper or online

	online	
New scientific concept is introduced and combined with similar scientific notions across sciences (10min)	Students keep notes, participate, answer cold call questions	Powerpoint presentation, online resources
Past paper questions with cross-curriculum concepts including the new concepts (10min)	Students answer the questions, then check out the online resources provided to improve their answer	Past paper questions and QR codes with online resources to improve the student's answers
Mark scheme is displayed on the board (5min)	Students mark with red pen for self-assessment	Mark scheme for past paper questions
Activity or online educational game for consolidation of knowledge (5min)	Students' response to the quiz-based retrieval questions	Online educational game and resources for the activities

Teacher creates a new online game with retrieval practice questions based on the feedback of the previous activities for the next lesson	Students participate in the new online games	Online educational game
Surveys on cross links in sciences and motivation on online educational games (once)	Students respond	Three Surveys

Table 1: Intervention plan with teacher's and students' actions

During the eight lessons of the intervention the students were exposed to different tasks to facilitate the investigation of the two research questions. Each intervention lesson had a gap of 3 to 4 usual lessons from the next intervention to allow time for the students to absorb the scientific concept and check their retention with spaced retrieval practice of online educational games. Another reason for the gap between the intervention lessons was to allow the delivery of the curriculum based on the school's lesson plan and to cover a greater scope of scientific concepts for the purpose of this study.

In principle, each one of the eight intervention lessons was planned purposefully for the study and followed the same pattern. Initially, there was a starter

followed by an introduction of the new concept. In case of a revision lesson, there was a reintroduction of many different concepts that cross connected among sciences. The next step was a couple of past paper questions with cross-curricular concepts, followed by the mark scheme on the board and the students improving their answers with red pen. Afterwards, the students were exposed to either an activity or an online educational game (with specific content and questions) for the students to consolidate the knowledge. The teacher was checking the red pen notes on students' books and preparing a new online retrieval game or other activities for the next lesson to check students' retention on cross-curricular concepts.

In the meantime, four extra intervention activities were created and deployed for the purpose of this study. These activities were used together with purpose made online educational games in specific points during the intervention lesson to maximise the student retention and understanding. The first activity (see Appendix figure 1) of connecting punnet squares with vector and scalar quantities was introduced on the lesson of the scalar and vector quantities in physics, which had followed the biology topic regarding inheritance and evolution. Thus, the students were aware of both concepts before the attempt to merge them. The second activity (see Appendix figure 2) of rearranging equations using magnetic letters of the alphabet was introduced in a chemistry lesson about the mole equation, as well as in the physics topic of forces and motion and in the biology topic of the equation for magnification to provide the students with many opportunities to see the correlation between mathematic equations and sciences. Furthermore, the third activity (see Appendix figures 3a, 3b and 3c) was about past paper questions that need to retrieve knowledge from at least two different sciences to get full marks. For example, the past paper question about the human eye and the lenses (see

Appendix figure 3a) was introduced during a revision year 11s revision lesson, while the rest past paper questions were deployed in the classes once they had finished the relevant topics, so they could make the cross-curricular link. Some of the questions could not apply to the year 9 class since they have not cover specific GCSE content yet. Also, the fourth activity (see Appendix figure 4) with the table and the dice was used in a revision lesson, as a plenary to consolidate and build the cross link of scientific concepts.

In the meantime, with regard to the online educational games, Blooket, Gimkit, Quizizz and Quizzlet were used for retrieval practice with specific cross-curricular content. For example, one online game had questions in which the only answer was 'energy', (see Appendix figure 5). Another online game had questions in which the only answer was 'atoms' (see Appendix figure 6). Moreover, there was a Blooket game in which the students were asked to rearrange different equation in the same pattern as with the rules in the second activity (see Appendix figure 2).

Each class was exposed two times at each activity in these eight intervention lessons, and the online educational games were played in the eight lessons as well as in the usual normal lessons in between the intervention lessons as a starter or plenary. For example, the Blooket game about the rearrangement of the equation played by each class at three different occasions, before and after the second activity with the magnets was introduced and explained to students, and once again after three weeks for spaced learning. Similarly, the Blooket games on energy and atoms were introduced to the students twice with a 3-week gap between each try.

After the end of the eight lessons the students were asked to complete the same questionnaire as before and an extra survey with 15 more items.

Research methods

Initially, I asked 120 students of four GCSE classes to participate in optional questionnaire on google forms twice, before and after the intervention. The purpose of repeating the initial questionnaire after the intervention was to compare and see if the intervention had changed students' responses. The mean age for the students participating is 14 years. All the classes have a ratio 3 boys to 1 girl. The surveys were given at the start of the lessons to increase the response rate and allowed enough time to be completed. However, it was clarified to the students that the questionnaire was optional, and an alternative task was given as a starter activity. Additionally, there was a collaboration with other colleagues in the science department with pre and post qualitative questions. The demographics of the students and the teachers are presented here below.

Students	Females	Males	Mean Age	Ability
Year 9s	4	9	13	Mix
Year 10s	5	12	14	Mix
Year 11s	2	11	15	Mix

Table 2a: Demographics of the students

Teachers	Gender	Age	Subject	Year of Experience
A	Female	50	Physics	17
B	Male	49	Physics	2
C	Male	45	Chemistry	12
D	Female	39	Biology	4
E	Female	33	Biology	8

Table 2b: Demographics of the participating teachers

Student questionnaire

The items of the survey were based on a Likert scale for 1 (strongly disagree) to 5 (strongly agree). The items were as per below in the column 2, with six positive and six negative statements (3, 4, 6, 7, 9 ,11). The latter have been reverted to positive for the statistical coding analysis later. Also, at the end of the intervention, fifteen extra post research items were applied to the same classes with 7 positive and 8 negative statements (16, 18, 19, 22, 23, 24, 26 and 27), and thus they are reverted for the statistical coding later.

Therefore, in the table 3 below, each research variable (first column) appears in the same row with correspondent pre and post survey items (second column) and some extra post research items (third column). The additional post research items were numbered following the first post survey items, for easier referral in the discussion section.

Variables	Pre and post survey items	Additional post survey items
Students' perception of cross-curricular links in sciences and mathematics	1. I could find similarities among Physics, Biology and Chemistry 2. The concept of energy relates to all three sciences	13. I could find same or overlapping concepts among Physics, Biology and Chemistry past paper questions 14. The concept of ionisation relates to all three sciences

	3. What makes science lessons difficult is the maths concepts 4. I don't think that what I have studied in maths could possibly apply in science	15. The concept of radiation relates to all three sciences. 16. I don't think that maths equations could be used in science 17. The concept of particles relates to all three sciences 25. The activity in the photo is an effective method to understand how maths and science are connected to each other (see Appendix Figure 2) 26. The activity in the photo is not a helpful way to explain vector and scalar quantities using Punnett square diagrams (see Appendix Figure 1) 27. The activity in the photo is not a useful method to understand the science subjects are

		connected to each other (see Appendix Figure 4)
Students' motivation and attainment	5. The online learning platforms makes me more engaged in learning 6. Online learning platforms are more of a game than a learning tool 7. When I have not understood a concept during a lesson, I use online learning platforms to study further	18. Blooket starters or similar online games are not so effective for recalling things comparing to usual start questions on the board 19. I don't feel motivated when I complete online quizzes 20. I feel motivated when my teacher presents questions from more than one science subject during the lesson 21. I like science 22. I don't like physics 23. I don't like biology

	8. I remember more concepts that I learnt using online learning platforms comparing to other methods of studying 9. The online learning activities don't help me to become an independent learner 10. If I don't like a subject, I am more interested in this using online learning platforms 11. The use of online learning platforms may not increase my results on a future school test	24. I don't like chemistry

	12. I prefer to revise using a physical book instead of online learning platforms.	

Table 3: Research questions and variables

Regarding to the Column 2 and 3 research items in table 3, they were developed by myself based on my teaching experience with the support of theories on how to conduct research (Firth, 2019; Cain, 2018; Wilson, 2017;). In Column 2, the first and second items are an effort to investigate whether the students understand that the sciences and are related to each other, while the third and fourth item are exploring the idea of cross links between sciences and mathematics. These four items are linked to the first research question. On the other hand, the rest of the items (5 - 12) seeks to find connections between online learning platforms and students' motivation, engagement, and knowledge retention and so they are connecting to the second research question.

The post survey statements in table 3 Column 3 were purposefully chosen to stand alone as a one-off survey for the following reasons. Firstly, there was an attempt to keep the main surveys short to maximise participation of the students and full completion of the surveys. Secondly, the items 13, 14,15,16 and 17 are referring to concepts that some of the participating groups had not been taught before the intervention Thirdly, the statements 21, 22, 23 and 24 could apply once only since the limited amount of time of this research could not claim that will change the

preference of the students towards sciences. So, they were applied at the end, to avoid lengthy main surveys. Lastly, the statements 25 to 27 could only be asked after the research activities have been deployed. The post survey items will be used to evaluate the study variables. The items 13 -17 and 25 – 27 will evaluate the first research variable whereas the items 18-24 will assess the second research question.

Teacher data

Overall, 5 teachers out of 13 of the department participated in this optional survey for qualitative data collection (2 males and 3 females with a mean age of 43 and an average of 9 years of teaching experience. 2 physicists, 1 biologist and 2 chemist).

With regard to the science teachers, initially they were asked to complete a Google form with the following open-end questions:

1. Do you apply interdisciplinary teaching in science and cross-curricular teaching in mathematics and science on your teaching and, if yes, could you provide some examples?
2. What are the benefits and the drawbacks from implementing interdisciplinary teaching in science and cross-curricular teaching in mathematics and science?
3. What is your opinion about gamification of the retrieval practice via online platforms, such as Blooket?

A month later, a presentation was given to them about this study and the methodology and then, the teachers were requested to complete another optional survey with the following questions.

1. Based on the presentation, which activities of you may apply in your lessons and why?
2. Please add any suggestions for activities to demonstrate cross-curricular links between the science subjects and between maths and science.

Again, the same 5 members of staff participated in this questionnaire, explaining unanimously to me that this study could be beneficial to them and to the school as well.

Data analysis

The methodology applied on this study is descriptive statistics and there are two different types of data collection. Inferential statistics and t-tests were used for the quantitative categorical data collection of the students using Likert scale surveys (Gerald, 2018; Marshall & Jonker, 2011; Ross & Willson, 2017). On the other hand, the data collection of the teachers was qualitative, with open-end questionnaire for a deeper understanding and the approach of analysing these data was inductive coding bottom up from the teachers' specific responses comparing them with the well-established ideas in bibliography (Cascio et al., 2019; Chandra & Shang, 2019).

Furthermore, with regard to the student's survey, short simple questions were used to increase the response rate. The estimated time for completion the students' survey was less than a minute. The students' responses will be analysed for the frequency, the mean value, and the standard deviation for every mean value before the comparison with the theory.

Furthermore, in all three surveys the students participated had added their names. The names have been compared in the pre and post surveys and if a student had participated in one survey only, their answered were removed for

coherence of the results. Eventually, the responses of 43 students were included in the results. For the third survey, again only the responses of the same 43 participants, as in the previous questionnaires, were considered for the purposes of this study. No survey left incomplete since the students could not press submit on the surveys unless they have full responded to them.

At the end, the results of this study will be shared with the school so the policy makers may use the results of this study in the future.

Ethical consideration

In the meantime, the following arrangements were made to follow the principles for ethical research as per the CUREC proposal. Above all, the purpose of this study is for educational purposes only. In addition to this, I made sure that participants were not feeling endangered, harmed, or stressed by any aspect of this study. Furthermore, the purpose of the study was made clear to all of them, and how the data collected will be stored and disseminated following BERA guidelines (British Educational Research Association, 2018). Moreover, they were informed that, even if they had used their names on the google form quizzes, their names will not be shared with anyone, and the data collected have been stored secure and in accordance with data protection laws, so any privacy concerns were eliminated. Finally, after the completing of the study, the data collected will be destroyed once no longer required. In addition to this, understanding the power relationships when studying students, the students may answer more genuinely once they have been offered to choose if they wish to complete the survey. In this case, the random press of buttons to complete the survey, and thus to submit false results was mitigated. Besides, this intervention revision methods may not be effective and thus the school

revision resources will be delivered too, to avoid depriving some students from having progress.

Findings and Discussion

Analysis of the data collected by the students

The use of pre and post surveys is supporting the different cycles of this practitioner action research. The different classes from year 9s to year 11 had been taught different amount of content. Therefore, it could be safely assumed that they have a different starting point with regard to their assumption on the interrelations between the sciences and between sciences and mathematics. These assumptions were depicted on the pre-survey. Later, the students were exposed to the intervention lessons as described above in the methodology section. After the end of these designed lessons, the students were asked to complete the post survey with the same statements as the pre-test survey. Hence, the results from the two surveys could convey any implication that can be reflected to the research questions and support or reject their validity.

The null hypothesis of this research question is that the educational methods applied will not have any impact on changing students' perceptions about cross-curriculum in sciences and that the students will not be more motivated or engaged due to this intervention. So, the results on the pre surveys and the post surveys would not have significant differences.

Items			Pre-test		Post-test		t	p
			M	SD	M	SD		
Items of the first Variable	1	I could find similarities among Physics, Biology and Chemistry	3.28	0.882	3.79	0.94	3.114	0.003
	2	The concept of energy relates to all three sciences	3.65	0.813	3.86	0.833	1.177	0.246
	3	What makes science lessons difficult is the maths concepts (reversed item)	3.35	1.251	3.47	1.279	0.429	0.67
	4	I don't think that what I have studied in maths could possibly apply in science (reversed item)	3.91	0.971	3.98	1.012	0.334	0.74
Items of the second	5	The online learning platforms makes me more engaged in learning	3.60	1.116	3.84	0.949	1.044	0.303
	6		3.65	1.089	3.77	1.02	0.589	0.559

		Online learning platforms are more of a game than a learning tool (reversed item)						
Items of the second variable	7	When I have not understood a concept during a lesson, I use online learning platforms to study further (reversed item)	2.74	1.177	2.86	1.207	0.475	0.638
	8	I remember more concepts that I learnt using online learning platforms comparing to other methods of studying	3.35	1.066	3.37	1.001	0.108	0.914
	9	The online learning activities don't help me to become an independent learner (reversed item)	3.77	0.996	3.77	1.065	0	1
	10	If I don't like a subject, I am more interested	3.05	1.133	3.16	1.067	0.52	0.606

		in this using online learning platforms						
Items of the second variable	11	The use of online learning platforms may not increase my results on a future school test (reversed item)	3.35	1.021	3.35	0.997	0	1
	12	I prefer to revise using a physical book instead of online learning platforms.	2.84	1.09	2.93	1.009	0.388	0.7

Table 4: Students' responses relating to correlation in science and mathematics and online game effectiveness for items 1 to 12 before and after the intervention (N =43).

For the purposes of this study, paired t-test were calculated for the pre-test and post-test items 1 to 12. Based on the table 4, the t-test analysis demonstrated that the differences between the mean values were not statistically significant, with the exception of pair 1. However, the current intervention is action research with a very restricted sample, thus statistically insignificant results does not mean that the information gained from the study has not value. Also, the purpose of this study is not to generalise, so a non-significant t-test may not hinder the results. On the contrary, the means of the results show that the students' perception of interrelation of sciences and mathematics was improved. This conclusion will be analysed and supported here below.

In the meantime, one reason that might explain the low significance in the t-test analysis could be the small sample of the study (43). However, a bigger sample was not necessary for the purposes of this study. Also, a bigger sample size could lead to falsely low probability values, called p-hacking or selective reporting. (Head et al., 2015; Simmons et al., 2013).

Therefore, to check if the intervention might have an impact on students' beliefs about common concepts among sciences, there will be an attempt to compare the means (table 4 above) as well as the frequency of the agree and strongly agree options of the Likert scale, as per Figure 1 below. An increase in the post-test means and frequencies values comparing the pre-test means and frequencies values might support the claim that the corresponding research questions could be accepted to some extent (see Appendix table 1 for a presentation of the content of each item and the research questions discussed here below).

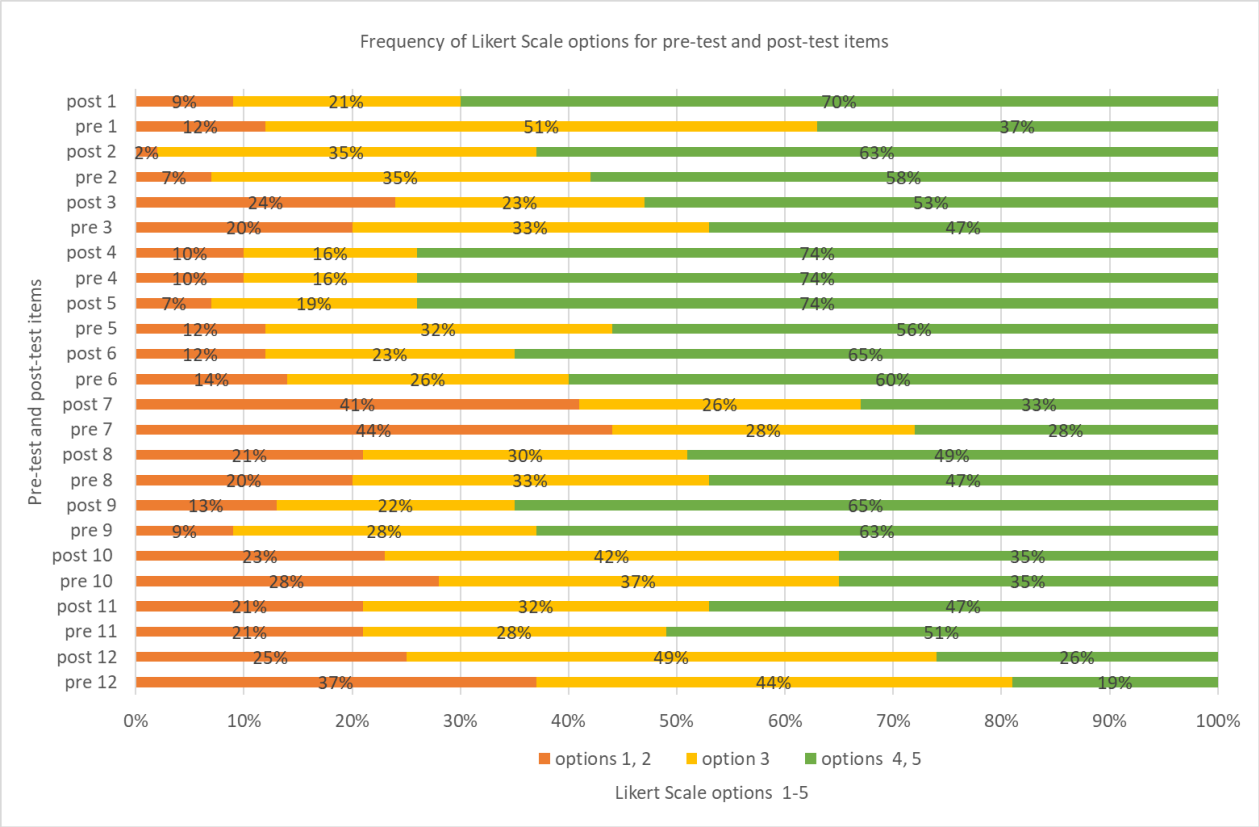


Figure 1: Frequency of students' responses to the questionnaire for items 1 to 12 pre and post the intervention (N= 43, options: 1, strongly disagree; 2, disagree; 3, neither agree nor disagree; 4, agree; 5, strongly agree)

Items 1-6: analysis of students' perceptions for cross links in sciences and maths

My initial expectations about students' perceptions were that the students may have a vague understanding about the cross-curricular links between sciences and mathematics before the intervention since they have not been exposed much to cross-curricular activities, based on my professional experience and on the lessons delivered to them so far. Therefore, I was expecting a lower pre-test mean comparing to the post-test mean of the surveys and a improvement of the students' perceptions after the intervention, which was the case as per the analysis below.

With regard to the first item about students' understanding of similarities in sciences, the findings of the study suggest that the post mean is higher (3.79) comparing to the pre-test mean (3.28) as per table 4.

Similarly, for the second item (concept of energy), the third item (maths difficulty in science) and the fourth item (apply maths in science), the post means are higher comparing to the pre-test means, as per the table 4 above. With regard to the frequency of the agree and strongly agree options on the Likert scale for the first four items, the post-test frequency is higher comparing to the pre-test frequency for all the items but the fourth, which has not changed.

These results might imply that the first research question: ''Can the implementation of a cross-science retrieval practice facilitate students' understanding of the interrelation of sciences and mathematics?" may have some credibility to a certain point after the intervention. As discussed in the literature review section, the cross-curricular teaching of science and mathematics could help the students to reach their zone of proximal development (Andreassen et al., 2019; Silalahi, 2019). Moreover, the increased means for the post survey items two, three and four could imply that after the intervention the number of students, who could grasp that many concepts are interlinked to all sciences, such as the concept of energy, has been increased. However, they may still find it difficult to transfer their understanding of energy in physics to chemistry or biology (Bertrand & Namukasa, 2020; Herfeld & Lisciandra, 2019; Kohn et al., 2018). The use of retrieval practice with cross subject questions (Karpicke & Blunt, 2011), as well as the use of a known model as a tool to develop a concept in another subject (Gobert et al., 2011; Michelsen, 1998) might bridge these gaps.

Items 5-12: analysis of students' motivation with online retrieval practice

With regard to the items five to twelve (5: online engagement, 6: playing than learning, 7: study with online platforms, 8: improved memory, 9: students as independent learners, 10: interest for online platforms, 11: results on future assessments 12: revision with online applications), as outlined in the intervention section, they are referring to the second research question: ''Can the implementation of an online cross-science retrieval practice facilitate students' motivation/ participation''. The post-test means for all these items, except the items 9 and 11, are higher than the pre-test means as per table 4 above. Furthermore, the post sums of the 4 and 5 options on the Likert scale for the items 5, 6, 7, 8, 9 and 12 are higher than the pre-test sums of the same options. The only exceptions are the item 10 in which the pre-test and post-test sums are the same and the item 11 for which the pre-test sum is higher than the post-test sum (Figure 1).

From the above findings, one could conclude that the second research question about the connection between online cross-science retrieval practice and students' motivation might be answered positively. First of all, the students might be more motivated in science after the application of gamification (item 5) (Scholten, 2020). Secondly, the online learning platforms could offer a better learning experience and help the students' retention (item 8) (Knight et al., 2010). Furthermore, the gamification in learning might have a positive impact on the behaviour of the students (De Freitas, 2018; Plass et al., 2013), which in turn could reduce the students' anxiety (Safta, 2015) and increase their motivation and engagement (items 5 and 6), After the intervention some students were playing online educational games in solo mode (Chen, 2019; Lay & Osman, 2018; Richland et al., 2012), or even creating their own online game (Wake et al., 2018) with specific

set of questions to challenge the rest of the class (item 7) (Lay & Osman, 2018; Zhu et al., 2016; Bornstein et al., 2002). Hence, it may be said that the participation of the learners as a game creator may increase their scores as well as their motivation (Lay & Osman, 2018). This outcome could also support a shift of the learning process towards an increased student's ownership and participation (Ko & Krist, 2019).

In the meantime, one possible reason for same pre-test and post-test means for items 9 (students as independent learners) and 11 (results on future assessments) might be the intervention has lasted only a few weeks, and there was not any official assessment for the students to compare their test results after the use of online learning games, as revision tools in the context of independent learning, during this period of time (Abel & Roediger, 2017; Ku et al., 2014). The outcome of both items 9 and 11 could possibly mean that more exposure time on online learning platforms is need for the students to become independent learners using online retrieval practice and feel confident that this method actually works in favour of their results in future assessments. In addition to this, the majority of students may still not prefer to use online retrieval practice for their revision (Karpicke, 2012; Petrovic-Dzerdz, 2019), and they may still prefer to use physical books to revise, concordantly with the item 12.

In support of this claim, one day during a revision lesson with year 9s (see Appendix item 2), the students were given the option to make informed choices of their revision activities (Reiners & Wood, 2015) and some of them requested from the teacher to set a Blooket game, while others prepared flash cards, or reread their notes and answer past paper questions. Two students of those, who opted out of the online game, later said that they have just found the Blooket game boring and needed some more challenging tasks.

One possible explanation to this outcome could be that many students assume that if they can remember a concept, they have mastered it, and therefore they do not use the mnemonic effect of retrieval practice when revising (van Peppen et al., 2021; Karpicke & Roediger, 2008). However, more students seem to recognise the use of the online learning platforms as a learning tool after the intervention, as it might be implied by the reversed item 6. Also, as it might have been expected, the majority of students in the sample could be identified as motivated averagely towards a revision using retrieval practice. Nevertheless, many students, not aware of the mnemonic effect of retrieval practice, assume that if they can remember a concept, they have mastered it, and therefore they do not apply retrieval practice when revising (van Peppen et al., 2021; Karpicke & Roediger, 2008).

Additionally, one possible explanation for the difference results in the agree and strongly agree sums in items 10 (interest for online platforms) and 11 (results on future assessments) could be that the use of online learning platforms might not have any effect on the level of motivation for the students who are completely disengaged in science (Kang & Pashler, 2014), although online games with timely feedback could trigger increased intrinsic motivation levels (Abel & Bäuml, 2020).

Moreover, as four year 10 students admitted during the intervention, they do not have easy access to the online resources at home, while two year 11 students said they do not like to play online games at home by their own and they would prefer the group games, because they feel they learn better when they are engaged with other students (Kapp, 2013; Chen, 2019). Besides, during the intervention with the Blooket games, I have noticed that some year 9 and 10 students were cheating

in order to win the game without focusing on the learning goals of the game (Reiners & Wood, 2015).

Finally, based on the knowledge collected so far, it would be useful to include a question in the pre surveys and the post surveys about the number of hours the students spend revising using online resources and physical books alike. This could be used in conjunction with item 12 to better understand students' preferences in online learning platforms before and after the intervention.

Items 13 – 27: analysis of the additional post survey items

Furthermore, as far as the second set of items (13 to 27) is concerned, they have applied as a questionnaire after the intervention only. Their means and standard deviation are graphically presented on Figure 2 below and the sums for agree and strongly agree options are presented on Figure 3 below.

Also, from the Figures 2 and 3 above, attempting an analysis for the results for the items 16 to 24, it could be argued that there might be some evidence the online educational games as retrieval practice on students' retention and understanding of the cross-curricular concepts between sciences and between sciences and mathematics could facilitate students' motivation and participation as per the second research questions.

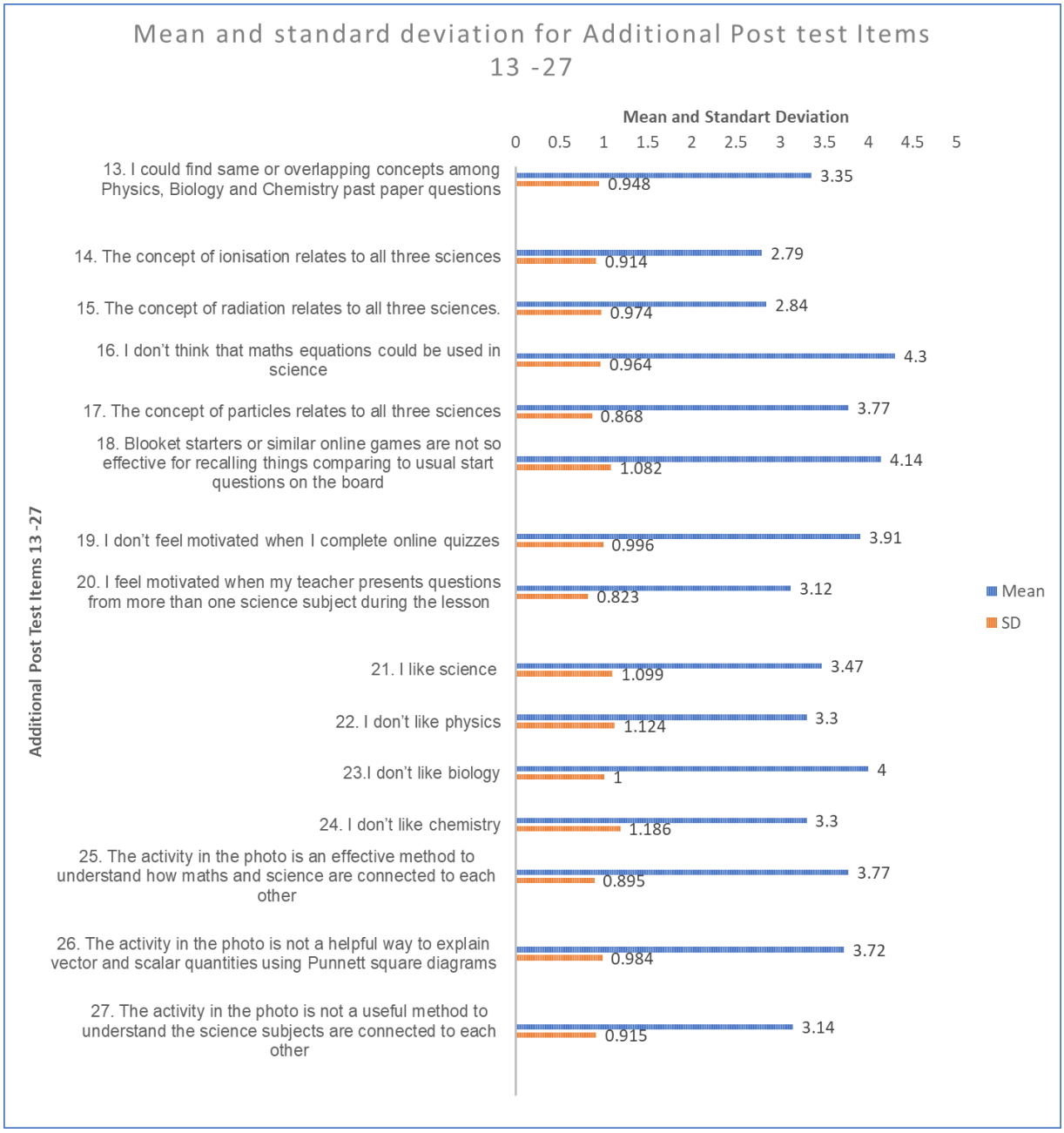


Figure 2: Means and standard deviation for the additional post survey items 13 to 27. (N=43, Reversed items: 16,18, 19, 22, 23, 24, 26, 27)

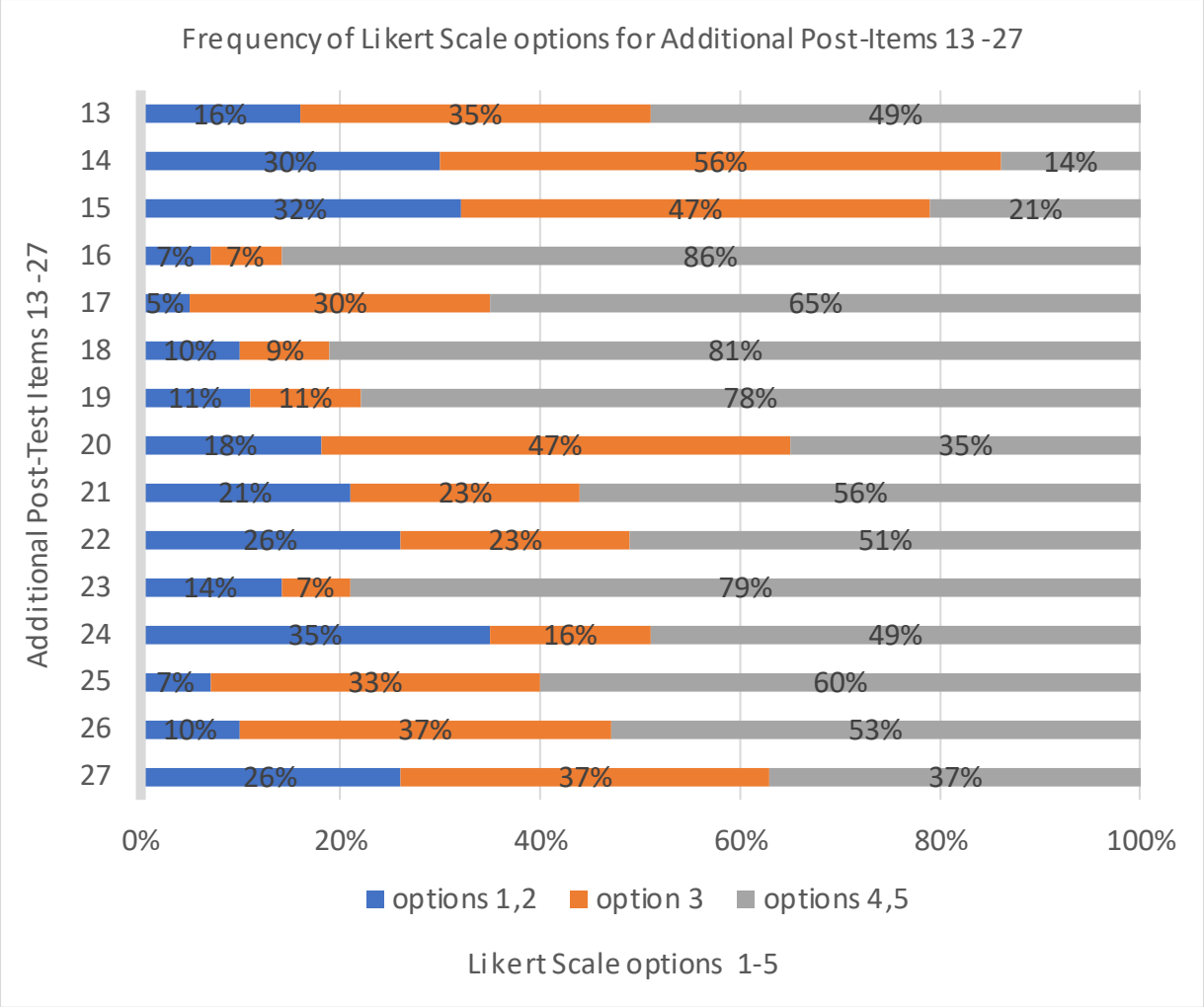


Figure 3: Additional post survey items 13 to 27 for frequencies and sum of the agree and strongly agree option of the Likert scale (N=43, options: 1, strongly disagree; 2, disagree; 3, neither agree nor disagree; 4, agree; 5 strongly agree)

As for the means of the additional post survey questions based on the Figure 2 above, all of them except items 14 and 15 are above 3. A detailed connection between these items and the targeted independent and dependent variables could be find in the Appendix (table 1). Hence, it might be said that there is some evidence, although not at a statistically significant level, to suggest that the implementation of a cross-science retrieval practice facilitate students' understanding of the interrelation of sciences and mathematics as per the first research question.

More specifically, the students' responses to item 13 (overlapping concepts in sciences) have a mean of 3.35. Considering that the students have been exposed to cross-curricular past paper questions during the intervention, this result could indicate their tendency to grasp the idea of cross linked between sciences. Also, if there was a try to cross compare different items, the pre-intervention item 1 has a mean of 3.28 and the post intervention item 13 has a mean of 3.35 correspondingly. Both items have been chosen to be compared since they both ask if there are similar concepts in sciences or not, although item 13 is specifically referred to overlapping concepts among science in past papers questions.

The items 14 and 15 are dealing with the concepts of radiation and ionisation, which are not properly taught in the participating year 9 group, since these concepts are not in their curriculum plan. Hence, their lack of knowledge for these terms might be a reason for a mean lower than 3 for both items 14 and 15, but it was preferred to maintain the same N across the statements to standardise the procedure. In accordance with this claim, three year 9 students have confirmed after the surveys that they have chosen the option 3 on the Likert scale, if they were not sure how to answer an item of the survey.

In the meantime, it could be said that the item 16 referring to mathematical equations in science has a strong resemblance to item 3 about maths difficulty in science and item 4 about applying maths in science. The Items 3 and 4 has shown a steady increase to their post means and post sums of Likert options 4 and 5, as presented above. Also, the statement 16 has collected the highest score and the highest frequency for Likert scale option 4 and 5 among all the statements, regardless they are before and after the intervention. The reversed item 16 correlates the mathematical equations with sciences in students' perception (Robert

Goldstone et al., 2005; Zhao & Schuchardt, 2021), and based on the findings, it might be inferred that the majority of KS4 students are well aware that they could have a significant disadvantage if they could not recall the applications of mathematics equations to solve science questions (Baxter et al., 2014; Pang & Good, 2000; Zakaria & Iksan, 2007), which may hinder their progress and potentially discourage them to follow a relative STEM career in the future (Kezerashvili et al., 2007; Nakakoji & Wilson, 2018).

As far as the items 25, 26 and 27, referring to the activities with the application of magnetic letters to rearrange equations, the Punnett diagrams correlation with scalar and vector quantities and the cross-curricular revision table with the dice respectively have all scored means above 3. The same items have collected high enough scores for the frequencies of the 4th and 5th options to have a significance in the outcome, especially if the sum of the 3rd option on the Likert scale were to be excluded in the calculations of the N.

Hence, it might be assumed that these activities have achieved to some extent to support the participants' understanding of the cross-curricular concepts among sciences and between sciences and mathematics. However, the fact that many students have chosen option 3 on Likert scale, it could support the argument that the students many times find difficulty in perceiving the physics equations as functions of one variable and understand in depth the mathematic implications in physics (Sokolowski, 2021), or they may need further guidance to transfer graphical skills from mathematics to sciences (Potgieter et al., 2008). Maybe the fact that the mathematical formulas are referred as equations in physics could be a confusing factor for the students. Furthermore, during the intervention with the magnetic equations, most students could rearrange the equations easily after some practice.

However, the lower ability students found difficult to apply the same rules in the context of an exam question which required the rearrangement of the equation (Southall, 2016; Foster, 2021). Also, the students seem to understand better numbers than letters, so they were more successful in rearrangement, if they had substituted the letters with the number before attempting any rearrangement. The things could become more complicated, especially with the year 9s classes, if the students were asked to convert the quantities in the base units and then solve the equation. It appears that some students lack the substantive knowledge of the place value, so they could not apply the disciplinary knowledge of conversion.

Furthermore, the outcome for the reversed statement 18, with a high mean and a high percentage of the agree and disagree Likert scale option, might imply that the students prefer the gamification as a starter to a pen and paper starter, probably because the interaction with online platforms has become a second nature to them (Straker et al., 2013). It seems from the intervention that more students were prompt to participate in the online starters, such as Blooket, in comparison with the students' engagement in pen and paper starters. Also, the online games could provide straight away feedback to the students and this feedback could be a reason that their game scores have been improved over the time before the end of game (see tables 5 and 6 below). After some lessons, the students have been invited to engage in the same game with same questions, and, this time, their game scores have been improved. This outcome could be possibly explained partially because of the instant feedback and partially because of the spaced learning (Karpicke & Roediger, 2007; Kelley & Whatson, 2013). Overall, their results have been improved with the online educational games (Ku et al., 2014), and their engagement has been increased

definitely creating a positive climate during the lesson (Lister, 2015; Looyestyn et al., 2017); especially at the last period of the day in which students are more tired.

The items 19 and 20 might also be used as evidence to support the above assumptions. Firstly, the reversed item 19 has a mean 3.91, while the item 20 has a mean 3.12. In addition to this, the point system, as per the tables 5 and 6 below, possibly explains that the students carried on participating in the game, even if they have already tried all the questions at least once (in total 21 questions), so they could get more points and increase their ranking answering the same questions after they have received the online feedback. Also, this repeated retrieval practice with online games might have increased to some extent the crucial thinking of the students since they have improved their scores during the second attempt (Hussein et al., 2019; van Peppen et al., 2021). This could be further supported by the fact that there was same time limit for both attempts (7 min) and similar number of points gained overall by each student respectively. Therefore, it might be concluded that the answering speed has remained the same, but the accuracy has increased, which is in contrast with relevant research (Attali & Arieli-Attali, 2015). It seems that the method of asking the same question multiple times, facilitates students learning, and therefore their responses are improved. On the other hand, there were some wrong answers, even if the students tried many times the same questions, and thus it might be said that the quick answers due to the competition may have led to lower learning results since some students may have guessed the answer without thinking (Koppitsch & Meyer, 2021; Wang & Tahir, 2020)

Students	Corrects Answers	Incorrect Answers	Percentage of success	Total Points
A	128	12	91	309
B	47	11	81	294
C	49	5	91	265
D	44	3	94	240
E	98	6	94	237
F	21	5	81	180

Table 5: Online educational game on cross-curricular questions about the energy concept, first attempt

Students	Corrects Answers	Incorrect Answers	Percentage of success	Total points
A	114	9	93	315
B	84	12	88	298
C	61	7	90	173
D	81	6	93	267
E	118	4	97	338
F	37	3	93	92

Table 6: Online educational game on cross-curricular questions about the energy concept, second try a month later

For the items 21, 22, 23 and 24 their mean is above 3 with a clear preference to Biology. Also, the frequency for 4 and 5 options has the majority in all items. Biology might be higher in preference because it has less links with mathematics and equation in GCSE level and it has more links to living organisms and nature, thus the

student could understand easier some difficult concepts, such as energy. For example, a students could easily grasp the idea that the energy is transferred from food to the human body, but they might find it difficult to understand how the gravitational potential energy of a falling object is transferred to thermal energy and dissipated to the surroundings (Neumann et al., 2013; Park & Liu, 2019). On an online educational game with relevant questions, more students could identify the former than the latter examples of energy transferred. Hence, it may be beneficial to deliver such concepts with a bottom-up approach, teaching the ideas in a context familiar to the students, bringing many examples and analogies from real life and then attempt the more complex applications of the same concepts (Chi & VanLehn, 2012).

Analysis of the data collected by the teachers

With regard to the questionnaires answered by the teachers, before the delivery of the relevant session about this intervention, the following summarised responses have been received for each question. The questions were open-ended, and the analysis was qualitative (see Appendix table 2 for the questions answered by the teachers).

How to apply interdisciplinary teaching in science with examples (Question 1)

Three teachers (A, C, D) answered that they provide links between the sciences as that it can help in giving more context. For instance, linking endothermic/ exothermic reactions to respiration/photosynthesis or a lot of particle model of matter is shared between all sciences and helps model things, such as diffusion, osmosis and heat transfer. As far as the mathematics and its correlation to sciences, the teachers responded that they talk to the maths department and check

the language that they use so they can use the same terminology if it's accurate for what we try to do. They also teach rearranging equations the same way the maths department teach basic algebra as well and constantly referring back to when they have done this in the mathematics. This approach might be an effective way of supporting students' progress in science with the application of mathematical equations as tools in science (Baxter et al., 2014; Pang & Good, 2000; Zakaria & Iksan, 2007).

Also, the same three teachers (A, C, D) mentioned that they teach other skills including rounding, using significant figures, decimal places, standard form, resultant forces, plotting graphs/ interpreting graphs, calculating gradients, calculating means, calculating volumes and trigonometry. In such a way, they could provide a teaching with many aspects through a collaborative cross-curricular development with other departments (Sund & Gericke, 2020; van Schaik et al., 2019).

The benefits of interdisciplinary teaching in science and mathematics (Question 2)

Consistency Firstly, three teachers (B, C, E) have named consistence as a benefit. By using the same terminology, students gain consistency in their understanding which can speed up the learning process, since the repetition of scientific language could help them to adopt and use such a vocabulary in their answers, which in turn may lead to the introduction of cross-curricular culture among the lessons (Savage & Fautley, 2007).

Engagement. Secondly, two teachers (A, D) have proposed that implementing interdisciplinary teaching helps students to see science as a whole and

provides challenge by making them form links between separate sciences, thus it can help with engagement as they can learn a bigger picture.

Grading. Another benefit is that the students who have good basic maths skills could gain more marks in their exam papers, especially in the Triple Physics GCSE paper through maths skills, even before knowing much of the science content, as outlined by four teachers (A, B, D, E).

The drawbacks of interdisciplinary teaching in science and mathematics

On the other hand, they have named some drawbacks, such as the interdisciplinary teaching, that may confuse students who are struggling to grasp the basic concepts. Furthermore, there can be issues where the science curriculum might use a mathematical skill before it's covered in maths, so taking up more teaching time and risking undermining maths teaching by using different methodology or different language. Therefore, it could be said that the teachers should be encouraged to collaborate with other colleagues in multidisciplinary methods of learning (Margot & Kettler, 2019; Veishene & Dsouza, 2022). Another potential problem mentioned is that the way that science teachers learnt maths at school doesn't always match how it's taught now. For example, one teacher mentioned that they were taught to rearrange equations by "bringing the ___ up to the other side", but this phrase is neither familiar nor useful to students) (Bartels et al., 2019). Furthermore, another issue is the conventions in exams - e.g., in maths the students are taught that graphs must have a title and that the lines of best fit must always be straight, whereas in science the title is not important, but the axis labels are very important, and the lines of best fit could be either straight lines or smooth curves. Therefore, it depends on teachers' ability and perception to merge

the knowledge appropriately of different disciplines to maximise the effects on the students (Heywood et al., 2012).

How to effectively apply gamification with retrieval practice (Questions 3, 4, 5)

All teachers concluded that it is a very useful and engaging tool, where students strive to do better. They have also agreed that motivation is the key to engaging students in the classroom. One teacher mentioned that gamification is something that they have worked on in their lessons i.e., understanding the different motivators, and how it affects student behaviour for learning.

With regard to Blooket, the teachers agreed that it is a useful tool, and they like it, as there are multiple ways to "win" in a Blooket game. Thus, Blooket games could motivate all students, not just the brightest ones. This game also repeats the questions within the same session, providing both learning opportunity as well as assessment for learning. Another teacher (C) added that they regarded it as an effective method of engagement. ‘’Blooket appears a very popular method for many pupils that do not otherwise engage very well.’’ Therefore, the gamification could be used as teaching and engaging the students (Ikwumelu et al., 2015; Mostafa et al., 2018). The same teacher (C) added: ‘’However, I have found that due to the way that the games can work, being at the top of the leader board does not necessarily mean that they have done very well on the questions’’. So, even if the teachers could apply gamification to encourage the desirable behaviours and assign positive points for such behaviours (Zichermann & Cunningham, 2011), this might not lead necessarily to higher learning outcomes (Koppitsch & Meyer, 2021), or significant improvement of critical thinking (van Peppen et al., 2021). On the other hand, this collaboration

through peer competition might be beneficial in terms of conceptual knowledge and structure for the students (Chen, 2019; Richland et al., 2012)

Furthermore, another teacher (E) commented on Blooket: ‘’It's fantastic for engaging students in revision that can otherwise be repetitive and hard to motivate them to do. It's a really useful strategy to help them to master the content recall that they need to build a solid foundation for then moving on to explanations and application’’ Hence, it might be argued that the gamification could initially work on recalling facts and then support the students to understand higher order questions and possibly make the cross links among sciences (Agarwal, 2019). Finally, the teachers concluded that such tools should not be a standalone activity, but they should mix up with other methods of testing fact recall (Leonard et al., 2020). A multidimensional access of the memory, for example with writing, drawing, speaking and interacting online is likely to make the retention and understanding of the knowledge more secure, they have added. This is in accordance with the theory claiming that a variety of online resources and tools may improve the learning process for cognitively advanced tasks (Perrucci et al., 2012).

With regard to the teachers answers on the questionnaire after the delivery of the relative session about this study, there will be an attempt to summarise and explain them here below.

Application of the four extra intervention activities

Activity with the magnetic letters for rearranging equations. The teachers overall expressed their preference to activity with the magnets to rearrange the equations, mentioning that it could be a useful alternative approach to "unstick" students struggling with equations in sciences and mathematics alike. It worth

mentioning that after the presentation of the intervention, a teacher liked the activity with the magnetic equations, and they have applied it straightforward in their classes with positive comments from the students. They have also integrated this activity in revision resources, and they have shared them across the department (Kohn et al., 2018; Sund & Gericke, 2020).

Activity with the revision table and the dice. All the teachers also have expressed that the revision table with the dice is a simple but effective strategy to set up for consolidation and revision lessons in a cross-curricular context. This might tackle the issue that many students do not apply retrieval practice since they are not aware of the mnemonic effect of retrieval practice (Karpicke & Roediger, 2008).

Activity that connect scalar and vector quantities with Punnet diagrams. On the contrary, two teachers (B, D) said that the activity of explaining scalar and vector quantities with a Punnet diagram, would take too much explaining to be very useful. It could be claimed that both concepts are complex, and the students should master each concept in depth, prior of any attempt to combine them, otherwise new misconceptions in science may be developed (Soeharto & Csapó, 2021; Steedle & Shavelson, 2009).

Activity with the past paper questions with cross links. In the meantime, four of the participants (B, C, D, E) agreed that they are using past paper questions, which require retrieval of scientific knowledge from at least two sciences for an answer to challenge their students. This could be beneficial not only for developing the scientific literacy of the students (Avargil et al., 2018), but also for helping the students to reach their zone of proximal development (Andreassen et al., 2019; Silalahi, 2019).

Suggestions of activities with cross-curricular links

The cohort of participants commented that they should liaise with the department of mathematics to ensure we use common language for example: averages, graphs etc. (Lillejord & Børte, 2016; van Schaik et al., 2019). They have also agreed that they should use gamification to apply full questions of cross-curricular subject material. Another unanimous proposal is the use of mind maps that cross link topics and ask the pupils to say where else they have noticed these links. It seems that their proposal is in accordance with the theory proposing that once students engaged in game-based learning applications, they could get better scores in forthcoming tests (Ku et al., 2014; Papp, 2017). Also, since many students are not interested in science, the addition of topics that are interesting to the students and have cross-curricular links might have a positive effect on their motivation (Djudin, 2018). This wide approach of teaching science might also support students to develop a problem-solving-skills perspective (Crippen & Antonenko, 2018; Sjöström & Eilks, 2018; Stuckey et al., 2013) and later on they might follow a relevant degree or occupation (Belova et al., 2017).

Hence, to approach and possibly answer the third research question, it may be alleged that the teachers' perspectives on a cross-science retrieval approach are in accordance with the current theory and they are welcoming new teaching methods to improve the students' retention. In the meantime, they are aware of the limitations of these theories, and they seem to apply a combination of different approaches to facilitate the teaching and learning.

Limitations

During the analysis of the findings, some limitations of this study came into light. Firstly, the degree to which students have engaged with the designed activities may vary; some of them were fully engaged, while others were not motivated to participate at all. Secondly, the natural progression and developing maturity of the students (Reiners & Wood, 2015) may have an impact of the results of this study, although this factor was not taken into consideration as a variable. Thirdly, after the intervention has been completed, there were some revision lessons in which the students did not seem to agree on which method to follow for revising. Even though different revision activities of varied effectiveness were presented to the students (see Appendix item 2 first slide), there were still some students who preferred to use a low effectiveness revision method that previously worked for them, such as rereading notes in their books (Petrovic-Dzerdz, 2019; Rowley & McCrudden, 2020; Badali et al., 2022; Karpicke et al., 2009).

Furthermore, although I have acted as a practitioner/researcher and I informed students that their grades would not be affected by their responses, our teacher-student relationship may have caused some social desirability biases in student responses. Besides, this study applies to a state secondary school and therefore, it is highly probable that the student of a grammar or an independent school would have answered the research items in a different way.

Another limiting factor could be that I have held multiple roles (of a teacher and of an observer) and conducting a study at the same time could make it difficult to draw distinctive lines between the professional teaching and the purposes of this study. The teachers many times adjust their lessons as they deliver it for the benefit

of their students, whereas an intervention should follow a specific timeframe and methodology to evaluate the research targets.

Finally, the preference of Likert scale questionnaires for the students and interviews for the teachers are based on the following limiting factors. The students may have different starting point on their assumption for cross links between different subjects, and thus a wider sample could be more appropriate to incorporate as many different views as possible. On the other hand, the limited number of teachers in the school predefined the use of open-end questionnaire to maximise the input of the information, since it cannot be a valid sample for quantitative statistics.

Conclusions

Based on this study, game-based cross-curricular activities have much to offer in the school science classroom. Not only could they help teachers present sciences as developing disciplines closely related to the life, but they could also help the learners understand what they are doing and why (Ward-Penny, 2010). Without disregarding that this study findings are limited, it was designed and applied successfully since it has made some significant contributions to the school community. The intervention was most useful for the students, as a method to support them in bridging their knowledge gaps and understand that many scientific concepts are cross linked in sciences and mathematics. Furthermore, the online educational games of this study achieved to some extent to engage the students in cross-curricular activities. However, the teachers, who would like to implement these activities should be aware of some parameters. Firstly, the activities may need to be adjusted for the needs of the classes. Secondly, the activities should be used purposefully with specific context to maximise their effect and not just for filling the

time. Thirdly, the students need consistent training in cross-curricular concepts using science capital and real-life examples, thus they could master these concepts and be able to apply them across the sciences and in their future life.

Besides, my colleagues and I have learnt how the activities in this intervention could motivate our students and how to deliver cross-curricular ideas using gamification. Firstly, we have understood that gamification appears to be a promising method to engage students (Kapp, 2013), especially the low motivated ones, and possibly help them understand that the retrieval practice could become an interactive tool with tasks that actually work (Kang & Pashler, 2014; Abel & Bäuml, 2020; Steinmayr et al., 2019; Scholten, 2020). Secondly, we have realised that game-based cross-curricular activities could enhance students' learning experience by showing the interdependence among different disciplines (Sund & Gericke, 2020; Rapanta, 2021; Heywood et al., 2012). Thirdly, the science department had met occasionally to discuss the application and the barriers of the intervention and there will be future meeting to collaboratively seek how to strengthen the pedagogy involved based on the findings (Margot & Kettler, 2019; Veishene & Dsouza, 2022).

Implications

The experience of this study has informed my expertise as a teacher, my colleagues' practices, my school future teaching and learning projects and possibly the educational research community.

Personally, different parameters of this study have supported my development as a teacher. Firstly, the literature review revealed to me so many aspects in teaching and learning that I was not aware of, for example, how to better apply gamification in order to engage and motivate my students. Besides, before I applied

this intervention, I had had a vague idea where to introduce some cross-curricular concepts in my lessons. However, I have decided to deliver this intervention in specific lessons following other researchers experiments and ideas. Furthermore, I have studied in depth about spaced learning, and I could apply it effectively in my lessons.

Secondly, the design of this intervention showed me so many variables that have to be taken into consideration in order to deliver an outcome, for example, the preparation of quantitative and qualitative surveys, the careful selections of the questions to be asked in the surveys, the timely application of the intervention for a specific period of time, the translation of the results in a meaningful way and the appropriate presentation of the outcome.

Moreover, the intervention itself had shown the differences between the theory and the application. In particular, working on action research and delivering lessons to the students at the same time was rather challenging and productive since I was working on two projects simultaneously and afterwards, I was acting as an external observer to analyse the results, as if I was giving feedback to my own practices. Last but not least, I have understood how important the cross-curricular activities are to help students understand that the science we do at school is the same as the science we may use outside the school and how the gamification of cross-curricular could activate the students to reach to that conclusion (Ikwumelu et al., 2015; Mostafa et al., 2018; Westwood, 2006).

Hence, from now on I will adapt my teaching to include online educational games with cross-curricular ideas and I will update them regularly to meet my students' needs. Also, I will use regularly and timely retrieval practice with cross-

curricular concepts to maximise the knowledge retention. Furthermore, I will improve the four extra intervention activities and seek to include more cross-curricular ideas in similar activities. I will also share all these resources with my colleagues, and we will work together to improve them.

Furthermore, I will apply the theory studied for students' motivation and gamification by using appropriate online tasks and I will try to teach them how to become independent learners by using online retrieval practice for revision. Last but not least, I will start an after-school club for students to develop and play online educational games.

With regard to my colleagues' practices, the intervention has triggered some meetings and discussions. In one of our meetings, we had a consensus that rereading a topic does not help in depth understanding (Petrovic-Dzerdz, 2019; Rowley & McCrudden, 2020; Badali et al., 2022; Karpicke et al., 2009), and that many students sometimes appear to have a compartmentalised view of sciences, even if for the same concepts (Ward-Penny, 2010). Meanwhile, we have agreed that the four extra intervention activities could be implemented in the lessons straightaway. For example, the activities with the magnetic letters and the revision table with the dice could be used once per week as standalone tasks. Also, we have agreed that the regular yet spaced use of online educational games, such as Blooket and Quizziz, could capture students' interest as well as offer value feedback for students' progress and understanding.

With regard to the school teaching and learning policy, the school senior leadership team had set as a two-year target to bring different departments together to increase their collaboration. In the meantime, the results of this intervention had

revealed possible communication channels between sciences and mathematics. Hence, both the school policy and the intervention led to an inset day in which science and mathematics teachers came together to discuss cross-curricular implementation (Baxter et al., 2014; Pang & Good, 2000; Zakaria & Iksan, 2007). Topics discussed during this meeting included but not limited to:

- uses of terminology, such as weight, mass, speed and velocity (Westwood, 2006).
- development of a cross-curricular lesson plan for teaching graphical skills, such as lines and curves of best fit (Ward-Penny, 2010; Potgieter et al., 2008).
- creation of a step-by-step method for applying, rearranging, and solving equations (Sokolowski, 2021).
- implementation of commonly teaching approach for supporting students to develop a problem-solving strategy (Westwood, 2006).

Finally, this study contributes to research on game based cross-curricular teaching. Currently, there is not much research undertaken on this field although in the near future more school may adapt their curriculum to include online activities since there is a shift in digitilised education (Straker et al., 2013; Luckin et al., 2012; Dillenbourg, 2016) in a worldwide attempt to train the students on how to become independent learners using the internet (Pinchuk et al., 2019; Kapp, 2013; Hamari et al., 2014; McKain, 2019). Anecdotally, three students approached me towards the end of the year and advised me that the activities given over the course of this intervention helped them in both understanding and remembering the content on the final test. Based on this feedback, future research could investigate the same activities applying quantitative and qualitative methods alike. Also, recording some

students' opinions with interviews may help to improve the way that the activities are delivered or the activities themselves.

Next steps

My next steps as a teacher based on the intervention are twofold. First of all, during the next term, there will be a continuous professional development course in my school in which I will deliver the outcomes of this study to other departments and possibly to other schools in the trust. My intention is to keep open a communication channel for further discussion and cooperation on the basis of this study. I may also take the study further by including teachers of mathematics in the questionnaire to compare their opinions. Additionally, in the finding section I may use different statistical methods, such as the chi square test to analyse the collected data and then triangulate the results to create a more in-depth picture of the topic.

Secondly, I will attempt to develop a student friendly online platform in which the demonstration of mathematical equations using the magnetic letters and other activities of this intervention will become freely available online. Later on, I will seek advice on how to improve the platform asking my students and colleagues with a final step to make this idea widely available through social media for every school to use.

As for my school next steps based on this study, the science department has agreed from September onwards that there will be a collective attempt to teach students how to revise effectively using online platforms and become independent learners (Gunawan et al., 2019; Baxter et al., 2014; Pang & Good, 2000; Zakaria & Iksan, 2007) and to build teachers' confidence in deliver cross-curriculum ideas outside of their specialism (Avramides et al., 2015; Goodyear & Casey, 2015; Elo &

Nygren-Landgärds, 2021; Bartels et al., 2019). Also, we have agreed to prepare and implement lesson starters with a mix of cross-curricular retrieval practice questions and game-based activities. Furthermore, the science and maths teachers have agreed to work collaboratively to create some shared resources to overcome usual misconceptions and apply common practices across the boards.

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Appendix

Figure 1: Activity to connect punnet squares with vector and scalar quantities

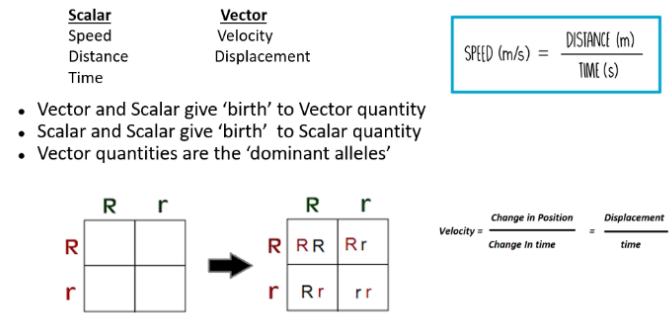


Figure 2: Activity with magnetic letters on the board to solve mathematic equations

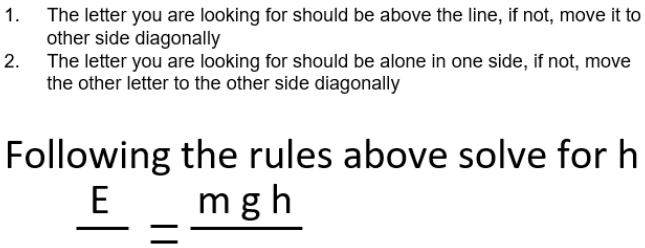


Figure 3a: Past paper question connecting biology and physics

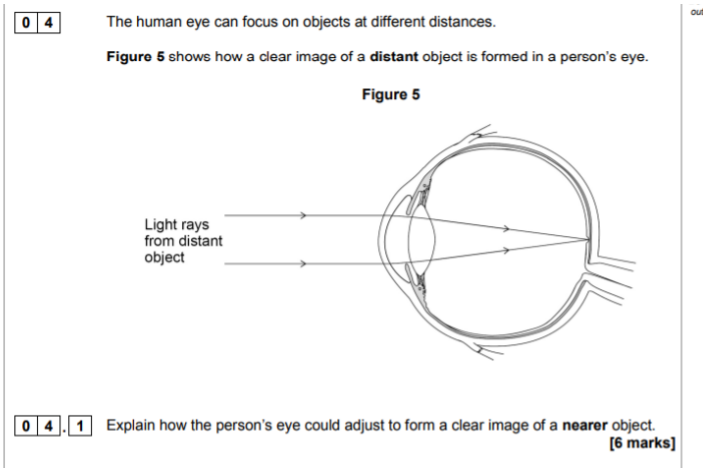


Figure 3b: Past paper question connecting biology and chemistry

Chicken egg shells contain calcium. Calcium ions are moved from the shell into the cytoplasm of the egg.

Table 2 shows information about the concentration of calcium ions.

Table 2

Location	Concentration of calcium ions in arbitrary units
Egg shell	0.6
Egg cytoplasm	2.1

(e) Explain how calcium ions are moved from the shell into the cytoplasm of the egg.

_____

_____

_____

_____

Figure 3c: Past paper question connecting biology and physics

(b) The aorta transports blood from the heart to the body.

In a person at rest:

- blood travels at a mean speed of 10 cm/s in the aorta
- blood travels at a mean speed of 0.5 mm/s in the capillaries
- the speed of blood decreases at a rate of 0.4 cm/s^2 as blood travels from the aorta to the capillaries.

Calculate the time it takes for blood to travel from the aorta to the capillaries.

Assume that the speed of blood decreases at a constant rate.

Use the equation:

$$\text{rate of decrease in speed} = \frac{\text{change in speed}}{\text{time}}$$

Give your answer to 2 significant figures.

Figure 4: Activity using a revision table and dice

	1	2	3	4	5	6
1	cells	atoms	radiation	nucleus	elements	Mutation
2	batteries	cancer	gas	mass	heat	enzyme
3	energy	food	animal	field	osmosis	virus
4	diffusion	plants	water	Active transport	electrons	Oxygen
5	Carbon dioxide	gene	tissues	time	Speed	hydrogen
6	lenses	wave	light	compounds	proton	photosynthesis

Roll the dice twice on the QR code and find two words on the table.
Then, discuss with your partner, how these words are related.

Figure 5: Blooket game for showing energy is a cross link concept in all sciences

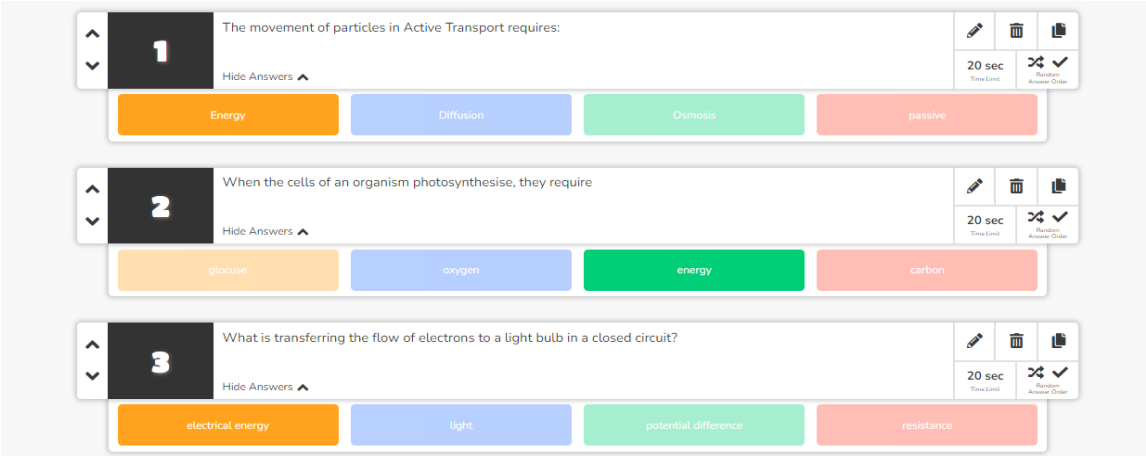


Figure 6: Blooket game for showing atoms is a cross link concept in all sciences

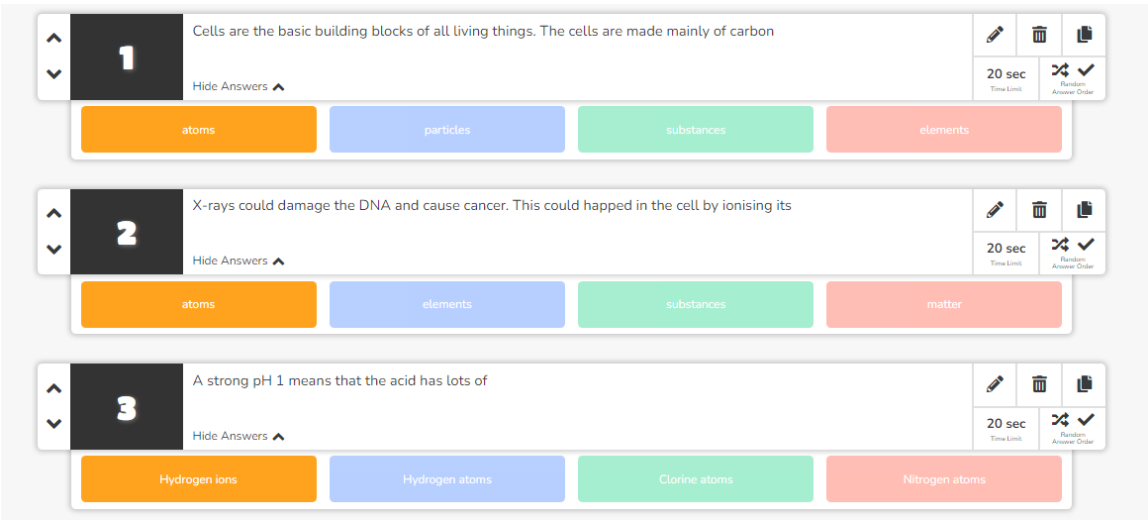


Table 1: Link of each item on the surveys with the research questions.

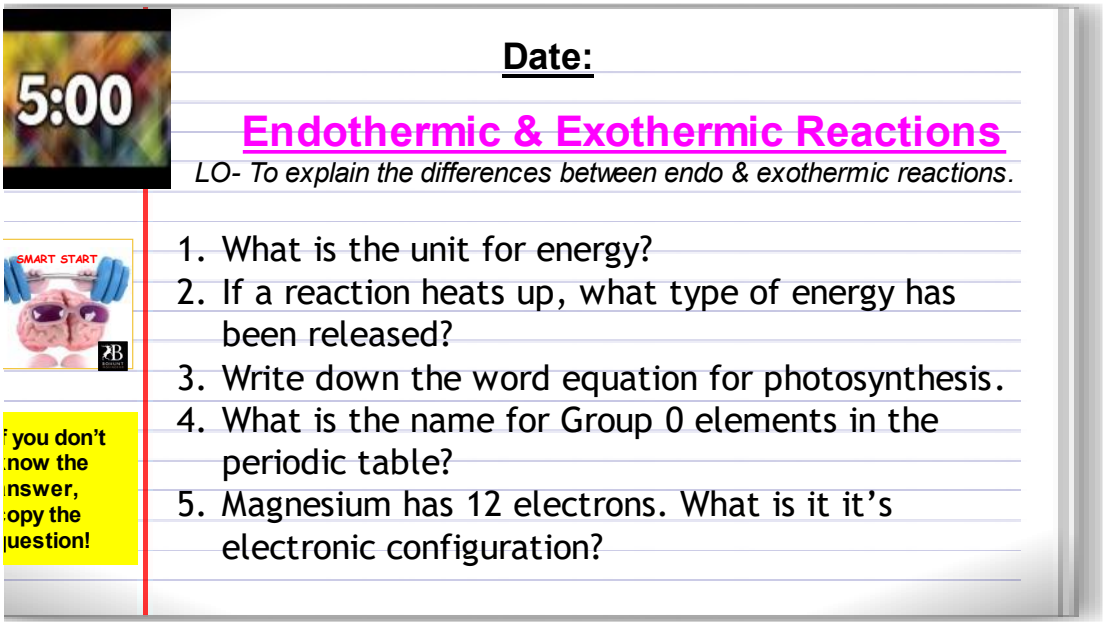
Column 1	Column 2	Column 3
Variable	Pre and post survey items	Additional post survey items
Dependent: Students; perception of cross curricular links between sciences and between sciences and mathematics Independent: Specially designed online educational games and novel activities with cross curricular retrieval practice questions	1. I could find similarities among Physics, Biology and Chemistry 2. The concept of energy relates to all three sciences 3. What makes science lessons difficult is the maths concepts 4. I don't think that what I have studied in maths could possibly apply in science	13. I could find same or overlapping concepts among Physics, Biology and Chemistry past paper questions 14. The concept of ionisation relates to all three sciences 15. The concept of radiation relates to all three sciences. 16. I don't think that maths equations could be used in science 17. The concept of particles relates to all three sciences 25. The activity in the photo is an effective method to understand how maths and science are connected to each other (Figure 2) 26. The activity in the photo is not a helpful way to explain vector and scalar quantities using Punnett square diagrams (Figure 1) 27. The activity in the photo is not a useful method to understand the science subjects are connected to each other (Figure 4)
Dependent: Students' motivation and attainment Independent	5. The online learning platforms makes me more engaged in learning	18. Blooket starters or similar online games are not so effective for recalling things comparing to usual

Specially designed online educational games and novel activities with cross curricular retrieval practice questions	6. Online learning platforms are more of a game than a learning tool 7. When I have not understood a concept during a lesson, I use online learning platforms to study further 8. I remember more concepts that I learnt using online learning platforms comparing to other methods of studying 9. The online learning activities don't help me to become an independent learner 10. If I don't like a subject, I am more interested in this using online learning platforms 11. The use of online learning platforms may not increase my results on a future school test 12. I prefer to revise using a physical book instead of online learning platforms.	start questions on the board 19. I don't feel motivated when I complete online quizzes 20. I feel motivated when my teacher presents questions from more than one science subject during the lesson 21. I like science 22. I don't like physics 23. I don't like biology 24. I don't like chemistry

Table 2: Questions answered by the teachers

Question 1	Do you apply interdisciplinary teaching in science and cross curricular teaching in mathematics and science on your teaching and, if yes, could you provide some examples
Question 2	What are the benefits and the drawbacks from implementing interdisciplinary teaching in science and cross curricular teaching in mathematics and science?
Question 3	What is your opinion about gamification of the retrieval practice via online platforms such as blooket?
Question 4	Based on the presentation, which activities may you apply in your lessons and why?
Question 5	Please add any suggestions for activities to demonstrate cross-curricular links between the science subjects and between maths and science.

Item 1: Examples of the activities during the intervention lessons

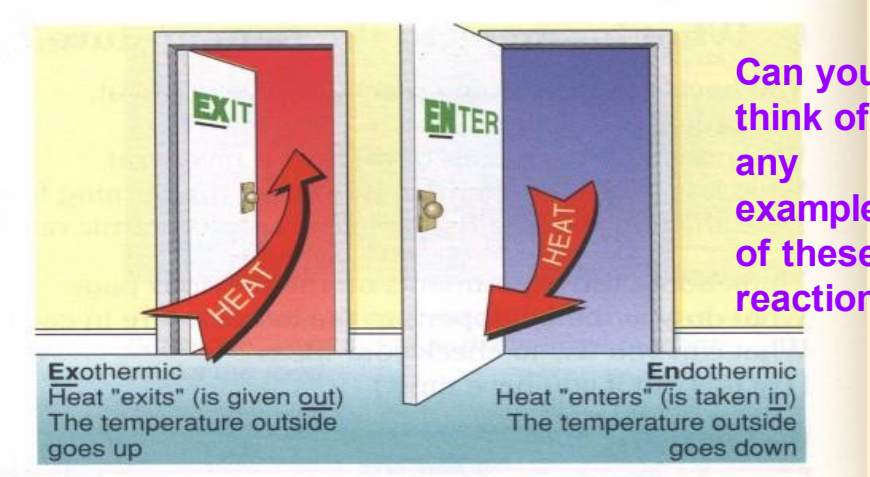


Endothermic & Exothermic Reactions

LO- To explain the differences between endo & exothermic reactions.

1. What is the unit for energy? **Joules**
2. If a reaction heats up, what type of energy has been released? **Thermal**
3. **Photosynthesis: carbon dioxide + water ---->oxygen + glucose**
4. **Group 0 elements are known as the Noble Gases**
5. **Magnesium: 2:8:2**

LO - To explain the differences between endo & exothermic reactions.



Can you think of any examples of these reactions?

LO - To explain the differences between endo & exothermic reactions.



LO - To explain the differences between endo & exothermic reactions.

Exothermic



- **Exothermic reactions release heat energy**
- This means the surroundings (the beaker/ test tube) will **heat up**
- We say that the energy of the surroundings has increased because the temperature has increased
- Examples: combustion (burning), metal and acid, respira

MAKING BONDS!

LO - To explain the differences between endo & exothermic reactions.

Endothermic



- **Endothermic reactions absorb heat energy from the surroundings**

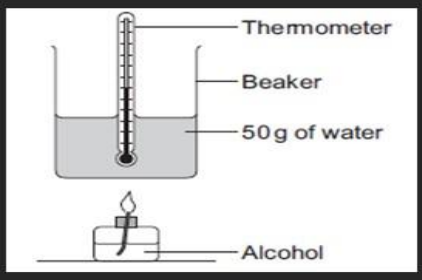
- This means the surroundings (the beaker/ test tube) will **cool down**
- The temperature of the surroundings goes down because the energy has gone down

BREAKING BONDS!

- Examples: photosynthesis, dissolving ammonium nitrate

Alcohols are used as fuels.

A group of students investigated the amount of energy released when an alcohol was burned. The students used the apparatus shown in the diagram below.



In one experiment the temperature of 50 g of water increased from 22.0 °C to 38.4 °C.
The mass of alcohol burned was 0.8 g.

Calculate the heat energy (Q) in joules, released by burning 0.8 g of the alcohol.
Use the equation:

$$Q = m \times c \times \Delta T$$

Specific heat capacity (c) = 4.2 J / g / °C

3444 J

if answer incorrect:

one mark for temperature increase = 16.4 °C

one mark for mass of water = 50 g

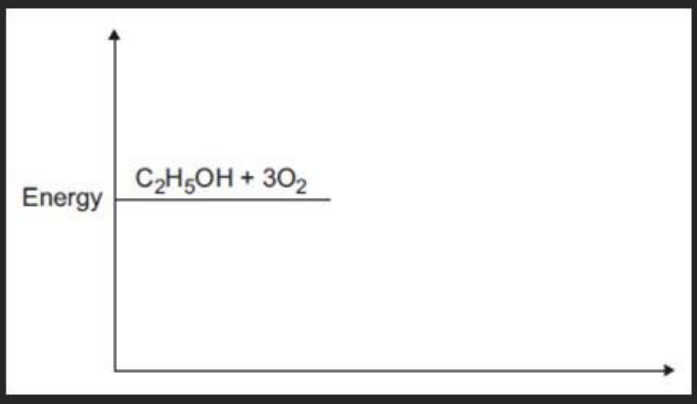
ecf for one incorrect value gains two marks for correct calculation

no ecf for two incorrect values

Complete the energy level diagram for the combustion of ethanol.

On the completed diagram, label:

- activation energy
- overall energy change.



products line lower than reactants

activation energy labelled

overall energy change labelled

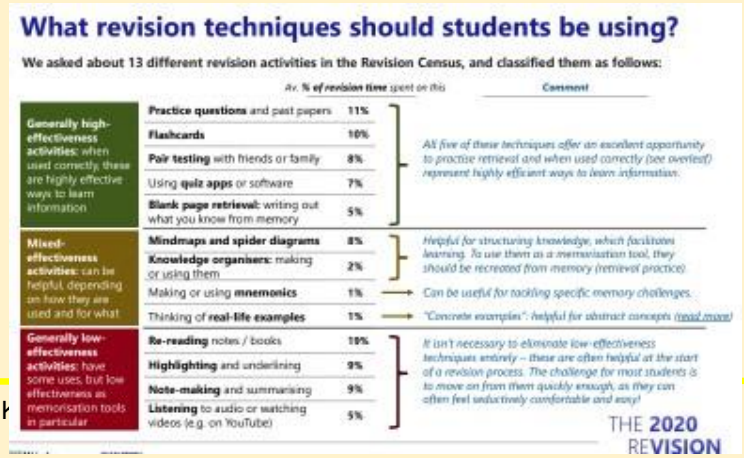


Item 2: Lesson plan for revision in science using a cross curriculum approach

Title: How to Revise

LOs:
Understand ways to help recall information
Practice ways to improve your understanding of a topic
Apply your knowledge and understanding to an exam questions

SMART START - Which of these techniques do you use?



Title: How to Revise

LOs:
Understand ways to help recall information
Practice ways to improve your understanding of a topic
Apply your knowledge and understanding to an exam questions

Revision

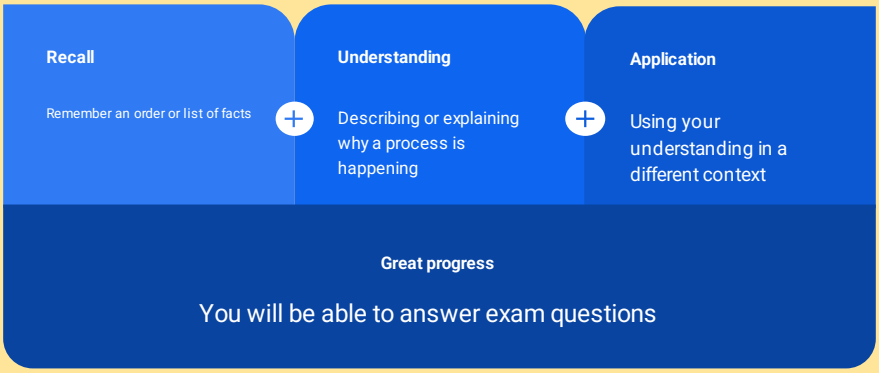
Revision is always hard work.

For it to be of maximum benefit, it needs to challenge you.

However, being challenged doesn't need to be boring!!!

Key words: Recall, Understanding, Application, Synthesise,

Steps to great revision



Recall



- Use checklists/specifications to understand what you need to know
- Use quizlet/flashcards/blooket to learn the definitions in engaging and different ways
- Get people to test you on recalling the different definitions

Understanding



- Watch videos/GCSEpods and then re -write them in different ways
- Explain to a friend/family member a concept (i.e. ionic bonding), what bits did they not understand? This is most probably the bits you don't fully understand either
- Draw a concept (i.e. transpiration) without using any words

Application



- Complete exam questions



Task 1



Spend 10 minutes in silence looking through the quizlet flashcards. This is either **flashcards** or **learn** (not match or other games)

Spend 5 minutes **on** match or other games (or continue with learn or flashcards)

https://quizlet.com/_6eaj5s?x=1jqt&i=umlaz

Task 2



Write down all the key words you can think of from this topic.

This has got to be by memory

Task 3



Pictionary time

In your row, you are going to play pictionary using the **key words** from Task 2 (they are now on the board)



Task 4



Taboo time

Pick 5 key words that you struggle with.

Write a taboo card for each one



Task 5



- Complete exam questions

https://JEHOOOP.exampro.net

Task 6 Electricity revision

1. Complete the Quizizz.

1. Complete the 2 summary worksheets on google classroom. Use the information on the slides to help you if you are stuck.

1. Watch the GCSEPods (scan the QR codes).

1. Complete the exam questions on the slides (continue clicking through this powerpoint).

Series and parallel

IV graphs

Plugs