EXPLORING THE ROLE OF GAMIFICATION WITHIN STEM TEACHING AS A MECHANISM TO PROMOTE STUDENT ENGAGEMENT, DEVELOP SKILLS AND ULTIMATELY IMPROVE LEARNING OUTCOMES FOR ALL TYPES OF STUDENTS

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Abstract

It is recognised that many European countries are currently facing a crisis amongst their younger generations in respect of scientific vocations. The number of students specialising in science, technology, engineering and maths (STEM) disciplines has been in steady decline in recent years and Europe faces the concrete risk of an acute shortage of suitably qualified scientists, technicians and engineers. This could have a profound effect on the competitiveness of European businesses and a knock-on effect in terms of employment rates and economic growth.

There is strong evidence that for many young people their disengagement from STEM subjects starts during secondary education. The drivers of this disengagement are various but research indicates that there are primarily two factors at play: first, there is a commonly held perception that amongst young people that scientific subjects are difficult to learn and master; second, there are misapprehensions regarding the employment pathways available to STEM students with many young people believing that studying these subjects will lead to poorer pay and a less attractive working life.

Evidence suggests that the teaching of STEM subjects requires radical reform. Immersive, experiential learning and the deployment of self-directed learning approaches can be the catalyst for deepening student engagement and improving learning outcomes. However, in schools, colleges and universities today too much STEM teaching remains teacher-led, didactic and one-dimensional. At best, this makes the learning experience more challenging in relation to student performance; at worst, potential STEM students are put off these subjects for life due to an inability to grasp key concepts or to fully engage in the content of lessons. For those students who do stick with STEM subjects, their ability to develop the skills and competencies they need to operate effectively within highly technical employment environments can be diminished meaning that employers are required to undertake considerable retraining in order to bring graduates up to speed.

These dual problems – of the attractiveness of STEM subjects to learners and the effectiveness of STEM teaching in relation to learning outcomes – require novel solutions. The NEWTON project – funded under the Horizon 2020 programme - is a large scale initiative to develop and integrate innovative technology-enhanced tools for teaching and learning and to create a pan-European learning network platform that supports fast dissemination of learning content to a wide audience in a ubiquitous manner. A key part of the NEWTON project is to develop, integrate, deploy and disseminate state of the art technology-enhanced teaching methodologies based on gamification. Gamification – whereby game mechanics are integrated into a non-game experience – has a well-documented impact on user enthusiasm, particularly amongst Millenials, many of whom have grown up playing games and retain this interest through adolescence and into adulthood. This paper will explore how gamification might be deployed within STEM teaching as a mechanism to increase student engagement, how, through gamification, the learning outcomes for students undertaking STEM subjects might be improved and what role gamification may play in supporting learning outcomes for STEM students with special educational needs.

Keywords: gamification, game-based learning, STEM teaching, pedagogical approaches to learning

1 INTRODUCTION

The importance of ensuring that science, technology, engineering and maths are subjects that are attractive, well-taught and engaging cannot be overstated. Within a global context of climate change, over-population and diminishing resources, we need to educate and develop the scientists, technologists and engineers who will ultimately find ways of addressing the myriad problems that we face at an individual, communal and societal level. Furthermore, within Europe, we are failing to adequately attract and retain talented young people with STEM education in comparison to counterparts in other parts of the world (most notably the Far East and the USA). This is already hindering our competitiveness and diminishing the strength of the European economy. In parts of Europe where employment rates are still low amongst young people and graduates, a greater focus on job-creating innovations in technology and the sciences could drive up opportunity and increase economic and social stability across Europe.

The comparative failure to attract talented young people into STEM subjects is, in one particular way, ironic. We now have, at our fingertips, a range of technologies that are accessible, affordable and able to transform the teaching and learning experience. Although technologies are being used across the curriculum landscape, it is perhaps in STEM subjects where their application becomes most compelling. Visual technologies for example – virtual reality; augmented reality; 3D visualisation tools etc. – have the power to create entirely immersive learning opportunities that, even 5 years ago, were beyond the reach of most schools, colleges and universities. However, effective use and understanding of these technologies remains patchy. If we are able to find better ways of harnessing these technologies, we may see significant benefits both in the attractiveness of STEM subjects to learners and in the learning outcomes for those learners.

Allied to an engagement with new teaching technologies is a growing interest in evolving pedagogical models that will further increase student engagement and create a more compelling and effective learning experience for learners. Amongst the panoply of new techniques that are gradually becoming mainstreamed across the European teaching landscape, gamification – and within that, game-based learning - is gaining traction. The generation of young people born in the 21st century have grown up surrounded by and immersed in technology. Within this context, gaming has become a dominant social phenomenon. The marriage of technology, games and learning has enormous potential that is only now being exploited.

The Newton Project, funded by the European Commission under Horizon 2020, is a large-scale initiative that seeks to explore the dynamics of these disparate but connected factors. The primary concern for Newton is to understand how we can adapt and implement existing technologies as a means of creating greater engagement in – and better learning outcomes for - STEM subjects in schools and tertiary institutions across Europe. Within that context, the project is also seeking to investigate the role that gamification and game-based learning might play in improving learner outcomes and supporting greater enrolment in STEM subjects. This paper sets out some of the ideas that, over the coming months, the Newton Project will seek to explore in this regard.

2 THE CHALLENGES OF STEM TEACHING AND LEARNING

It is widely recognised and acknowledged that most European countries are currently experiencing a crisis amongst young people in respect of the numbers that are choosing to follow educational pathways into scientific, technological and engineering vocations. The number of students specialising in scientific disciplines has, for some years, been in decline across many European countries, and this is creating a shortage of suitably skilled scientists across a range of disciplines to support research and innovation. Since 2000, the proportion of graduates specialising in science, mathematics and computing in Europe has dropped from 12% to 9%. There is strong evidence that many young people begin their disengagement with STEM subjects during their secondary education. Decisions on which educational pathway to follow are typically taken at 14 or 16 years old and learners are often then ‘stuck’ with that choice as they progress into tertiary education or into employment.

The drivers for this disengagement are complex and a variety of evidence exists to suggest why this is. Certainly, there is a perception held amongst many young people that, for one reason or another, STEM subjects are ‘not for them’. This might relate to the perceived difficulty that undertaking these subjects poses. STEM subjects are generally thought to be challenging and harder to achieve a high grade in than humanities or arts subjects. In an educational environment where we are increasingly

obsessed with exam results – and the pressure to get good grades bears down on many young people as they enter secondary education - learners cannot be blamed for following pathways that they believe will be easier in terms of grade achievement. This challenge may also relate to a belief – and, in many cases, a misapprehension – that STEM subjects do not lead to positive or progressive employment prospects. Furthermore, there is evidence to suggest that the perception is that a STEM subject is more directly 'vocational' than an arts or humanities subject and therefore young people are forced to choose a specific pathway before they are perhaps ready to.

There is a further challenge that faces STEM teaching and learning and that can impact negatively on the flow of talented learners into STEM subjects. The methods of teaching – and the tools and techniques that are used to teach – are not always effective in achieving the right learning outcomes. Many areas of science and technology are constantly evolving. This means that the content used to teach, and the approaches that are adopted, also need to evolve to keep pace. This necessitates genuine engagement with technologies that are fit for purpose. If STEM subjects are not taught in an effective, modern way, then the chances of failure – in terms of learning outcomes and, ultimately, the ability of that learner to integrate into higher education or employment - are high. There is significant evidence to suggest that there is a mismatch between the skills and competencies of STEM graduates and the needs of the industries into which those graduates are hoping to work in. In many cases, employers complain of the need to completely retrain those that they recruit from colleges and universities, throwing a negative light on the education that candidates have received up to that point. Whilst this is in no way true of every institution, it is certainly a challenge for secondary students for whom the 'leap' into further education can often be enormously challenging. The only way to close that gap – and to thereby build more credibility within these subject areas – is to evolve the way in which the subjects are taught alongside the ongoing updating of curricula in line with industry requirements and in concert with the best of what colleges and universities are offering post-school.

3 THE CONCEPT OF PROJECT NEWTON

In response to the disengagement from STEM subjects that we are seeing from across Europe, a number of national initiatives have been launched. Many are focused on the goal of designing and developing innovative teaching and learning programmes that both attract new learners and that deliver a high quality, engaging and effective learning experience. However, many of the projects that are ongoing are limited by their ambition, by their scope or by their attractiveness to learners. The Newton Project differs in that it aims to build an innovative e-learning platform focusing on:

- Providing diverse forms of teaching and learning for formal, non-formal and informal education
- Supporting different levels of education from secondary and vocational schools to universities and further learning, fostering reservoirs of talents
- Employing novel content types and presentation technologies based on multi-sensorial and multi-modal interaction with learners
- Creating personalisation and adaptation of content to best match user profile and their learning environment.

Furthermore, Newton will develop new teaching and learning practices based on novel technologies aimed at attracting learners and keeping them engaged with the learning process. Within this context, gamification and game-based learning will be a key differentiator. The Newton Project will introduce all these aspects as a means of developing and reinforcing basic knowledge in STEM subjects for learners who are studying at secondary and vocational school level. The aim will be to improve teaching practices and thereby increase the level of comprehension and skills acquisition amongst STEM students. In so doing Newton will help to alter the perception (and the reality) of STEM subjects as being difficult to learn. The project will also extend the focus of innovative learning approaches to learners with special educational needs.

The NEWTON project will employ a new 21st century teaching and learning paradigm in which the student is the centre of the learning process (moving away from the more 'teacher-centric' approach which characterises much of the didactic approaches to knowledge and skills acquisition that we still see in many classrooms across Europe). The power of this dynamic and student-centric approach is that is enables different learners to learn in different ways, at different speeds and it empowers learners to take control of their own learning experience. In this approach the student acts as a performer who is able to actively control the flow of information according to his/her specific needs and

abilities. Furthermore, by basing the approach on a personalised concept of the learning process, the opportunities for gamification and for game-based learning are significantly increased. We will explore these possibilities within Newton shortly. However, before we do that, it may be instructive to explore more deeply the role of gamification in learning and to set the context for how we might implement gamification techniques into the Newton learning paradigm.

4 THE ROLE OF GAMIFICATION IN LEARNING

To begin with, we need to be clear about our terminology. There is, in some minds, a confusion between 'gamification' and 'game-based learning'. In the literature review on the subject conducted by Ilaria Caponetto, Jeffrey Earp and Michela Ott (2014), the authors clarify this usefully. They describe how until fairly recently the term 'gamification' was typically used to denote the adoption of game artefacts (especially digital ones) as educational tools for learning a specific subject. In other words, gamification was used as a synonym for game-based learning rather than to identify an educational strategy informing the overall learning process, which is treated globally as a game or competition. However, within the literature review, this terminological confusion appeared in only a few isolated cases, suggesting that a certain level of taxonomic and epistemological convergence is underway [1]. For our purposes, we would consider game-based learning as the use of (typically) digital games to promote learning. If we talk about 'gamification', we are thinking more specifically about the application of game mechanics (more of which in a moment) to the learning process. Of course, there may, in some cases, be a mixture of both game-based learning and gamification.

In respect of gamification – and the game mechanics mentioned above – we are here thinking about the dynamics that are common to both digital and non-digital games. Dicheva et al., 2014 define game mechanics as including (but not limited to) the following: points, badges, levels, progress bars, leaderboards, virtual currency, and avatars; point systems that manage the acquisition and spending of points that quantify user performance; badges that are given for special achievements; user ranking based on the received points and badges; published/shared leaderboards that reflect user performance in comparison to other users; levels that show the user's expertise and progress and where the player is in the game; progress bars that provide a percentage-based graphical representation of the players' progress; virtual currency used for purchasing in-game (virtual) goods [2]. The Dicheva et al study goes on to define the educational gamification design principles that are most commonly deployed within learning contexts. These include:

- GOALS: specific, clear, moderately difficult, immediate goals
- CHALLENGES & QUESTS: clear, concrete, actionable learning tasks with increased complexity
- CUSTOMISATION: personalised experiences; adaptive difficulty; challenges that are perfectly tailored to the players skill level; increasing the difficulty as the player's skill level expands
- PROGRESS: visible progress towards mastery
- FEEDBACK: immediate feedback or shortened feedback cycles; immediate rewards instead of vague long-term benefits
- COMPETITION AND COOPERATION: social engagement loops
- ACCRUAL GRADING
- VISIBLE STATUS: reputation, social credibility and recognition
- ACCESS/UNLOCKING OF CONTENT
- FREEDOM OF CHOICE: multiple routes to success allowing students to choose their own sub-goals within the larger task
- FREEDOM TO FAIL: low risk from submission; multiple attempts
- USE OF STORYTELLING: including the adoption of roles in the form of avatars [2]

This list is by no means exhaustive but it is instructive in considering the ways in which we might apply game mechanics or, as Dicheva et al have it, 'gamification design principles', to the job of teaching STEM subjects. The Dicheva paper goes on to review a range of evidence in relation to the effectiveness or otherwise of utilising gamification design principles within an educational context. The study draws some critical conclusions, namely that the majority of the papers reviewed report encouraging results from the application of gamification, including

- significantly higher engagement of students in forums, projects, and other learning activities (e.g., Anderson, Huttenlocher, Kleinberg, & Leskovec, 2014; Caton & Greenhill, 2013; Akpolat & Slany, 2014);
- increased attendance, participation, and material downloads (Barata, Gama, Jorge, & Gonçalves, 2013);
- positive effect on the quantity of students' contributions/ answers without a corresponding reduction in their quality (Denny, 2013);
- increased percentage of passing students and participation in voluntary activities and challenging assignments (Iosup & Epema, 2014);
- minimizing the gap between the lowest and the top graders (Barata, Gama, Jorge, & Gonçalves, 2013).
- Hakulinen & Auvinen (2014) conclude that achievement badges can be used to affect the behavior of students even when the badges have no impact on the grading.
- The papers of this group also report that students considered the gamified instances to be more motivating, interesting, and easier to learn as compared to other courses (Mak, 2013; Barata, Gama, Jorge, & Gonçalves, 2013; de Byl & Hooper, 2013; Mitchell, Danino, & May, 2013; Leong & Yanjie, 2011).

When we consider the range of options available in respect of gamification tools and techniques – and then when we gain a deeper understanding of the potential benefits of gamification to the learning process - we can start to see how this could be usefully applied to the challenges outlined earlier in respect of STEM teaching.

Alongside this, we need to consider the concept of game-based learning – that is the use of gaming technology for educative purposes. The mass appeal of the modern video game experience has not gone unnoticed with many applications being explored well beyond the entertainment industry. The emergence of "serious gaming" – that is games that have a 'serious' purpose or objective that takes their value beyond simply entertainment – is being witnessed in a range of areas of modern life including education, health and the environment. Within the education sector, you can easily see why young learners, given the choice between playing a video game or listening to a teacher, would usually choose the first and not the second. A good game is immersive – it engages, enchants and excites. For educators wanting to communicate ideas, the ability to hold the interest of the learner is essential. Through the experience of playing a game – the physical interaction, the challenge to progress, the promise of an epic win – the player becomes immersed and the attention in held. Many modern games also involve a collaborative or team element which only adds to the level of immersion. Within the context of education, games can be an enormously compelling way to stimulate student engagement.

The nature of gaming also dovetails very neatly with the prevailing thinking around classroom pedagogy. Video games are user led (in that they allow the user to be the protagonist in their own story and to function at a level that is comfortable for them). In her book "Creativity and Education Futures: Learning in a digital age" Anna Craft highlights the value that technology can have on learning. She references the shift towards the learner-centric approach to education and views this as being in line with an increase in the use of technology. Game players are masters of their own universe [3]. If we can translate this into the experience of the learner in the classroom, the offer becomes compelling. At a more advanced level, games offer a range of options in relation to the personalisation of a user's game experiences. Advanced video games adapt to the abilities and achievements of the player. What's more, gaming technology produces data that can be used to further customise the individual experience. Players can be tracked in relation to their progress and achievements and reports can be produced on how well the player is doing. This data capture function could offer a new approach to the assessment of learners within the context of video gaming.

Further evidence of the value of game-based learning can be seen in the work of Kärkkäinen and Vincent-Lancrin (2013) and their review of the HP Catalyst Initiative. This is particularly informative for our purposes as it focuses on the application of gaming to STEM teaching. The difference here from the work of Dicheva et al is that the key focus is on the implementation of a technology-based game (rather than on the wider topic of gamification of the learning process). Kärkkäinen and Vincent-Lancrin frame the value of games for learning within STEM in a range of key aspects, most notably:

- Creating opportunities for learning by doing - the interactive, reactive and often collaborative nature of educational gaming enables learning by doing and allows students to (repeatedly) make mistakes and learn from them.

- Supporting student learning - educational gaming which covers specific topics or subject areas and takes place within a set of defined rules can be highly effective at supporting knowledge and skills acquisition.
- Promoting student engagement and motivation - based on play and increasing challenges, educational gaming can foster student engagement and motivation across subjects and education levels.

Their work concludes that educators should consider adopting these broad technology-supported pedagogic models to improve students' learning outcomes, including the development of higher-order thinking skills, and to expand the range of learning opportunities made available to students [4].

Another factor plays into the likely increase in the adoption of game-based technology within the classroom. Today, gaming technologies are increasingly accessible to those wanting to develop serious games. Traditionally, the world of gaming has been dominated by large-scale software houses who have the resources to develop and launch hugely successful video games largely played on proprietary consoles. Although the mainstream commercial gaming scene is still dominated by such games – high end console titles with Hollywood movie budgets – new technologies are creating new opportunities for game development meaning that games with a more discreet audience (like educational games) can now be developed to a high standard and within realistic budgets. We are also seeing a steady increase in the popularity of online gaming driven by HTML5 and other highly accessible game engines that enable a wider base of users to build new games based on existing libraries of content. We have also seen a steady rise in the popularity of mobile games alongside the ubiquity of smart phones adding an additional channel for educational game developers to exploit.

With this in mind, we can begin to see why it is that gaming offers huge potential within the education space:

- Games have the power to engage in a way that few other activities do; this is particularly true for young people who have grown up surrounded by games and gaming technology
- Gaming technology creates a user-centred experience that can be highly personalised and that can provide highly detailed levels of data on user progress and user experience
- The cost of developing convincing digital games is now significantly lower than at any point in history, enabling many more individuals and organisations to become participants in the experience (including educators)

Although the case for gamification and game-based learning within education is compelling, there are caveats that we must attach to this. First, evidence suggests that the level of engagement within the gamified classroom can be dependent on the degree to which an individual student is, themselves, playful and switched on to the game experience. Equally, the educator must be able to accept and embrace such an innovative and dynamic pedagogy for it to be successful. In short, not everyone – teacher or student – has the same reaction to games and to play. Furthermore, there is still some contention regarding the efficacy of game-based learning in relation to the specific learning outcomes achieved through the process. There have been some evidence-based studies that suggest the learning achieved through games and game-based education can be limited – the student may enjoy the experience but they may fail to retain much of the knowledge or skills that the intervention was designed for. This suggests that we need to be vigilant in the way that we apply gamification and game-based learning within the classroom environment and that we need to continue to prove the impact that this has on learning beyond simply proving a point about student engagement.

5 THE APPLICATION OF GAMIFICATION IN PROJECT NEWTON

The Newton Project is, as previously mentioned, specifically focussed on supporting student engagement and achievement within STEM subjects. The project itself is not primarily concerned with games and gamification – it is not a project about developing STEM games. The scope of the project is broader than that, taking as its starting point the idea that STEM education can be significantly enhanced through a novel application of technologies alongside new approaches to teaching and learning. Indeed, it is the combination of these approaches that may prove most compelling. With this in mind – and taking account of the observations within the previous section of this paper - the following areas will be explored during the research and development phases of the Newton Project in relation to the deployment of gamification within the learning process:

- SOCIAL GAMIFICATION – through adopting a collaborative approach to the achievement of specific goals, learners will be supported to share learning content and to pursue different paths or tasks through the creation of teams established within a virtual environment and facilitated to chase the same specific goal; these teams may be localized or may be distributed (i.e. between different schools); a social element will also be explored in terms of encouraging learners to share their learning experiences and achievements with other 'players'
- PERSONALISED GOAL-SETTING – as an alternative to the previous point, learners will be able to explore tasks and challenges as individual 'players' with their own journey defined by the choices they make, their interests, their level of expertise and other relevant factors; the process of first setting the goal and then working their way towards achievement of the goal will be key to this and the tracking of progress (and feedback on that progress) should be built into the model
- COMPETITION – either within an individual or a team setting, the facility to compete with others around the successful achievement of tasks or learning activities will be explored, particularly in reference to the motivating factor that competition has on those individuals and teams; competition could be between individuals or teams within a single institution or could be aggregated across a number of different institutions, even in different countries
- REWARDS – connected to the concept of competition, the incentivising of achievement through rewards will be explored as an additional mechanism to drive student engagement and to stimulate learner enthusiasm for the successful completion of learning activities; the nature of the rewards on offer should be explored through both virtual concepts (points/badges/awards) and through real-world rewards (prizes/financial rewards etc.)
- ADAPTIVE GAMIFIED CONTENT – alongside the concept of personalised goal setting outlined above, we will also explore the implementation of adaptive learning content as a mechanism for improving learning outcomes; this will involve implementing systems that are able to intuit achievement and success of the learner and then offer content and options that are responsive to the relative level of the learner; part of this process will be to provide the learner with continuous feedback on their progress towards a stated goal and, potentially, adapted incentives to encourage them towards their goal
- SCENARIO-BASED LEARNING – within the context of STEM learning, there may be significant opportunities to provide learners with the experience of assuming a role within a pre-determined setting; this is a staple technique of many popular video games and could be used to engage the learner in their tasks; furthermore, this approach could enable the learner to develop skills of empathy and self-awareness alongside the harder, more technically-oriented STEM skills
- GAME DATA AS ASSESSMENT DATA – the data that any game-based experience generates could have potential as a form of assessment data in relation to the achievements of, and competencies of, specific learners; this will be explored as an additional concept alongside the areas outlined above

Furthermore, there may be scope within the Newton project to explore more directly the application of game-based learning within STEM teaching. This would involve the development or adaptation of educational games for use within a STEM teaching setting. At the time of writing, the project is in its early phase and the feasibility of developing bespoke video games for application within the pilot schools is yet to be fixed. However, it would clearly be of value to explore both the opportunities to gamify the learning process (as outlined above) and the possibilities for embedding STEM learning content into a video game setting.

In each case, our task in Project Newton will be to find novel and innovative ways to implement gamification and game-based learning. Our responsibility will then be to test the value of these approaches against a range of criteria including:

- How feasible it is to apply the approach within a standardised learning environment
- The value of the approach to different types of learners including those with special educational needs
- The impact of the approach in terms of the achievement of learning objectives in comparison to more traditional classroom-based activities
- The impact of the approach on student engagement, student motivation and the attractiveness of the learning experience in comparison to more traditional classroom-based activities
- The reaction of other related actors beyond the learner to the approach (including teachers, school leaders and parents)

- The socio-economic impact of the approach, with a particular focus on the barriers and constraints that may be faced by schools and colleges in implementing the approach
- The potential to integrate the approach with other teaching and learning technologies (both existing and emerging) and any challenges that exist with this
- The potential to integrate the approach with other pedagogies (both existing and emerging) and any challenges that exist with this

6 CONCLUSIONS

In conclusion, the opportunities that gamification represents for enhancing both the attractiveness of, and the impact of, STEM teaching and learning are clear. Although there is already significant evidence as the the potential that gamification and game-based learning have to support educational objectives, there remains relatively little data on the impact that can be achieved specifically with STEM students. The scale and focus of the Newton Project will offer a unique platform for the exploration of these ideas within the context of a Europe-wide pilot project and the results have the potential to set new standards in how gamification can be effectively integrated into teaching and learning.

Furthermore, the implementation of gamification alongside other emerging and novel pedagogies and technologies promises to shed further light on the way in which these approaches can be integrated across a wide range of settings and utilising a blend of tools. The challenge will be to ensure that the efficacy of the approach is proven and that student enthusiasm for the learning event is not considered a proxy for educational achievement. We already know that young people enjoy games – this is not news! What we need to do – within the Newton Project and more broadly as researchers and educators – is to demonstrate the real value of adopting what, for some, will be considered as ‘fashionable’ concepts. If we believe that games are a critical part of the future of learning, we must be rigorous in how we assess the impact of our approaches and only then can we begin to see a pathway that will integrate gamification and game-based learning into the mainstream of European education.

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