Game Intelligence

Sam Devlin*, Peter I. Cowling*, Daniel Kudenko*, Nikolaos Goumagias†, Alberto Nucciareli‡, Ignazio Cabras†, Kiran Jude Fernandes§, and Feng Li‡.
*University of York, Contact: Sam.Devlin@york.ac.uk
†Newcastle Business School, Northumbria University
‡Cass Business School, City University London
§Durham University Business School

***Abstract*—Game Intelligence is knowledge gained by the player or by analysing the data players generate by playing digital games. Serious games for education, raising public awarenesss or changing the players' behaviour are well established and have provided Game Intelligence for decades [1]. However, more recently a trend has begun, inspired by the success of FoldIt [2], [3], of developing games for scientific discovery. These games lower the barrier of entry to complex scientific topics, allowing gamers to contribute to cutting edge research. We argue that this approach is currently underutilized and explore a vision where these games have wider impact. Furthermore, we will discuss the potential of extracting Game Intelligence from games designed originally for entertainment, potentially making all games into scientific discovery games.**

I. Introduction

Game Intelligence is knowledge gained by the player or by analysing the data players generate by playing digital games. This paper captures our vision of a future where all games can generate knowledge. Either through gamer-scientists contributing to a wide range of academic topics by playing scientific discovery games or by quantitative analysis of the data generated by gamers in digital games for scientific benefit. As we will show, games can yield educational, social and scientific benefits and have begun to seed a new era of scientific experimentation into human behaviour, preference and interaction, in economics, biology, sociology, psychology and human-computer-interaction.

Furthermore, the growing trend of Gamification (the use of game design elements in non-game contexts [4]) has significantly increased the space and variety of games available. Concepts previously considered to be hindered by playing video games, such as promoting an active lifestyle and educational achievement, are now available as commercial games. For example, consider the hugely successful Wii Fit [5] and Big Brain Academy [6] games from Nintendo.

Recently, games have been made to achieve specific experimental goals [3], [7], [8]. Every action in these digital games, from an in-game purchase to a simple button push, generates data. Therefore, given that an estimated 200 million hours of gameplay occurs every day in the USA alone [9], digital games can potentialy provide a huge population of gamer-scientists. The exciting possibility of such scientific discovery games is beginning to be realised in biology and related topics, but could be taken up across a far wider range of academic disciplines. Significantly increasing the educational, social and scientific benefits of games.

Furthermore, given the digital nature of modern video games and the growing ubiquitous presence of an internet connection, the analysis of vast quantities of gameplay data is now possible. In particular, the recent growth in mobile and casual (e.g. Android, iOS, and Facebook) games provide a new tool yielding a major step-change in experimental studies of human behaviour; moving from small samples to potentially huge numbers of participants. This data can help us to understand individual behaviour and preference on a hitherto impossible scale, making it feasible to use all modern video games as a powerful new tool to achieve our scientific and societal goals.

This paper will begin by reviewing educational games in the following section to introduce the many topics already taught by video games and to emphasise the maturity of the field with regards to imparting Game Intelligence to players. Then, in Section III, we will discuss existing scientific discovery games noting an unecessary bias towards biology and related topics. In Section IV, we will discuss game analytics, the quantitative study of in-game data, typically used to improve game design and monetization but noting the few existing studies of game data for wider scientific impact that serve as a proof of concept for our vision which will be summarised in the concluding section of the paper.

II. Educational Games

Engaging students using games has been common practice throughout human civilization [9]. It is often argued, that we learn best whilst we are at play. Therefore, it is simply a natural progression that the games we use to teach can now also be digital [10], [11]. Subsequently, educators around the world have begun to embrace video games as a tool both in the classroom and to reach out to lifelong learners.

This section is not intended to provide a comprehensive survey of the vast range of digital educational games, but instead to emphasise the breadth of topics games can and do teach. For clarity, we have divided this section into games for (A) learning, (B) raising awareness and (C) self improvement. Games for learning teach topics typically considered necessary for academic and personal development, whilst games for raising awareness teach players of social, environmental and political issues.

It is possible, however, to create games that fall between these topics. For example, the free to play online game Free Rice [12] asks players to answer questions on maths, science, geography, languages and the humanities. For every correct answer, 10 grains of rice are donated to the United Nations World Food Program. The difficulty of questions presented to the player adapts based on the number of correct answers they give. This can provide an ideal learning environment, as the game attempts to keep the player in a state of flow [13] where they will remain engaged in the game and experience a steady improvement in their performance. Whilst the player is learning their chosen topics, due to the feedback from the quiz game, their awareness of world hunger should also be raised by the website design.

A. *For Learning*

To highlight the breadth of educational games, this section will present our novel syllabus for lifelong learning through video games. We will begin with a child's education and end with a well adjusted adult who, taught by games, is knowledgable of recent breakthroughs in science and has learnt other critical social skills. It is worthwhile to note that, whilst many early educational video games were only used in classrooms and unlikely to be large commercial successes, well polished titles such as Nintendo's Big Brain Academy [6] series have recently shown that there is a larger market receptive to these games.

A fun example to start our gaming syllabus is the immersive virtual world of Smarty Ants [14], a video game for teaching children to read. Every student-player in Smarty Ants gets an ant avatar, that they can personalise, and adopts a pet dog as their reading partner. Through completing reading and comprehension mini-games student-players write books and produce music dvds to store in their ant's home. This world provides a fun and engaging environment to help student's learn to read and begins to introduce them to authentic literature. Furthermore, Smarty Ants provides teachers with a dashboard filled with data on their students' progression. Given the digital implementation of the game, Smarty Ants is easily able to track data on each student's reading ability that would be difficult to otherwise obtain.

Gamified mathematics programs, such as Mathletics [15], have been used to engage students by exploiting competitiveness amongst peers. The adaptability of digital games to match the player's skill is helpful to maintain the student-player's consistent progress through the subject. However, there are some examples that go further and have adapted mathematics in to game mechanics. Specifically, DragonBox proudly boasts that it "secretly teaches algebra to your children!" [16] By representing numbers and mathematical notation as tiles/cards, DragonBox initially hides the underlying algebra players are performing and instead presents isolating a term (abstractly represented as the DragonBox) as a puzzle game. As the player progresses through levels, the abstraction begins to drop with some tiles being revealed to be numbers. By the end of the game children are performing algebraic manipulation with purely mathematical notation displayed on the screen using the same mechanics as the original tile/card puzzle game.

For teaching history, a classic example is Oregon Trail. From 1971, this video game has been used in American schools to teach the realities of partaking in the ninteenth century emigration across the USA. The game is often remembered for the phrase "You have died of dysentery" due to the frequency of games ending this way, imparting a strong message on those who try to romanticise this period of history.

Educational games for learning do not, however, need to be limited to those built specifically for this purpose. A lot can be learned from games intended primarily for entertainment purposes. For example, the depth of detail in Creative Assembly's Total War games [17] and Sid Meier's Civilization series [18] can teach student-players a lot about history, geography and even politics. The advantage of these games is due to their larger budgets and focus on fun, student-players can become more engaged and play for longer. In some instances, student-players may not even be aware they are learning but subconciously the details of these games will inevitably be memorised given sufficient play time. Another example of using video games intended for entertainment as educational games is the use of the Walking Dead game in classrooms to teach morality [19]. Student-gamers take turns to play the game in front of a class room, then discuss the moral implications of the decisions the player made.

To complete a traditional education program we must also include video games for learning basic science. Radix Endeavor [20] is a multiplayer online game where student-players take on quests in a world where science is being kept from the people by an evil ruler. To complete their quests students must learn scientific concepts to then share with others. This example again makes use of the digital implementation to both give immediate feedback to the student-player and provide data on students' progression to the teacher.

Finally, given the ubiquitous presence of computers in the workplace, Information Technology has now become a fundamental skill for all children to learn. Typically this currently involves developing familiarity and comfort in using office products such as word processors, spreadsheets and presentation software. Microsoft's Ribbon Hero 2 [21] adds games to their office suite making student-players complete quests for points throughout the ages. This approach is intended to motivate gamers to explore more features of these products.

It is important to aknowledge that a child's early learning experiences in school are not all related to the topics taught directly in class, but also to the social skills learnt from the integration in a class. Radix Endeavour touches on these skills due to the multiplayer aspect of the game. However, some games are directed specifically towards teaching these skills. In particular, "If..." [22] teaches social and emotional learning skills to help children build their emotional intelligence.

Education is also not limited to academic subjects, and can also include the development of creative and artistic skills. Rocksmith [23] builds upon the game mechanics of the highly successful Guitar Hero [24] and Rock Band [25] titles but instead of using instrument themed game controllers, players plug in a real electric guitar and learn the true instrument as they progress through the game. Rocksmith also includes a number of mini-games to teach student-players essential guitar skills. For example, to learn scales student-players are chased down a motorway by a police car and must play the next note in the scale to avoid the slower traffic and make their getaway.

Another critical skill to learn for traditional academic success is how to pass exams. Again video games have an answer; ZumFun's Exam Elf [26] teaches skills critical to exam success such as time management, how to prioritize questions and checking your work. Furthermore, to motivate engagement with the library, Lemon Tree [27] is a social game that can help student-players by encouraging them to use the facilities and study more.

Having survived the tough examination period, and successfully passed thanks to her thorough education, our gaming student decides to take a year out travelling before deciding on whether to go to gaming university or to go straight into a job (perhaps by taking a gaming apprenticeship). However, whilst planning the trip she realises that to get by she will have to learn some new languages. A gamified app and website, Duolingo [28] (based on Luis von Ahn's previous work on collecting data from human computation games by input-agreement [29]) is, therefore, her next educational video game of choice. Unlike previous educational games that simply fed back the student's progression to a teacher, the data collected by Duolingo is used to translate real digital texts for the profit of the game's developers. This is a great example of the other possibility of Game Intelligence; generating knowledge from the player's data. This is an idea we will explore more in Section III. Microsoft also created a similar gamified tool, the Windows 7 Language Quality Game [30], for localising their operating system to all the languages they support. Both games use the student-gamers engagment with the game to create translations the game developers can use elsewhere.

After returning from her travels, if our student decides to further her studies, video games have been developed to teach more advanced topics as well as the basic curriculum presented in the preceeding examples. For instance, A Slower Speed of Light [31], [32] is a 3D adventure game where the speed of light slows down with each orb collected in the game, gradually introducing the visual effects of special relativity. The game is based on an open source toolkit, OpenRelativity [33], for the game development environment, Unity. OpenRelativity generates graphical renderings of the Doppler effect, searchlight effect, runtime effect, time dilation and Lorentz transformation in real time. Being able to play in a world where these effects are visible and manipulable allows student-gamers to grasp the challenging concepts behind this advanced topic.

For an alternative example, Floqua [34] puts the player in the role of a fish trying to guide other fish to the safety of the sunken castle whilst avoiding bigger fish that will eat them. Underneath the cartoony visuals and engaging gameplay is a model of social networks that have been observed in real fish [35], [36]. The game includes a freeplay mode where the social networks formed and their strengths can be illustrated on top of the game in real time. There is also an accessible account of the science behind the game available on the developers website. Games such as Floqua and A Slower Speed of Light are less common than games teaching simpler education concepts, but these examples are included to show they are available and they can be equally engaging and educational.

If our gamer student is then inspired to partake in study towards a research degree (PhD, EngD, Masters by research), video games are also being developed to help teach research methods and statistics essential to this vocation. The Continuing/Higher Education in Research Method's project (CHERMUG) [37] has online digital games for teaching research students about both quantitative and qualtitative research. These games were partially developed in collaboration with Playgen, a company that has created games for training in both educational roles and the workplace. This company's games emphasise that educational video games can teach both academic skills and topics but also the skills and knowledge needed to succeed when our gamer-student goes into a job.

However, Playgen are not the only company working on games for vocational training. It is important when considering the breadth of educational games to emphasise that some games teach skills that are not academic in nature. For a high profile example, consider the America's Army games [38] developed to help with recruitment to the US army. Unlike typical video games based on war scenarios, America's Army teaches the gamer-student many skills neccesary on a battlefield (including medical training, basic maneuvers and teamwork) instead of focussing purely on shooting.

Finally, a novel use of developing technologies shows that video games could be used to teach us to control our fears, stress and anxiety. Nevermind [39] is a biofeedback-enhanced adventure horror game which gets harder the higher your heartrate goes. Therefore, to succeed in the game the player must go outside their comfort zone and learn to cope with facing their fears.

Educational games are fantastic resources to motivate young students, but from reviewing the existing library of such games two trends are evident. Firstly, these games often treat learning as a chore that must be completed before rewarding the player with the more fun elements of the game. This trend has also been noted by Strange Loop Games [40] who also argue that educational games need to reach for something more than they currently are. Furthermore, these games are often and unnecessarily limiting their target audience to younger generations. The average gamer is now 31 years old [41] a statistic that should encourage more games teaching advanced concepts and targetted at an adult audience.

B. For Public Awareness

The games in the previous section focussed on teaching academic subjects or personal skills. In this section the focus shifts to teaching players about current social, political and environmental issues. The motivation of these games is on raising awareness by giving an insight and/or teaching the player to feel compasion towards a topical issue.

For example, regarding medical conditions, the fantastic Depression Quest [42] and Actual Sunlight [43] put players in the role of a depressed character. Far from the typical hero role, players learn to appreciate the dehabillitating effects of this condition. Alternatively, Stroke Hero instead teach players how to recognise the symptoms shown by and summon help for a person suffering a stroke [44]. Regarding political issues, Poverty is not a Game [45], Food Force [46] and Darfur is Dying [47] were developed to raise awareness of poverty and world hunger. Similarly, PeaceMaker [48], a game that puts players in the role of either the Israeli Prime Minister or the Palestinian President, teaches players about the ongoing issues in the Middle East. Finally, regarding environmental issues, Ora [49] and Treemagotchi [50] teach gamers to care for the rainforests and about environmental sustainability.

Commerical games have also been used for raising awareness of medical and political issues despite originally being intended for entertainment purposes. In particular the US Center for Disease Control (CDC) have used Plague Inc. to teach about the spread of viruses [51] and the popular Papers, Please! [52] teaches gamers some of the harsh realities of life during the cold war. Games are a powerful medium for raising awareness and should, therefore, be used more frequently to reach out to the growing numbers of players worldwide. We envision a world where more game developers tackle difficult but important topics in current social, political and environmental issues.

C. For Self Improvement

The games in this section encourage players to partake in activities we know we should do (e.g. excercise) or that we are self prescribing (e.g. see Habit RPG [53]) but need the extra motivation games can give. These types of games are closely related to BJ Fogg [54], Ian Bogost [55] and others' [56], [57] work on behavioural change games and persuasive technologies. Therefore, Fogg's eight-step design process [58] and behaviour grid [59] are useful resources for creating such games. However, as with all persuasive technology, ethical considerations must be taken [60]. If a game can change your behaviour for your personal good, it can also change it negatively for the developers' gain.

As positive examples of self improvement games, Chore Wars [61], Habit RPG [53] and Mindbloom [62] gamify everyday activities to try and engage players into doing things you know you should be or that you want to do. By specifying in any of these games a desired goal, players become motivated by accountability. This motivation is furthered when the game includes social elements, a feature key to the game mechanics of Chore Wars and Mindbloom's Proof!.

More seriously, Dumb Ways to Die [63], is a free-to-play game promoting safety near railways. The game itself is simple but addictive, but the game aesthetics and accompanying song stand out and help clearly deliver the intended message. If more games of this level of polish could be created self-improvement and behavioural change games would flourish.

It is important also to consider that digital games need not necessarily be limited to those sat in front of a computer or looking at a screen. This is particularly relevant for self-improvement games due to the recent influx and great success of exercise games using smartphones and other wearable technology such as Zombies, Run! [64]. In this game players take the role of a survivor amidst a zombie apocalypse, the player completes missions by running in the real world. A detailed narrative of events is relayed to them audibly during their run, including random zombie encounters that must be evaded by short intervals of sprinting, and collect items they can use to improve their base/camp when returning from the run. The game has been highly successful with over 800,000 players worldwide and has since lead to 4 related titles from the same developers. One of these titles, The Walk [65], follows a different storyline and is intended instead to incentivise players to walk more. Interestingly this game was created with the UK's National Health Service (NHS) and funded by the Department of Health. We envision that more government funding of AAA games would be a novel and successful method of influencing policy and behaviour change.

III. Scientific Discovery Games

The previous sections of this paper gave examples of games imparting knowledge to the players, but extracting knowledge from video games being played, is also possible; as demonstrated by a growing number of games and studies. This section considers games specifically designed for players to contribute towards finding new scientific knowledge.

The successful contributions to biology of FoldIt [2], [3] is a great example that falls into this category of gamified science. We expect the recently released as beta Nanocrafter [66], from the same team at the Center for Game Science, will be an equally representative example of gamified science. Another great example, is a contribution to behavioural game theory from a Facebook game [7]. This study released a classic game theory game as a free game with graphics, leaderboards, and social network tie in. The resultant data was huge, given the popularity of Facebook, and included the social ties between players, allowing the authors to analyse whether the relationship between players affected their strategies.

Also, Phylo [8], [67] a free online puzzle game, that underneath is collecting data for multiple sequence alignment of DNA. By abstracting complex concepts, games can make advanced scientific topics accessible to non-experts and allow them to contribute without entirely understanding the topic they are helping with. Phylo does this by abstracting DNA nucleotides to coloured squares giving it a similar look to many popular casual puzzle games (e.g. Bejewled). FoldIt also took this approach, albeit to a lesser extent, by illustrating proteins with a cartoon style and simplifying the structure.

Another popular trend for generating Game Intelligence from gameplay is getting players to label data. The National Library of Finland took this approach with remakes of Lemmings and Whack-A-Mole for checking the translation of texts [68]. Many other gamified experiences including Zooniverse, Eterna, Eyewire, Citizen Sort and Cancer Research's Cell Slider also use this method. The most recent game from Cancer Research, Play to Cure [69], also does but is highlighted here as it makes a significant effort at hiding from the player that they are simply labelling data whilst some of the previous examples of this approach do not. In Play to Cure the player plots a path for his spaceship trying to maximise the amount of resource they can collect. They then jump in their ship fly down the route they plotted whilst shooting asteroids and being able to fly off their plotted route if they spot they have missed areas with lots of resource. Given that the location of these resources is generated from real data relevant to cancer research, the player's are both labelling the dense areas of the data in their initial route plotting but also double checking their work when they fly back over the path and steer to correct it.

A unique alternative approach to generating Game Intelligence is Nick Holliman's work on stereoscopic 3D game design. Nick and his students are trying to create a game that is impossible to play without a stereoscopic 3D display [70] with the intention of furthering our understanding of how human vision operates in complex 3D scenes. This example falls somewhere between this section and the next because, whilst it is a game designed for scientific discovery, it also requires significant game analytics to derive the knowledge generated from gameplay.

Finally, Seth Cooper et al's advice on designing these games [71] and Luis von Ahn's ideas on input [29] and output [72] agreement as a a mechanisn for collecting data in human computation games are useful insights on how to design these types of game. Drawing from their experience developing FoldIt, Seth Cooper et al. advise that the visualisation of and interactions in these games must accurately represent the natural rules of the system whilst also hiding unnecessary complexity, making the game approachable by all. To do so requires an extensive iterative process of development involving three stakeholders; the players, the game developers and the scientists. Include the last of these groups is a novel problem to all games providing or generating Game Intelligence, but one that will become easier as the popularity of these games rises and more scientists become gamer-scientists themselves.

Whilst the games in this section are all fantastic contributions to science and exciting new applications for games, we note two typical trends we have observed that significantly limit the current impact of scientific discovery games. Firstly, games for scientific discovery can be so much more than simply tools to crowdsource data labelling. This has been demonstrated by the novel solutions to advanced open research topics generated by FoldIt. By making difficult concepts accessible through abstraction and giving players the tools necessary to find new solutions, FoldIt allowed gamers to contribute directly to scientific breakthroughs. It made them the scientists, not just an unpaid assistant. If more games follow this design pattern, more varied and exciting scientific discovery games will be developed and a more motivated population of gamer-scientists will be able to assist in more breakthroughs.

Secondly, the vast majority of current scientific discovery games are focussed on biology and related topics. We expect this has occured because the original proof of concept game, FoldIt, was also based on this topic. However, there is nothing about the concept of a scientific discovery game that limits the application to just these topics. Scientific discovery games could, and hopefully will, be developed for all academic topics. Again growth in this direction would significantly widen the variety of these games, helping to reach out to a broader audience of potential gamer-scientists widening the impact and recruiting more to play and contribute.

IV. Game Analytics

Game analytics is the study of game telemetry and transactional data collected from within the game [73]. The previous sections of this paper focussed on games specifically designed for education or scientific discovery. However, some studies have already been performed extracting Game Intelligence from existing games that were originally designed purely for entertainment. The potential of this approach to research has been supported/publicised in Science by an article focussed on the potential of World of Warcraft and Second Life as scientific testbeds [74] but we believe that the analysis of game telemetry data from any game could potentially be of scientific interest.

As with any large dataset, data mining is an essential tool for the analysis of game telemetry. A recent review of game Artificial Intelligent(AI) [75] identified large scale game data mining and gameplay-based player experience modelling as key areas for ongoing research. Typically, existing applications of game data mining have focussed on better monetization or game design. However, a few proof of concept examples show that the analysis of in-game data could have far larger impact and would be an interesting direction for future research.

A. For Game Design and Monetization

Game analytics is typically used in industry to maximise profit. For example, data collected from Madden NFL 2011 [76] was mined to predict features of a game that would maximise player retention. This study suggested various alterations of game mechanics such as reducing the number of options available to players in game and presenting the controls more clearly. Other studies to maximise revenue have focussed on predicting when players will quit, with the intention to target these players with offers [77], [78], or modelling how long players will remain engaged [79].

Understanding which game features retain players and how long players will engage with a game, may originally have been developed due to a motivation to maximise profit but the results still provide knowledge and insight on good game design. There are also examples based on game data mining to improve the design of AI opponents in games. For example, video replays from Quake 2 have been used to learn an AI that imitates human-like behaviour [80] and game data from Starcraft has been used to advise the design of AI players by modelling human strategies [81].

Player modelling has also been used to generate new levels for games including Super Mario Bros, the classic side scolling platformer, with the intention of inducing the desired experience for the player [82], [83]. An alternative approach to player modelling [84] used clustering with data collected from Tomb Raider: Underworld to find 4 typical types of players; veterans, solvers, pacifists and runners. Similar clusterings of players have been used subsequently as features for supervised learning to create models for modifying game difficulty/parameters based on the type of player [85], [86]. Clustering to find player types has also been done in Pacman [87], Snakeotron and Rogue Trooper [88], and Teria and Battlefield 2 [89]. Finally, association rule mining, typically used to identify products shoppers often buy together, has also been used to inform game design. A study of Rogue Trooper [90] learnt associations between game design and player experience, helping the developers to identify areas of the game environment needing review.

This is not an exhaustive list of the applications of data mining for game design and monetization, since our intention here is to instead show the breadth of applications that fall into this topic. Whilst this is an interesting area of research and a very productive tool for game developers, our vision is concerned with a far grander possibility of game data mining where the analysis of game telemetry data contributes to science across academic topics.

B. For Science

Whilst the majority of game analytics studies have sought to extract knowledge relevant to monetization either directly or indirectly via game design, some exceptions of analysing gameplay data to answer wider scientific questions do exist. The studies covered in this section serve as proof of concept that this approach to generating Game Intelligence is both plausible and an exciting new research direction.

Applying existing game analytics methods to current examples of gamification could lead to social and scientific benefits. This approach is taken by researchers in the educational data mining and learning analytics communities, who often analyse data from serious games to gain insight into education [91], [92], [93]. Alternatively data from games originally intended for entertainment, has also furthered research into education by analysing replays of people playing Starcraft 2 to explore how people learn complex skills [94].

Similarly, massively multiplayer online games have been analysed frequently due to the large player bases and interesting social interactions that occur. Whilst most studies in this area are qualitative studies of the gamers themselves, a few quantitative studies of data generated in these games have been completed with the intention of generalising results for scientific impact outside of the game. Specifically, the "Corrupted Blood" epidemic in World of Warcraft was studied to model how infectious diseases are spread in the real world [95], [96], social network analysis in Everquest 2 explored the characteristics of people capable of maintaining multiple roles with implications for how managerial roles are handled in real businesses [97] and a study of how wealth inequality emerged in Pardus has been compared to the same occurence in real economies [98]. Some major commercial games companies, Valve and CCP, have also performed economical studies of their games; Team Fortress 2 [99] and EVE Online [100] respectively. Both have stopped publicising the results of this research but continue to work with academics in economics and other topics on a private consultation basis.

These studies demonstrate the potential of using data generated from games intended purely for entertainment to extract Game Intelligence. However, the sparseness of such quantitative studies occuring does not correlate with the growth and availability of data generated by modern digital games. Many early career researchers and research students spend a significant portion of their work trying to generate datasets for analysis that could be captured far quicker by video games. Making use of this resource is mutually beneficial for both academics and game companies, as the publication of research regarding data from games is both an intended goal for academics in this area and also advertising for the games company involved. Our vision is one where far more academic researchers collaborate with companies to analyse their game telemetry data to answer questions of scientific importance, therefore focussing their research more on what questions are to be answered and less on how to collect the required data.

V. Conclusions and the Future of Game Intelligence

This paper has tried to capture the breadth of topics covered by Game Intelligence. To show that video games can both teach us everything from basic concepts to advanced research topics and also expand global knowledge through the data players generate whilst gaming. Game Intelligence captures the knowledge gained through games that raise awareness of social, political and environmental issues and those that aim to change our behaviours and motivate us to self improvement.

The vast quantity of educational and self improvement games, too many to cover in this paper alone, undeniably demonstrate the ability for video games as a medium to have developmental benefit to players. As noted earlier, a slight bias in these games seems to be a focus on simple concepts packaged as games for younger generations. We presume this has occured due to the misconception that video games are for children, a belief that is contrary to recent statistics on the demographics of gamers [41]. Therefore, we strongly advocate the future development of educational games for adults teaching complex topics such as the proof of concept titles A 'Slower Speed of Light' [31], [32] and 'Floqua' [34].

Alternatively, the recent introduction of scientific discovery games shows that time spent gaming can also be constuctively used to generate further knowledge. As we have argued in this paper, developers and academics combined have made a great start in this area but the exciting potential of these games is currently underutilized. For further development, game developers and academics from a far wider range of topics need to collaborate on scientific games so as to broaden the genre and maximise the reach to a larger audience of gamer-scientists. Furthermore, more scientific games should learn from the game mechanics of FoldIt where players can do much more than simply label existing datasets. By empowering the gamer-scientists, more players will be motivated to contribute.

To realise our vision and get more games companies to develop these games will require research into the engineering of innovative business models [101], [102] for serious games that will allow both publishers and developers to capture and deliver economic value via the development of such titles. Furthermore, new business models will open up opportunities to integrate more traditional ones in a new emerging ecosystem. One possibility we envision, inspired by the involvement of the UK's NHS and Department of Health in 'The Walk' [65], is the fantastic possibility of behavioural change games funded by national bodies. For example, instead of government's investing in simple TV and advert campaigns, imagine an interactive campaign to encourage people to stop smoking developed by a major games developer and based on the existing research of designing behavioural change games.

Finally, the application of game analytics to answer questions of scientific importance from gameplay data shows Game Intelligence can be extracted from many games originally intended solely for entertainment purposes. This approach takes advantage of the growing ease of collection and availability of data from video games. Although the number of examples of existing studies not focussed on monetisation or game design is limited, the applicability of the approach has been empirically demonstrated by the few early studies in Section IV-B. We strongly believe that the impact of Game Intelligence extracted by analysing big data from video games will be large and will lead to many fascinating future studies.

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