Game-based Research Collaboration adapted to Science Education

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Abstract: This paper presents prospects for adapting scientific discovery games to science education. In the paper a prototype of The Quantum Computing Game is presented as a working example of adapting game-based research collaboration to physics education. The game concept is the initial result of a three-year, inter-disciplinary project "Pilot Center for Community-driven Research" at Aarhus and Aalborg University in Denmark. The paper discusses how scientific discovery games can contribute to educating students in how to work with unsolved scientific problems and creation of new scientific knowledge. Based on a discussion of the concrete development of the *Quantum Computing Game*, the aim of this paper is to open a broader discussion of the potentials and implications of developing this class of games for new types of innovative science education.

Introduction

One of the educational challenges in Western economies is teaching students to participate creatively in knowledge creation and development and to meet these challenges, the primary task of educators has been defined as preparing learners to participate creatively in the knowledge economies that most Western countries have become (OECD, 2000). In spite of the focus on educating students to actively contribute to the knowledge society, few schools teach students how to create knowledge; instead, students are taught that knowledge is static and complete, becoming experts at consuming rather than producing knowledge (Sawyer, 2006).

Games are well suited for framing complex systems and real-life settings through narratives, rule making and game dynamics. Several examples of games that simulate scientific and engineering professions exist today (e.g. Squire & Klopfer, 2007; Magnussen, 2007). The motivation for developing such games stems from a critique of the teaching of standardized skills to children in the current school system. The skills acquired in this system do not prepare them for a future that involves a constantly changing, complex work life (Shaffer & Gee, 2005). Recently, games have emerged in which players are invited to participate in real-life professional research processes, rather than simulations of them (Cooper et al., 2010). In this paper, the *Quantum Computing Game* is discussed as a working example of the implications of creating and applying what can be called 'game-based research collaboration' to advance innovative science education.

Background

Game scenarios offer a medium equipped for complex simulation of professional approaches. By integrating many different aspects of real-life learning environments and framing them in a simulation, a player can identify with and relate to the experience in more concrete ways. The access to simulated professional tools provided by this type of game supports authenticity, allowing players to tackle complex problems in professional contexts (Magnussen, 2008). More recently, so-called scientific discovery games, in which players' contributions to real-life research practice are an integrated part of the game, have been developed. In such scientific discovery games, complex scientific problems are translated into puzzles and a game-like mechanism is provided for non-expert players to help solve the problems presented (Cooper et al., 2010). A prime example is the game *Foldit*, in which gamers take part in the virtual experimental folding of amino acid chains, competing to find the protein structures existing in Nature (Cooper et al., 2011).

There are many aspects in the design of this class of game common to designing other types of entertainment or educational computer games, such as tutorial levels for newcomers and game mechanics for collaboration or competition dependent on entertainment or educational goals. There are, however, unique aspects that influence the design process in central ways when designing scientific discovery games. The most distinguishing feature is that the solutions to the puzzles in the games are unknown (Cooper et al., 2010). The game is designed for non-expert players to advance a scientific domain and this unique challenge influences several aspects of the design. Visuals and graphics make experimentation with highly complex solutions and scientific information possible and, at the same time, must be accessible to beginners. The interactive design must make exploration processes possible but, at the same time, respect real scientific constraints. Finally, the scoring mechanism needs to award multiple player strategies while remaining true to the latest model of the scientific phenomenon in question (Cooper et al., 2010).

In seeking to adapt this class of games in schools as an educational medium for teaching students to produce new scientific knowledge and collaborate with researchers, there are also a number of design features and educational reflections that need to be taken into consideration. One such aspect could be the extension of online games to include interaction in the physical space of the classroom (such as laboratories) with scientific tools other than those in the virtual game (Hansen et al. 2010). The role and participation of the teacher is another aspect to take into consideration when designing scientific discovery games for public school science education. As mentioned earlier, one of the unique aspects of this class of games is that the solution to the puzzles is unknown. Therefore, the teacher will not have the solution to the problems that students try to solve and will need to adapt a role other than that of the all-knowing advisor. Motivational factors in this class of game are another interesting aspect and the question can be asked as to whether the prime motivational factor is for players to collaborate with researchers, or is that secondary compared to playing the game or solving scientific problems.

This paper presents the initial concept and prototype of the *Quantum Computing Game* as a working example of how scientific discovery games can be adapted to science education to allow students to work with creation of new knowledge through game-based research collaboration. The game development and research project has several objectives. First of all the objective is to solicit the help of players in solving a concrete research challenge in the field of quantum computation and similar community initiated open problems. The aim is thus also to generate a format for extensive involvement of the general public in an otherwise highly esoteric field of science. Additional to these objectives the *Quantum Computing Game* should also work as a test bed for the extension of the concept to other scientific disciplines. In this paper we examine in detail the particular challenges of a third objective in the project; to adapt the game concept to a science educational context. The first prototypes for testing are presented alongside with reflections on challenges of integrating the game into science education.

Game Assisted Quantum Computing

The Pilot Center for Community-Driven Research that the *Quantum Computing Game* was created as a collaborative effort between researchers at the Department of Physics and Astronomy and the Department of Computer Science at Aarhus University and the Department of Communication at Aalborg University in Denmark. The development of the game thus takes place as an interdisciplinary collaboration between researchers in fields of quantum computing, learning technology, and computer science. The three-year funded Pilot Center and development of the game were initiated in January 2012 and are thus still in its initial phase. The focus of the quantum game project is the research-based production of a game-based platform for player participation in quantum computing development and research. The idea behind the establishment of the Pilot Center is thus twofold. Centre researchers want to experimentally develop both a prototype of a quantum computer and to develop the *Quantum Computer Game* in which players collectively contribute to the development of algorithms that can be implemented into the physical quantum computer.

Quantum computing

A quantum computer is a collection of 2-level constituents (quantum bits or qubits) upon which logical operations can be performed. In contrast to conventional bits, however, these qubits are quantum mechanical systems, which mean that they obey the basic rules of quantum mechanics. Here, a defining quality is the ability of systems to exist in multiple states simultaneously (principle of superposition). In particular, the qubits are allowed to be in any combination of the two levels 0 and 1 simultaneously. This means that instead of e.g. 10 bits always representing one number from $1\text{-}2^{10}$,10 qubits could in a certain sense represent all 2^{10} numbers at the same time and in principle perform operations on all of them in parallel. There are some caveats but the main point is that it has been proven that a quantum computer would be able to perform certain important task much faster than all of the conventional computational power combined (Shor, 1994; Grover, 1996). This realization has spurred immense experimental as well as theoretical effort in the past two decades. Already in 2001 a working prototype of a quantum computer was developed using individual atoms in organic molecules in a solution as qubits and a technique called nuclear magnetic resonance (NMR) for manipulation (Vandersypen et al., 2001). Unfortunately the structure allowed for only 7 qubits and during the past decade this number has painstakingly been increased to slightly above 10. In a departure from the conventional approach of assembling the quantum computer one qubit at a time researchers have recently begun speculating whether ultra-cold, self-assembled crystals containing hundreds of atoms can be used to implement a large scale quantum computer. Such an architecture, where quantum software is realized by moving individual atoms around in a strongly focused tweezer of light (Weitenberg, et al., 2011) forms the basis of the scientific challenges of the Quantum Computer Game.

The Game

The theme and mechanics of the first prototype of the game are grounded in research in quantum physics at the Department of Physics and Astronomy at Aarhus University in Denmark. The basic problem that players are challenged to solve is the optimization of the transportation of atoms in a quantum computer (see figure 2 and 3). The game mechanics is based on an architecture using optical tweezers for transportation of ultra-cold atoms in quantum computers (Weitenberg et al., 2011). We anticipate a community contribution on many levels. First of all, the players contribute by testing the endless number of patterns for moving atoms with the tweezers and creative solutions for solving the transportation problem, which is an extreme computational challenge for a computer to perform. This will be effective not only due to the sheer quantity but also because players can potentially apply the distinctly human skill of pattern recognition to perform a much more intelligent optimization that computers can. Furthermore, an important concept in the quantum computer game will be user participation in the initial design phase and in subsequent extensions.

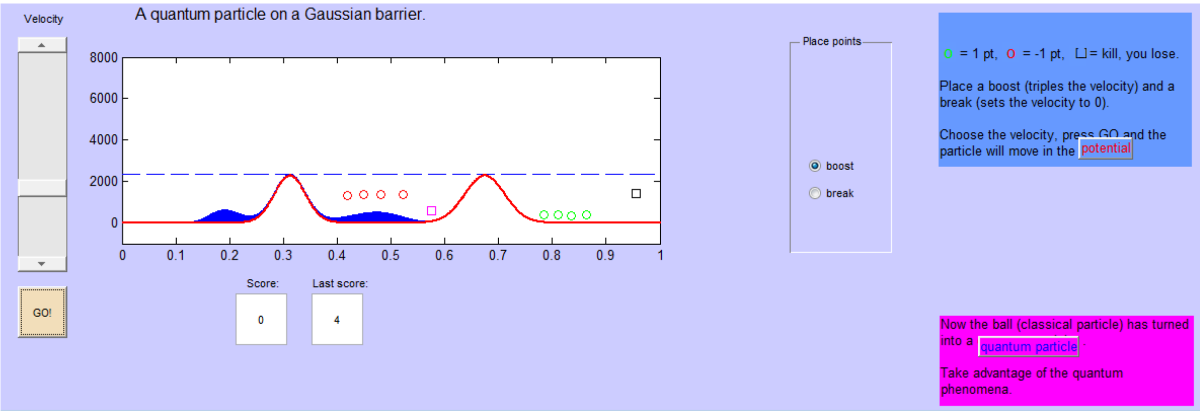

***Figure 1*: A tutorial game from the first part of the *Quantum Computing Game* illustrating the splitting of an atom in two in order to avoid the negative point (red) and only pick up the positive points (green).**

The game has two parts. The first part consists of tutorials in which players are introduced to aspects of quantum physics and learn how to manipulate game mechanics (see figure 1).

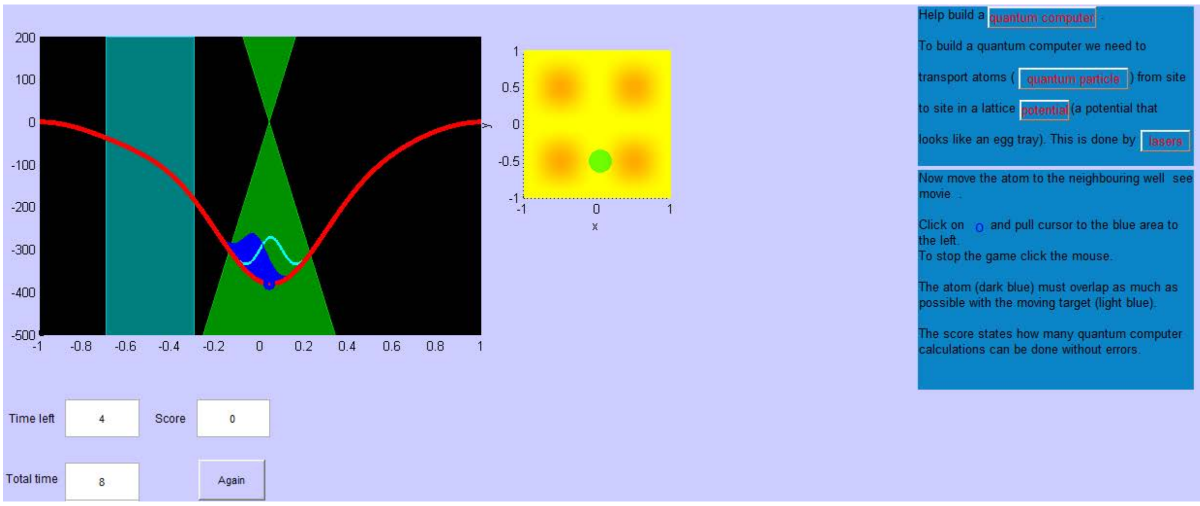

***Figure 2*: A scientific game from the second part of the *Quantum Computing Game* where players move the atom from a well on the right to a well on the left. The aim is to realize the transport with minimal sloshing of the atom.**

Players can continue playing games in the tutorial part or they can move on to the advanced part. (see fig. 2 and 3) to start solving real research problems and have their performance logged.

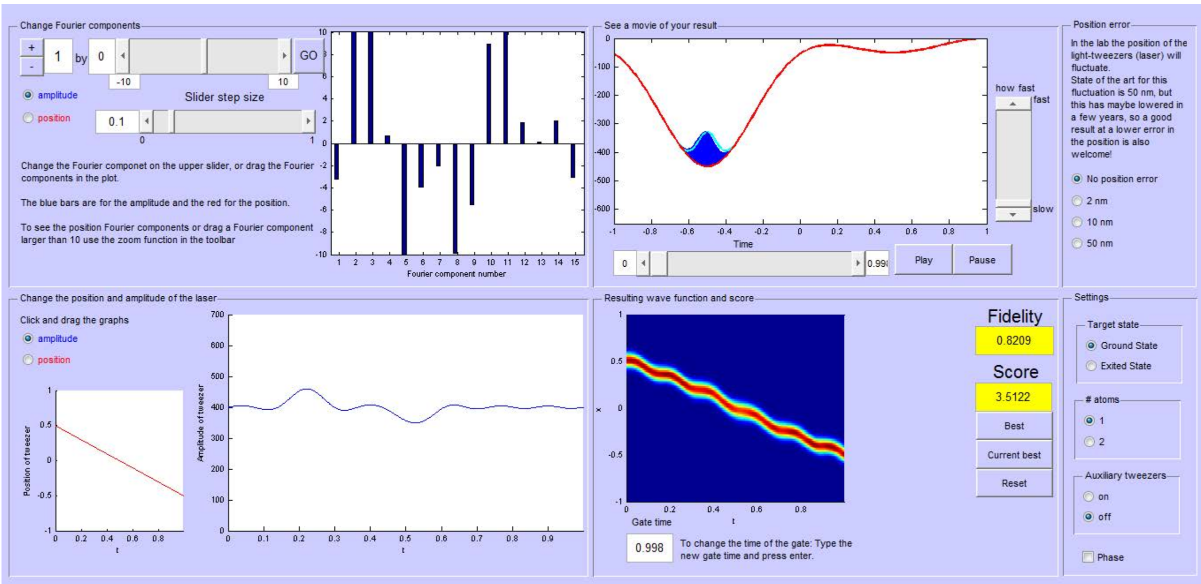

***Figure 3*: An advanced scientific game in the second part of the *Quantum Computing Game* where the motion of the tweezer can be controlled globally.**

In the *Quantum Computing Game* the key scientific objective is to develop algorithms with small enough error probability to allow for quantum computations on a large scale without errors piling up. For each attempt, a score is calculated based on the quality of the resulting quantum computer. All players' performances are logged centrally and the global high-score will always correspond to the state-of-the-art of the research field, which can thus be extended for each hour dedicated people play. The game also allows for players to develop their own sub-games and participants can thus both contribute with computing power, but also take part in a continues development of the game.

Methods and the first development phase

The design of the game and interventions is set up in a design-based research process (Brown, 1992). The first prototype was developed to establish an interface from which players could develop algorithms as candidates for implementation in the quantum computer. As the project group had little knowledge on the motivational factors and suitable interfaces for manipulating the scientific information, it was decided to do a rapid test of a first rough prototype to provide initial data for the further development of the game. By testing the first prototype, both online and in classrooms, data on player interaction, and experiences in both settings will be collected and used in the development of the next version of the game. Interventions with the first prototypes was completed in February and March 2012, in which video observations of game playing in two high school classes and surveys with teachers and students was collected. The collected data from these interventions are still under examination. An online test phase is currently being conducted with approximately 100 volunteer beta testers in order to log and collect test data and do surveys at different stages of the game.

In this first phase of the project, the project group discussed the interface and whether it was accessible for the target groups. In the context of this paper the target group of relevance is high school students with physics on a high level, or players on a more advanced level. It was discussed whether the visuals and graphics made the game accessible to beginners, even of this more advanced target group. The potential motivational factors for players were also discussed. Following a promotional effort, science teachers from different schools contacted the project group to volunteer to be part of the first game tests. The overall motivation for these groups seems to be the opportunity to contribute to quantum physics research and to collaborate online with researchers. The project group also discussed whether the game interface should be further developed with visuals of real-life tools and experimental settings to enhance the player experience of working with quantum physics researchers. Another question is whether to expand the game-play with other possible modes of experimentation, as atom transportation actions may be too narrow to support different types of creative player experimentation. The question of whether the visuals and graphics support the player experience of experimenting with complex solutions to quantum physics problems and at the same time is accessible to beginners will also be part of the first tests of the game. These observations will also focus on understanding how the game experience could be enhanced and deepened as an integral part of science education and what additional interactions, experiments and tools could be included in the educational version of the game.

Conclusion

This paper has presented a concept for and a working example of the *Quantum Computing Game* as a framework in which students can experiment with unsolved scientific problems and contribute potentially new solutions to real-life research questions. As described, the game is in its first phase of development and the results presented here are quite preliminary. The purpose of presenting the project in this early stage of development is to initiate a discussion on how game formats that support student experimentation and creation of new knowledge in science education may be created and employed using the *Quantum Computing Game* as an example. How this kind of game development implicates an adaptation of the online format for the school setting that includes teacher roles, physical classroom settings and different types of tools were also discussed. The most distinctive aspect that distinguishes this class of games from other educational game formats is the lack of concrete solutions to the scientific puzzles presented in scientific discovery games. This of course makes scientific discovery games highly interesting in a science education context as they provide a medium for students to work with open-ended experimentation and to contribute to real research at a high level, a potentially strong motivator for some groups of students.

Compared to the graphically-rich formats of science games that simulate professional working processes and professional values, scientific discovery games can be in danger of only appealing to students already interested in the specific science concept presented. The highly-technical visuals and graphics characteristic for scientific discovery games are unlikely to appeal to students not already interested in the subject area. Scientific discovery games are often highly specialized since they are framed by the areas of interest of researchers. One possible solution for making the format accessible to a broader group of students is to extend and combine the possibilities of game-based research collaboration with the rich environments available for the many types of interaction that professional simulation games pose also involving metaphorical models for the simulations. This could also strengthen the focus on professional values, tools and thinking processes as part of student work with scientific problems and innovation.

References

Brown, A. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *The Journal of Learning Sciences*, 2(2), 141-178.

Cooper, S., Firas Khatib, Ilya Makedon, Hao Lu, Janos Barbero, David Baker, James Fogarty, Zoran Popović and Foldit Players. (2011). Analysis of social gameplay macros in the Foldit cookbook. In *Proceedings of Foundations of Digital Games*, FDG 2011, Monterey, CA, SA

Cooper, S., Adrien Treuille, Janos Barbero, Andrew Leaver-Fay, Kathleen Tuite, Firas Khatib, Alex Cho Snyder, Michael Beenen, David Salesin, David Baker, Zoran Popović and Foldit players (2010). The challenge of designing scientific discovery games. In: *Proceedings of Foundations of Digital Games*, FDG 2010, Monterey, CA, SA.

Grover, L.K. (1996). A fast quantum mechanical algorithm for database search. Proceedings of the 28th Annual Symposium on the Theory of Computing, ACM Press, New York, pp. 212-218.

Hansen, F. A., Kortbek, K. J. and Grønbæk, K. (2010). Mobile urban drama for multimedia-based out-of-school learning. In Proceedings of MUM'10, the 9th International Conference on Mobile and Ubiquitous Multimedia. December 1-3, 2010, Limassol, Cyprus. ACM, New York, NY.

Magnussen, R. (2007). Games as a platform for situated science practice. In de Castell, S., & Jenson, J. (Eds.), *Worlds in play: International perspectives on digital games research* (pp. 301–311). New York, NY: Peter Lang.

Magnussen, R. (2008). Representational inquiry in science learning games. Doctoral dissertation, Aarhus University, Copenhagen, Denmark.

OECD. (2000). Knowledge management in the learning society. Paris, France: *OECD Publications*.

Sawyer, R. K. (2006). Educating for innovation. *Thinking skills and creativity*, 1(1), 41–48.

Shaffer, D. W., & Gee, J. P. (2005). Before every child is left behind: How epistemic games can solve the coming crisis in education (*Tech. Rep. No. 2005-7*). Madison, WI: University of Wisconsin-Madison,Center for Education Research.

Shor, P. W. (1994) Algorithms for quantum computation: Discrete logarithms and factoring, Proceedings of the 35nd Annual Symposium on Foundations of Computer Science (Shafi Goldwasser, ed.), IEEE Computer Society Press, 124-134.

Squire, K., & Klopfer, E. (2007). Augmented reality simulations on handheld computers. *Journal of the Learning Sciences*, 16(3), 371–413.

Vandersypen, L.M.K., Steffen, M., Breyta, G., Yannoni, C.S., Sherwood M.H., & Chuang, I.L. (2001) Experimental realization of Shor's quantum factoring algorithm using nuclear magnetic resonance. Nature 414, pp. 883-887.

Weitenberg, C., S. Kuhr, K. Mølmer, J. F. Sherson (2011) Quantum computation architecture using optical tweezers. *Phys. Rev. A* 84, 032322.