ABSTRACT
We will link the concepts of tangible games and actuated output, both of which exist within the field of tangible interfaces. Our focus is on researching the possibilities for integrating actuated output in tangible tabletop games. We believe this combination is promising because the advantages of tangible interfaces are suitable for combination with games, and actuated output can add an extra dimension to these tangible interfaces. We will provide our insights on the potential of this combination by examining existing projects and evaluating the possibilities they offer for the future.

Keywords
Actuated output, tangible interfaces, pervasive games, tangible tabletop gaming

1. INTRODUCTION
In this age of rapid technological advancement it is our observation that all forms of computer-supported games are becoming more and more realistic and immersive. With the extreme levels of detail already available in modern day graphics equipment designers are looking to venture into new frontiers to separate their products from the crowd. This trend started many years ago with the introduction of force feedback into console game controllers, and is now being revolutionized by innovations like the motion-sensitive Nintendo Wii-controller [1]. Increasing amounts of products like this have been making their way to the market over the past years, such as the Sony EyeToy [2], which is a camera used as an input device for a game console. Scientific research projects show possibilities that could mean this is only the tip of the iceberg in gaming innovation [3].

The field most involved in this kind of project is Tangible User Interfaces (or TUI). In this field research is aimed at developing new methods of interacting with computers through the manipulation of physical objects. The field of tangible interfaces is one that contains a great number of different application possibilities. A great deal of research is going into tangible interfaces at this point in time, and most work on the subject is very recent.

In our opinion, the strength of games lies in the combination of creativity, competition/cooperation and social interaction. The combination with tangible interfaces promises more room for creativity in design and also offers possibilities for increasing social interaction [4]. As for the relevance of this research, we believe that this field has great potential, although a great deal of work still needs to be done. The field of games represent a great amount of commercial possibilities, both for leisure and for educational purposes. In 2008, more than 430 million units of videogame software were sold in the US alone [5]. Games may be the most obvious application of tangible interfaces for the consumer market. Computer games already form a huge market, and with the novelty and increased accessibility [6] gained from tangible interfaces it seems an almost obvious match.

In this paper we will focus on one particular subject within tangible interfaces. This subject is actuation, or actuated output. Actuation may well be the next dimension in tangible interfaces [3]. While tangible interfaces in general deal with using more tangible objects in user input, actuated output deals with making the output back to the user more tangible. While the term actuation is not very specific, and thus many things can be considered actuated output, we will focus mainly on systems that introduce some form of motion or deformation to physical objects. In this way it becomes possible to add a new dimension to systems using traditional output devices (screens, audio) or even do without these devices altogether.

We will look to link the subject of actuated output to the subject of games that use tangible interfaces. Because this subject is very broad, we will limit our scope to tangible tabletop games. By this we mean games making use of tangible interfaces that can be played in an indoor tabletop setting. This set of games represents a fusion between the setting and social atmosphere of traditional tabletop games (like Monopoly [7]) and the action and usage of technology offered by console video games.

The specific issue we wish to address is to make an assessment of the future possibilities offered by combining tangible tabletop games with actuated output. In order to address this issue we wish to identify the factors in which actuated output and tangible tabletop gaming offer improvements over traditional games. Based on these factors we will determine which forms of actuated output and tangible tabletop gaming offer promise for the future when combined, and which further research could be worth pursuing.

We will draw conclusions on these points mostly through the study of literature and other materials describing existing products and projects. In order to find the factors we are looking for, the focus will be on finding research projects on the specified subjects. We will discuss the most relevant of these projects in this paper. While examples from both fields will offer a great deal of information, we must also consider user satisfaction in games in a more general sense.

The most logical (and probably best) method to research this subject and draw meaningful conclusions would be to actually design a game with a tangible interface and actuated output. This would not only give deeper insight into the development issues but also offer the possibility of doing a user experiment. This design and the accompanying experiment would however require far more resources than are available for this research.
both in time and in equipment/means to develop equipment. We will however offer our thoughts on the requirements for such a design, and provide a concrete example.

The rest of this paper will be organized as follows. First we will discuss examples of tangible tabletop games that represent the sort of games we wish to examine and that are relevant to our research. This will be followed by examples of actuated output systems that we feel could be suitable for use in tangible tabletop games. Next we will take a look at what the end result of this combination could look like and if anything like this already exists. After this we will start our discussion of the factors that make tangible tabletop games and actuated output attractive, followed by what these factors can indicate for the future. Finally we will make an overall assessment of the viability of the proposed combination, and offer our suggestions for any future research.

2. TANGIBLE TABLETOP GAMES

Many examples of tangible tabletop games exist. Here we will discuss several of these examples. We have selected these specific examples because we feel that they are a varied set of possible applications, because they are some of the more interesting projects in this field, and most importantly, because we feel they may be suitable for combination with actuated output.

We will explain for each example what it is, how it works, and which concepts make it different from other examples. Throughout this explanation we will identify the factors and principles that make these examples interesting to potential users.

2.1 The STARS Platform

The first example we will look at is the STARS platform [8]. This platform is based on the setting and principles of traditional board games, but looks to expand this situation by adding several forms of technology. The developers of the STARS platform state that the success of traditional board games, but looks to expand this situation by adding several forms of technology. The developers of the platform have found several ways to benefit from using computing technology in board games. The first is that because the system can contain part of the game logic, it allows more complex and therefore more realistic relations between objects. This allows for a game environment that is less simplified than traditional board game settings. The second advantage is that the platform can easily record and save the state of the game in order to continue the session later, something which can take a lot of administration in a traditional board game. The third benefit is that game boards can be far more complex because they exist largely in the virtual domain. Not only can these boards contain dynamic elements, they can also be larger than the actual physical playing space, because it is possible to scroll in them. The last advantage is that the players no longer have to deal with uninteresting overhead tasks such as shuffling cards and setting up game boards.

Even though the virtual domain offers a great deal of opportunities for automation, the designers purposefully decided not to let the virtual part of the system have too much involvement. Two cases where this becomes obvious is not including every game rule in the system, and using traditional dice instead of an internal random number generator. The developers do this because they feel that discussing the game rules and trying to manipulate dice rolls and argue about this is a part of the social environment when playing a board game.

While the developers did not perform a full scale user experiment, they performed an informal user evaluation. From this they concluded that the platform had succeeded in maintaining the social atmosphere of the traditional board game, while successfully introducing some new elements into it such as the private communication offered by the PDA’s.

Two additional interesting tangible tabletop games that are very similar to the STARS platform are False Prophets [9], which uses a projector mounted above the playing area to display the game board, and Weathergods [10], which has an interesting feature that uses a light conductor in the playing pieces to transfer light from the board display to color a ball in the piece.

2.2 SenToy

The second example we will discuss is the SenToy [11]. While the previously examined STARS platform offers a complete platform on which games can be played, the SenToy is an example of a single tangible input device. The SenToy is a doll which is used to control virtual characters by moving it and adjusting its posture. While it is not in itself a tabletop game, the SenToy’s size and wireless nature make it suitable for use in a tabletop environment.

The goal of the SenToy’s developers is mainly to get users more involved in games. They look to make the link between the physical and virtual worlds seamless. In the specific application for which they used the SenToy they attempt to foster emotional involvement with the game by allowing the user to influence the emotions of a game avatar through the SenToy.
The first step in the developing process was to find out if and how users were able to express emotions by manipulating the doll. The developers found that the most common expressions were easily conveyed by making gestures with a doll. They defined a specific gesture for each emotion that was used in the game.

Based on the information about these gestures the developers set out to develop the SenToy hardware. The SenToy was implemented as a soft and cuddly wireless doll with three sets of sensors placed in its plastic skeleton, as seen in Figure 2. These sensors can detect movement of the entire doll, the positions of the limbs, and whether or not the doll’s hands are placed over its eyes. This allows for the detection of the required gestures.

The SenToy was developed for use in the computer game FantasyA. This is a traditional computer game in the sense that it is played on a normal PC, and output to the user occurs via a screen. Throughout the game the user has to fight duels against computer controlled opponents. In these duels the player can influence their avatar’s emotions (and subsequently the opponent’s reactions) through the SenToy.

User testing showed that users often became very involved with the doll and the game. The required gestures were not all discovered naturally, but users seemed to learn them easily after some instruction. Many people showed emotional involvement by acting out the emotions themselves in addition to manipulating the doll. One extra point the developers make is that the doll turned out to be quite robust, as it did not break throughout testing, in which it was handled roughly at times.

2.3 Tangible Moyangsung
The third example we will examine is the Tangible Moyangsung virtual heritage environment [4]. This is a virtual representation of the Korean Moyangsung fortress. Within this virtual fortress users must navigate the surroundings to find sections of wall that have broken down, and repair them. While this is essentially not a multiplayer game, the developers studied cooperation in this system by letting users play in groups of two.

The actual setup of the system consists of 4 parts. The first is the (vertical) main display, on which users can view the virtual environment. The second is the horizontal touch screen display which displays an interactive map of the fortress that can be used to move around. The third is a device that looks like a traditional Korean hand mill, somewhat similar in function to a joystick, which is also used to navigate through the fortress. The last part is the puzzle board, which is the interface used to repair the broken wall sections. It consists of a grid of cells which can be colored by LED’s, and which detect the placement of transparent acrylic Tetris-style blocks. This board can be seen in Figure 3. The state of the blocks on this board is reflected in the virtual representation of the wall. These blocks must be arranged to fill the holes in the wall in order to complete the puzzle.

While the setup used by the developers doesn’t satisfy the traditional tabletop game setting, the tangible puzzle component could clearly be integrated into a tabletop environment. This part of the system is the most interesting to us. It allows users to place physical objects on a puzzle board which not only reacts to this (by the LED’s changing color), but also sends information about the placed pieces to the central game computer. This allows users a very natural way to handle the puzzle pieces and gives them a much more accessible model of the puzzle, since there is no need to fiddle with keyboard or mouse to change the viewport or move pieces around. This also introduces the possibility of cooperation, since physical bricks are inherently suitable for multiple users, while interaction through mouse and keyboard is limited to one person providing the input.

The developers of the Tangible Moyangsung system placed most of their focus on how the system facilitated group collaboration during the game. Participants of the study played the game both alone and in pairs. Results showed that users performed significantly better when working together. Users confirmed this by saying they found that it helped to discuss the game and share insights.

2.4 Summary
In the STARS platform, we see that the developers place their focus on the social setting and interactions that are typical to a traditional board game. They seek to further immerse the user into the game by making the game more dynamic, increasing realism, and introducing graphically enticing elements. Another way in which they improve upon traditional board games is by taking care of overhead tasks and thereby making it easier for the user to focus on the game experience.

In the SenToy example, we see that the developers create an input device that offers tactile interaction and allows users to convey emotional states to a computer game. It was well received by a varied group of potential users. These users did identify with the doll and became very involved in the game through it. We see that the developers also took an interest in the robustness of the device, which is an important quality for any tangible interface as it is supposed to be handled
extensively. While the application used by the developers is the game FantasyA, other applications can be imagined.

In the Tangible Moyangsung example we see that a tangible game system does not have to be competitive between users, but can also stimulate cooperation. The puzzle component has its focus mainly in the physical domain as the pieces are all physical and must be placed on the board, it is only the constraints and victory conditions of the puzzle that are defined by the virtual part of the system. The system also provides a graphical environment to give the users a sense of story and a universe in which these tasks are set. We find this example of a tangible game very interesting because while the puzzle pieces are purely physical and can be placed without any virtual system, there is no actual task to be completed. It is the system that offers the game logic and rules while the puzzle game is played only with the purely physical blocks.

3. ACTUATED OUTPUT

Here we will discuss several examples of projects that use actuated output. While this has been a popular subject of research for several years now it is clear that the field is still in an early stage. This is evidenced by the fact that most projects in this area are prototypes of entirely new concepts and very little exists in terms of (near-)finished products that are user ready.

We have selected the following examples because we believe they are interesting and offer good prospects of further development, and because they could be suitable for use in a tabletop environment. We will explain for each example what it does and how it does it, and indicate the aspects that make it interesting to users.

3.1 Project FEELEX

The first example we will discuss is project FEELEX [12]. The idea behind FEELEX is to offer a haptic surface on which graphics are displayed. What this means is that FEELEX is a surface that can be deformed and that can be touched and felt by the user. This way the user can feel things that are being displayed on the screen with their bare hands, without the use of extra devices such as haptic exoskeleton gloves.

The setup of FEELEX is the following. At the base there is an array of actuators. A flexible rubber screen is placed on top of the actuators. The actuators push up tiny rods which in turn lift a small portion of the screen. Because the screen is made of rubber this will create a bubble, so the shape of the screen remains spatially continuous. The rods also contain force sensors to monitor the force that the user exerts on the screen. The image is projected onto the screen by a projector set above the installation.

The first FEELEX prototype contained a 6x6 linear array of 4x4 cm motors attached to rods. While this made the screen 24x24 cm, which was considered by the developers to be the ideal size, they later worked to increase the resolution of the surface. This was done in the second prototype, where the distance between two rods was only 8 mm. This was chosen to be smaller than the width of a human finger. In this second prototype it became necessary to use a piston-crank mechanism for the rods since no motors were available that fit within the available 8mm of space.

As said before a projector above the screen projected the graphics onto the FEELEX. Since the vertical range of the actuators is limited, there was no need to correct the projection for distortion. The projector can display OpenGL images or simply playback AVI files.

The application that was developed in order to test the first FEELEX prototype was the Anomalocaris. An Anomalocaris is a small ancient creature. In this application an image of the Anomalocaris is projected onto the screen, and the screen is deformed to display its shape. Users can then touch the Anomalocaris, to which it can respond in a number of ways, based on where it was touched.

The FEELEX system offers a very natural style of interaction, which has several advantages over other haptic devices. First of all it is usable with only the bare hand, no complicated devices are required to operate it. Secondly, the image and the haptic sensation are located in the same place, which eases the connection between the two in the mind and increases the realism. Lastly, the FEELEX can be operated by multiple users at the same time because different parts of the surface can be interacted with independently.

The FEELEX however also has several drawbacks. The biggest problem is the hardware setup. First of all, it requires a large amount of actuators which need to be controlled at the same time and also have to be able to survive extensive handling. The second problem is in its limitations. The screen can only be deformed by a limited margin, and more importantly, it is merely a surface. It is not possible to feel the other side of objects.

Two similar interesting projects are Digital Clay [13], which is based on the same idea but works with hydraulics instead of servos, and Super Cilia Skin [14], which uses magnetic forces on rods attached to the surface in order to deform it.

3.2 The Actuated Workbench

The second example we will discuss here is the actuated workbench [15]. The actuated workbench is a system that looks to improve traditional tabletop applications by allowing the system to move objects that are placed on the tabletop. While many systems already exist that allow users to manipulate a system by moving objects on a tabletop, the system can only reply through sound or graphics. The actuated workbench is designed to change this.

The designers of the actuated workbench considered several ways of making this happen, one of which was motorizing the objects on the workbench. However it was decided that these objects would become too large, and that they did not want the objects to rely on battery power. It was also decided that the ideal solution would be able to move multiple objects at once, and that it would be silent.

What eventually resulted was an array of electromagnets placed below a small acrylic screen. While the designed array was only small (16.5x16.5cm), it was designed so that multiple arrays could be tiled together to create a larger board.

In the design prototype the objects that are placed on top of the system are small acrylic pucks that hold permanent magnets and an infrared LED for tracking purposes. The pucks are tracked from above by a simple camera with an infrared filter on it.

The objects on top of the screen are moved by turning the electromagnets on and off. Several mathematical formulas are used to calculate which magnets need to be turned on at which strength and at which time in order to move an object to the desired location. Using these calculations and by adding a felt pad under the pucks to stop them from sliding around, the
developers were able to make the pucks move around in a fluent and controlled manner.

The actuated workbench can offer a tremendous improvement to any tangible tabletop application for several reasons. For example, if a tabletop system is capable of moving objects it can undo physical input, correct inconsistencies between the real and virtual situations, guide the user, recall a certain state, or even mimic the input of a remote user so that multiple users can work together from different locations.

The developers mention several ways to improve the actuated workbench. The most obvious improvements would be to simply increase the speed, magnetic strength, scale and resolution of the system. Another improvement they mention is removing the current camera tracking system and replacing it with a magnetic tracking system which would allow the pucks to be completely passive. A very interesting but complicated idea is to make objects on the board jump up or even (momentarily) levitate using the magnets. It should also be noted that the developers actually mention games as a possible application for the actuated workbench. They mention the example of playing Pong with physical paddles and a puck representing the ball.

3.3 LinguaBytes

The last example we will discuss here is the LinguaBytes project [16]. While the previous examples have been mostly about newly developed technologies and ideas, this example is more focused on showing the value of actuation. It does this by describing the CLICK-IT prototype, which is a fairly close to finished application that makes use of several simple forms of actuated output.

The LinguaBytes project is focused on developing an interactive learning system for toddlers with multiple disabilities. The toddlers at which the project is aimed have a form of Cerebral Palsy and therefore cannot or hardly speak and have trouble controlling their muscles. Because of the differences between children, the product must also be adaptable to the specific demands of the user.

The choice for a tangible system when dealing with toddlers has several reasons. For one, these toddlers do not yet understand traditional GUI components such as menu structures and icons. They also sometimes have difficulty operating a mouse and cannot yet read and write so are unable to use a keyboard. Moreover, GUI interaction is designed for solitary use and leaves little room for social interaction with a parent. Lastly, toddlers are naturally explorative and rely on all their senses.

The developers introduce actuators in this project not as a way for the system to do something on its own, but as a way for the system to assist or guide the user. Since some of the system’s users have motor impairments it can greatly benefit them to be aided by the system.

The current prototype, named CLICK-IT, offers an interactive story to the toddler. This story is used in several separate modules that offer the toddler ways of exploring the story through core words. It also offers several exercises.

The paper mentions three examples of such modules. The first is the Phonotron, which allows the toddlers to input a word or character from the story by means of inserting a tangible object. This object is detected with an RFID tag and the base into which it is to be inserted can pull the objects towards it using an electromagnet in order to assist the toddler. The second one is the Bookbooster, which consists of an actual storybook and a screen into which this book can be inserted. Once the book is inserted the screen displays an animated version of the story and a slider on the bottom can be used to move the book forward and backward. This slider includes an electromotor that can assist the toddler by for example blocking the slider at the desired position. The last one is the PuzzlePointer, which is very similar to the Phonotron. It is a puzzle where the pieces are identified by RFID, and once the puzzle is finished the toddler can push the individual pieces to show an animation and play a sound related to that part.

The developers stress that actuators can make products more adaptive to the skills of particular users, especially the toddlers they worked with. It is also noted that while it is beneficial to aid the user, over time this can become annoying or patronizing. A final thought contributed by the developers is that “…actuation can be used to make the integration between the physical and virtual (or real and symbolic) worlds really seamless.”.

3.4 Summary

What we have seen in Project FEELEX is that the developers wanted to offer a haptic experience to the user that can be used with the bare hand and doesn’t require the use of complicated haptic devices. They also brought the visual and haptic stimuli together spatially, so that a user is actually touching whatever is displayed on the screen directly. It also becomes clear from the Anomalocaris test that tactile interaction is something that users eagerly engage in and enjoy.

What we have seen in the Actuated Workbench is that the developers want to make tangible tabletop systems capable of moving objects on their own. This is meant to strengthen the feeling that the physical object is a manifestation of some digital information because it unites the input and output in the same dimension. It also allows the system to accept and apply any state changes other than physical input, be it internal system logic, corrections, or input from a remote source. While the developed prototype does not offer any direct application, it is clear that this system can be used in a large amount of tabletop applications.

What we have seen in the LinguaBytes example is that actuated output does not necessarily mean that the system moves objects on its own, but it can also be used to assist users in various tasks which offers very different and unique advantages. We see that actuated output is stressed as a very valuable tool to further integrate the physical realm into a system. It also reminds us that different users have different needs and different limitations, and that these not only have to be considered while designing a system, but that the system can actually be designed to help in such cases.

4. EXISTING COMBINATIONS

We have not been able to find any research projects that deliver a combination of tangible tabletop gaming and actuated output. The LinguaBytes project we discussed is probably closest to this description, although it is not a game but a playful learning environment, and its use of actuated output is limited. There is however an example of a commercially available product that we feel illustrates the sort of application we envision.

This product is the motorized chess set. An example of such a set is the Excalibur Electronics Phantom Force [17]. A motorized chess set detects moves made by the player with sensors inside the board. It also allows the user to play against the internal chess computer by moving its pieces. An electromagnet is mounted on an x-y plotter underneath the board, allowing the game to move the physical playing pieces.
While the movement this device can produce is very limited, slow and noisy, the main principle is exactly what we are concerned with in this paper. A similar mechanism has also been used to move objects around in a tangible interface context in the PsyBench system described in [18].

5. FACTORS
Here we will isolate and discuss the factors that came forward from our examples. We will examine for each factor where we found it, what exactly it entails, and why it is important for a potential Actuated Output Tangible Tabletop Game (AOTTG). The factors we will discuss are divided into several categories for the purpose of clarity.

5.1 Immersion
The first and possibly most important point of discussion is the experience of immersion in the game. While the concept of immersion is most commonly related to traditional videogames, we believe that it also applies to AOTTG’s because they are part videogame. There is much discussion as to what exactly constitutes immersion [19], but here we will take it to mean the amount that the user feels “drawn into” the game experience. Immersion is created by a host of different factors, and we will discuss the ones that we feel are relevant to AOTTG’s.

It must be said that immersion is not necessarily a good thing. While generally it increases the enjoyment of the user experience, immersion increases the emotional connection between the user and the game, and this can also lead to strengthened negative emotions and experiences, such as anxiety [19].

Many of the factors we will discuss here are not well-defined and their exact meaning is a popular subject of psychological and anthropological research and debate. While we discuss them here in the context of immersion their influence on the gaming experience is not limited to that area. Many of these factors are related to each other and influence each other.

Realism. The STARS platform shows that developers try to increase realism to make games more attractive to users. Realism is a common goal in many videogames in order to make the game more believable and immersive. Board games however are often abstractions or simplifications of realism, so while it is attractive to have realistic rules and object relations, realism can also be taken too far and make a game unnecessarily complicated.

Graphical attractiveness. In all the tangible game examples 3d graphics are used to try and entice the user to the game. If the game is generally pleasing to look at this will ease the immersion by the user. It has to be noted that graphics do not have to be realistic in order to be enticing, for example games with cartoonish graphical styles can be just as attractive.

Complexity. The STARS platform shows that games can potentially be far more complex when computer technology is integrated. Like realism this should not be taken too far. While making a game board larger than the play surface may be a very nice extension, making a game too complex will only make it unattractive to new users.

Emotional involvement. The SenToy is a great example of getting users emotionally evolved in the game. Not only is the game focused on emotions, users also develop emotions towards the doll they use. This can go a long way towards immersing players in the game.

Multimodality. It is especially in Project FEELEX that we see an effort to involve additional senses into the user experience. By stimulating the user through multiple senses they are involved with the game in multiple dimensions and this adds to the immersion and realism.

Spatial consistency. Both Project FEELEX and LinguaBytes stress that it is important to the user that input and output are united in the same place. This strengthens the mental idea that this object is an actual representation of whatever data it represents instead of just being a handle to control the system with.

5.2 Social setting
There is no doubt that the social setting makes up a large part of the attractiveness of traditional board games. This setting should be the primary target for an AOTTG. A social environment can be both cooperative, as seen in the Tangible Moyangonsung example, or competitive, as seen in the STARS Platform. Of course it is also possible to combine the two by letting players cooperate with each other to compete with a team of other players.

A very interesting aspect of a social setting is that it tends to limit the amount of immersion that users can experience. While a social setting still allows users to become (collectively) immersed into a game, there is still a social context that is unrelated to the game. Players may for example converse about subjects unrelated to the game, decreasing their focus on the game and their immersion.

As suggested in the Actuated Workbench example, the use of technology may allow users to play tangible games with remote users. This allows the user to not only play with people that are not within reasonable traveling distance, but also means that the amount of potential opponents (or teammates) is far greater, making it easier to find enough willing users to play. The main drawback to playing with remote users is that the social environment is largely removed. Using things like voice and/or video chatting may bring some of this back, but the experience is certainly different from having all the players present in the same location.

5.3 Accessibility
Accessibility means the degree of ease with which a user can start and play a game. We want to distinguish between accessibility to the average user and accessibility relating to users that have some form of disability.

In the first case it is clear that an AOTTG would have to fulfill the rules for any sort of interface that it is clear to the user how they are supposed to interact with the system and which options are available. This interaction can be made more natural and intuitive by increasing the realism in the way the physical objects are used in the game. Accessibility can also be increased by taking away overhead tasks from the user as we have seen in the STARS Platform. This makes it easier to start a game and play. Being able to save a game state and recall it at a later point also helps in this regard as it allows the user to play even if they do not have enough time to finish a game session.

In the case of disabilities, many things can be offered as extras as shown in the LinguaBytes example. These were however fairly extreme cases, and one would not expect such a large portion of an AOTTG’s target user group to have such extensive disabilities. There are however many more common impairments that need to be accounted for. Examples include deafness, color blindness, bad eyesight. Even common things
like the limited reach of children should be considered when designing an AOTTG or in fact any system.

5.4 Practicality

While this does not directly contribute to the user experience, there are many practical concerns in developing a product that is ready for widespread use. Both the SenToy and FEELEX examples noted that the sturdiness of their prototypes was an issue. This is one of the many aspects that need to be considered when delivering a product to the consumer market. Space constraints are also a big factor. The second FEELEX prototype for example was far too large for use in a tabletop setting because the amount of space the motors take up is much larger than the effective surface area. Although this is unlikely to come up in a research prototype, the production price is also a big factor in delivering an attractive product.

6. FUTURE

In this section we will discuss those of the previously identified factors that we believe are the most important to the future of actuated output in tangible tabletop games. For the factors we lift out we will illustrate what makes them important and what they have to offer for the future of this combination. Following this we will discuss some of the issues that still need to be resolved before a successful AOTTG can be developed.

While most aspects of immersion are likely to be improved upon in the future, we do not believe that realism, complexity and graphical attractiveness are crucial to the success of an AOTTG. This is because traditional board games have enjoyed great success without exactly these factors. Board games offer a simplified abstraction of reality, which makes them easy to understand and intuitive to play. Complexity, realism and graphical attractiveness are strongly connected, as making things more complex is often a result of increasing realism, and graphical quality is often related to the amount of detail, which in turn is a degree of realism and also complexity.

We do feel that AOTTG’s should offer more complex games and game environments than traditional board games, but current generation videogames can already offer a degree of complexity that goes well beyond the traditional board game. Although it seems intuitive that people do not wish for a tabletop game in a social setting to be too complex, further research is required to see if this assumption holds up when the game offers easy ways to deal with this complexity.

We feel that the key to immersing the player into an AOTTG game is in the factors of multimodality and spatial consistency. Multimodality is also an important aspect of tangible interfaces in general, and spatial consistency is one of the main reasons for choosing actuated output. We believe that progressing in these areas will bring the game more and more into the physical realm, and make the underlying computer architecture less and less visible. We’ve discussed that immersion relates to the player of a game being drawn into the game world. We believe these factors can bring the game into the player’s world, which also facilitates the immersion. In essence it makes the game more “real” and tangible.

As far as social setting is concerned we think that this is one area where it is important to stay true to the original concepts that have made board games so popular. We’ve seen in the STARS Platform example that several tasks that could have been easily performed by the system were intentionally left to the users in order to stimulate the social context. We agree that it is very important to make sure that the technology used in an AOTTG does not take away from the social atmosphere. The only area here that could be improved upon in the future is trying to recreate the social atmosphere of the traditional round-the-table setting in a remote game.

On the subject of accessibility, we believe that AOTTG’s can expand tremendously upon the traditional board games. A lot of principles that are already commonly used in computing could be applied like zooming in on parts of a display in order to make reading easier, allowing different methods of input like speech commands, saving and loading, etcetera. Actuated output could offer the user to move their playing pieces for them should they not be able to reach or move them themselves. There are of course also problems that still need to be addressed. First of all it is very hard to tell what users would expect of an AOTTG since it is a new type of game we are proposing. While developers can fill in the concept in their own vision, the standards by which users will judge the product are unclear. Will users see it as an extended board game or as a socially oriented videogame? It is crucial to know this because it shows how the user will judge the product, and what their expectations are. This will be discussed further in the section on further research.

Aside from finding out what users want from an AOTTG most of the main problems to be solved are practical in nature. These include general aspects such as keeping the costs down, making the product portable, making it sturdy enough for frequent and rough handling. Such concerns, while key to the success of any product, will only come into play well down the line. They are of little interest to prototype developers.

7. CONCLUSION

In this paper we have illustrated the fields of tangible tabletop gaming and actuated output with several examples, and from these examples we extracted the factors that make them interesting. We have discussed the meanings and benefits of these factors, and made an assessment of what they could offer in the future.

We feel that we can safely say that the integration of actuated output with tangible tabletop games offers promise for the future. While many questions and uncertainties remain since there is virtually no previous work on this subject, we believe that an AOTTG could offer a very new and attractive gaming experience, while maintaining the social setting of traditional board games. This is indicated by the enthusiasm of users of both tangible games and actuated output systems, and by the factors and future possibilities that we have discussed. While using graphical computer output as a playing board can be a valuable addition, we feel that the most important improvement is using actuated physical game objects in order to keep the interaction with the game strictly in the physical realm while allowing the digital environment behind the scenes to facilitate new and exciting game concepts.

8. FURTHER RESEARCH

We have seen that a lot of additional research is still needed on the subject we discussed. Here we will discuss what still needs to be done. This will include a short description of the requirements for an AOTTG.

We already noted in the introduction that it is necessary to develop a working prototype of an AOTTG in order to be able to draw more conclusions about the idea. This is important for two reasons. First of all, developing a prototype would allow for the discovery of any problems that arise in designing and constructing an AOTTG. There is no doubt that many practical
concerns will have to be addressed, as in any development process. The second and most important function of a prototype would be the possibility to setup extensive user testing. We have already discussed that it is unclear exactly how users will look at AOTTG’s and what they will expect of them. This should be the main focus of such an experiment. We also noted that it is unclear exactly how far users can and wish to be immersed in a game with a social setting, this could also be addressed. Lastly it should be examined if the user truly experiences the game objects as being “in the real world” due to the actuation and their tangible nature or if they are still seen as control devices to the digital system.

We will now discuss what exactly is required of such a design in order for it to be able to answer these questions. We will do this by listing the most important requirements that must be satisfied for a game to be an AOTTG. Note that this is not a full definition of the term AOTTG, it merely illustrates the key points for designing one.

- An AOTTG must be playable in a tabletop setting.
- An AOTTG must allow for cooperative and/or competitive play by multiple users.
- The interaction with an AOTTG must happen predominantly in the physical realm.
- An AOTTG must be able to deliver feedback through the physical realm and not only through traditional media.
- An AOTTG may not require traditional input devices such as keyboards and mice.
- An AOTTG must be supported by a computer that handles user input, maintains game logic and delivers output.

There are basically three ways to find a game principle for an AOTTG. It is possible to extend a traditional board game (like the STARS Platform), to create a physical tabletop version of a videogame (a physical version of Pong was suggested in [15]), or even to come up with radically new concepts. While we will not go into much detail here, for a follow-up project we would choose to go with an extended board game because we believe that this will be easy for users to understand, while they can also choose to go with an extended board game because we believe this by listing the most important requirements that must be satisfied for a game to be an AOTTG. Note that this is not a full definition of the term AOTTG, it merely illustrates the key points for designing one.

9. REFERENCES