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The use of a Bespoke Computer Game For Teaching Analogue Electronics

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***Abstract*—**An implementation of a design for a game based virtual learning environment is described. The game is developed for a course in analogue electronics, and the topic is the design of a power supply. This task can be solved in a number of different ways, with certain constraints, giving the students a certain amount of freedom, although the game is designed not to facilitate trial-and-error approach. The use of storytelling and a virtual gaming environment provides the student with the learning material in a MMORPG environment. The game is tested on a group of second year electrical engineering students with good results.

***Keywords*—**analogue electronics, e-learning, computer games for learning, virtual reality

I. Introduction

THE project described here is focused on the creation of a computer game based on a previously published design[1] for a games-based virtual learning environment. The system design is focused on the utilisation of a multi-level, multi-player games-based model and its inherent support for constructivist learning in a higher education environment. The design has been tested previously with computer science modules[2,3]. The focus in this trial is the utilisation of the same design in a non computer science degree, and the choice fell on electrical engineering, more specifically analogue electronics.

There are several reasons for the choice of utilising a gaming format, games are generally built to offer freedom for the player to explore the environment and material, computer games also focus on the actions and interactions performed by the player and require them to take an active role. The authors would also argue that games utilised for learning purposes are inherently constructivist, and in addition the gaming format lends itself to support the known advantages of narrative from oral traditions and fits with the younger generation's interest in current trends in the entertainment industry.

The decision to adopt a games-based approach is also based on several studies that have shown the significance of using computer games in education. In particular, Henderson[4] published a study showing that playing a recreational video game provided beneficial informal educative experiences, even when used only over a short period of time. This study provides support for the cognitive worth of playing games, and it also contradicts the popular opinion by confirming that recreational video games are a significant cognitive artefact of youth culture.

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The decision to adopt a game-based approach to the development of e-learning follows on from a survey of current state-of-the art support for lifelong learning that was carried out by the authors[5], a key element of that investigation being the different techniques to improve learning and retention through engagement of the learner.

II. Learning in a Games Format

As we know from school, young people are not always eager to do difficult things. It has been observed by the authors that utilising elements from a constructivist learning format seems to offer good results. One of the key points of constructivism is to get the students involved in constructing their own learning experience and through this, giving the tutor the role of facilitator and supporter for learning. Experience has shown us that most students will, after some initial misgivings, elect to follow the active learning route and actively be involved in the learning process. In addition to the known pedagogical benefits of constructivist approaches, the rationale for this is that it is simply more enjoyable.

So the key points in our selected approach are: Keeping the learners' active, create a story to contain the learning material, hard fun or create a state of flow, and finally create opportunities for socialisation during the learning

A. Keeping learners active

Computer game designers work very hard to encourage players to finish a game they have started on, and preferably buy the sequel or next game in the series. The main "trick" game developers use to get a player to stay with the game is by establishing emotional connections with the on screen characters, both the avatar used by the player and in game characters and non player characters (NPC). The same is used to make players have the urge to return and continue when they have to leave. The emotional attachment between players is discussed earlier in the section on socialisation in a game environment. Freeman[6] presents this topic in his book on how to create emotion in video games. In games players make things happen, they do not just sit back and let impressions and events wash over them. Video games are by definition interactive.

In learning we generally want the students to take a deep approach to learning. Deep learning involves the critical analysis of new ideas. It requires the student to link new topics of understanding to already known concepts and principles, and leads to a better understanding and long-term retention of concepts so that they can be used for problem solving in unfamiliar contexts. Deep learning also requires commitment from the student, and for this reason, the gaming industry have

invested a large amount of effort into getting players to commit time and effort into their play activities, the challenge for educationalists is to tap into the same feelings, getting students to devote the same time and energy into learning.

Students learn more, and enjoy themselves more, when they are actively involved, rather than just passive listeners. Passive mode learning may seem the easy option for the students in the short run, everything is prepared and you just sit back and let it wash over you. Students who are not brought out of this passive state will usually learn little of the material thus presented, and will then tend to blame the tutor, for their lack of understanding.

B. Telling a story

Storytelling is by many referred to as "the original form of teaching". Storytelling is one of the most effective techniques for conveying information in a compelling and memorable way. Bielenberg[7] describes an experiment where students learned with stories and clearly remembered the facts better.

- Stories can help provide a structure for the information
- Stories can communicate information at several levels at the same time. “A story can simultaneously provide a context for the learning task, teach deeper cultural messages, give an emotional impression and ultimately help tie learning to personal experience.”
- A story can also be a powerful motivation to keep going, and find out what happens next, thereby helping the students to complete a course.

Adventure and role-playing games use the concept of stories to give the player a feel for the environment and to drive the game forward. The games use the stories in the same way as outlined above, providing structure and keeping the players going.

The inclusion of learning material into a games environment can be done using different techniques and levels of embedding. The authors have previously performed experiments with learning material layered on top of a games environment. The results from these experiments suggest that layering the learning material on top of a game is quick and inexpensive, and the environment and the game-play aspects within such an environment may be acceptable, while the engagement with the learning material is not. The experiments suggest that a greater level of sophistication is required in authoring learning materials into game-play to achieve player acceptance and hence augment learning[8].

The technique used when modelling the learning content in this environment is to utilise the learning content as the game content. The task set for the students requires them to progress through tasks in the learning material. There are no game play elements in the environment which are not closely linked to the learning material.

C. Hard fun

Csikszentmihalyi[9] introduced the concept of flow, through a study of people involved in activities such as rock climbing, chess and dance in 1975. He describes flow as a state of complete absorption or engagement in an activity and refers to the optimal experience. According to flow theory, flow can occur when an activity challenges an individual enough to encourage playful, exploratory behaviours, without the activity being beyond the individual’s reach. Flow has been shown to have a positive impact on learning, see Galarneau and Kiili[10,11].

Many people are advocating taking the hard work and discipline out of learning. However, we would argue that this is not the answer. Rather, what we should be doing is finding tasks that will harness the passion of the student to take on the hard work needed to master difficult material.

Therefore, one main aim for us as designers of learning material is to design content in such a way as to allow different students to obtain the state of flow, irrespective of their different knowledge and abilities.

D. Social Relations in games

Social relations between students during learning are an integral part of the authors’ philosophy for learning. Manninen[12] has shown that the communicative aspect of current multiplayer games is enabled by a relatively limited set of interaction forms. The communication between players in the prototypes described in this paper is mainly via IRC. But the avatars do also have a limited set of emotions they can express within the environment. Studies by Kolo and Baur[13] have shown that many players not only connect to a online game in order to play but also to stay in contact with the fellow players. Many players also connect to fellow players via messaging systems during game play. They engage via their characters in various social interactions from trading or fighting to entertaining other characters. Many players regularly meet the same characters online and address a relatively fixed group of playing partners. Kolo and Baur have also shown that knowing and meeting people in an online environment or game triggers frequent playing and not the other way round.

Students meeting face to face after a game session will continue to discuss the stories that have unfolded in the game environment, and they will naturally continue to discuss other topics that were discussed during game-play. More information on this topic can be found in the previously published design for a learning environment by the authors [1].

III. Game Based Environment

In evaluating the prototype, the authors sought to gain information on several areas, primarily:

- Do the students feel playing the game improved their knowledge, and does it actually improve their knowledge?
- Do they enjoy this form of learning, and do they find it useful?

A. Structure of the game

In our game-based learning environment the subject area is divided into topics and subtopics, which are then modelled as levels within the game.

The different levels contain multiple quests, each representing some areas of material that the student should learn. These quests will model the learning material within the context of the game. The quest format is founded on the simple principle of setting a task for the player and then rewarding them on the successful completion of that task. If the player does not succeed, the option is to go back and try again. The prototype is set in an online multi-user game where all the different players are present in the same virtual environment, giving them a possibility to help each other during the game. During a quest the player can be given any amount of help, since the aim of the game is to learn, not to determine if the students are capable of learning on their own.

In addition to helping each other, there are inbuilt characters in the game, referred to as NPC's, that will help students along and supply them with pointers to information needed to solve the different quests. This information can both be found inside the game or can equally well be obtained by any other source, text book, internet, fellow student, online or offline. As identified above, the aim of the environment is not to control where the student is obtaining the knowledge, just to aid them in learning. This is particularly important in relation to game-play, as players will often use "cheats" obtained from sources outside the game to progress past a difficult problem or onto a next level. In this instance, the "cheats" would involve learning the concepts the game is seeking to instil in the players, so this encourages the use of multiple sources of information, improving learning skills.

B. Learning content in the environment

The prototype was created specifically to be run as an addition to a second year module in analogue electronics. The lecturer for the module had previously identified areas where students in previous years were struggling and felt that any additional way of presenting this material would be beneficial.

A large part of the module is devoted to give the students a deeper understanding of the relations between voltage and current: Ohm's law. The authors have observed that students seem to have difficulty progressing from the very simple uses of Ohm's law. They therefore face challenges in understanding, for instance, how a voltage drop over a resistor affects the voltage potential in a circuit. The purpose of the game is to make students work towards a goal, making up the route to this goal of several steps similar to the tasks they normally would undertake in a class setting, solving the same overall task.

One of the main requirements for the game is the possibility of accepting several correct solutions, which is normally the case in the real world. In a traditional class setting, the students are presented with a single solution, and may be told that other solutions also exist but they have a limited ability to explore these solutions in a lab setting.

The starting point of the game is a situation where the students have access to a bicycle generator, and several electronics shops where they can get different components.

The task is to build an advanced charger for their mobile phones, utilising the bicycle generator as the power source for that charger. To complete the task the students have to start out by buying discrete components to build the different parts of the charger. There are a number of different steps which must be fulfilled to assemble the complete charger. Several of these are dependent on each other, while others are independent, based on the discrete components, thus allowing the students the freedom to explore the learning material on their own.

The students assemble the circuit in the different steps. Each of these steps contains elements that make it possible for the students to select both wrong and correct solutions, as in the real world. For instance, when assembling a voltage divider, choosing resistor values that are too small will result in a circuit burning up, while choosing values that are too large will result in excessive output impedance, and a useless circuit. Within these limits, there are several working circuits, which the students should be able to calculate. If the number of different resistor values is large enough, the simple trial-and-error strategy would be impractical and the students are placed in the position of having to utilise Ohm's Law to achieve a successful outcome. The students will face three different outcomes for the voltage divider: The circuit burns up; the circuit doesn't work (due to high output impedance, or wrong resistor values); or the circuit works correctly as desired. The students can attempt to solve the problem as many times as they wish, but as noted above the range of outcomes will exceed most students' willingness to just guess the solution, and we are reasonably confident that a successful solution will represent appropriate application of Ohm's Law.

1) Structure of the content

The game is made up of steps. These steps consist of simple electric circuits. The participants build these circuits on their own, using the components tray acquire in the in game shops. Some steps are made up of several intermediate steps. In order to construct more complex structures, some of the later steps are dependent on the fulfilment of preceding steps, while others are completely independent. There are several ways to progress through the game, Se Fig. 1.

As stated above, the students are instructed to build charger for a mobile telephone. The charger is simply a voltage regulator, shown in fig 2 as a block diagram.

In this block diagram the control element is simply a large transistor, while the voltage reference is a series connection of a resistor and a zener diode. The sampling circuit has an equally simple construction, with two series-connected resistors. The error detector consists of three different amplifiers: a differential amplifier, a small signal amplifier and a class B power amplifier.

In this way the tasks to be completed are divided into different building blocks. Of these, 6 can be built using only discrete components, which are available for the participants. This means that a player can start building any of the 6 units at the start of the game. These starting points are shown with bold frames in fig.1.

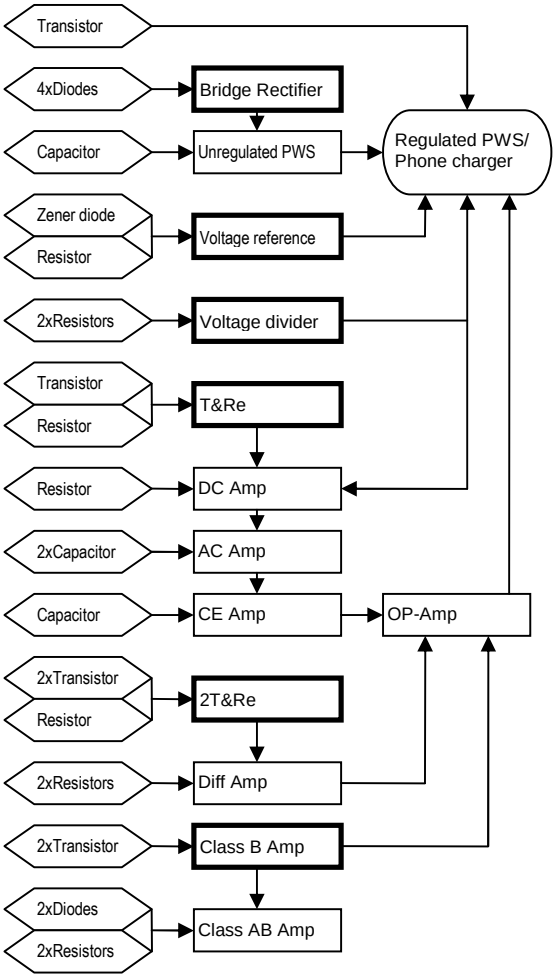

Fig. 1 Structure of game content

The error detector (OpAmp) can only be built after the three amplifiers have been completed. The construction of the last step (the constant voltage charger) can only be started after all the other steps have been completed.

This scheme is thought to give the students a thorough walk-through of the design of a stabilized power supply, including all the important calculations and considerations.

C. Gameplay and content

The participants start out as stranded on an island. The first person they meet gives each of the participants a mobile phone – with an empty battery. There is an old bicycle with a generator and this can be used to charge the battery. All the components needed are available through a number of shops on the island. The task for the students is to use their skills and knowledge to assemble these components into something useful – such as a phone charger. If the students lack some part of the knowledge or skills, they will have to to acquire this, either through the material embedded into the environment, by getting help from fellow students, or by going to sources outside the environment. The assembly of this phone charger (which is actually no more than a voltage regulator) is the main goal of the game.

In order to get access to the components, the participants are given a small amount of money at the start of the game. This can be used to buy components from the shops. For the game to be more realistic, the components are priced proportionally to what is expected in a normal (real-life) shop.

Fig. 2 shows the outline of how the voltage regulator should be assembled.

1) Voltage divider

The participants are told to make a voltage divider that gives out half of the input voltage. The testing the voltage divider would return burnt plastic if the resistance is too low, or a useless circuit of the output resistance is too high.

2) Voltage reference

The voltage reference is assembled from two different components: A resistor and a zener diode in a series connection. Although the circuit seems simple, the calculations are not. There are three possible outcomes when this assembly are brought in for testing: Burnt plastic, not working or, the desired, a working circuit. A too low value on the resistor would lead to burnt plastic, while a either too high value of the resistor or a wrong value on the zener diode would lead to a non-working circuit. In order to find the correct value of the resistor, the power rating of the resistor, the maximum input voltage, the power rating of the zener diode, as well as the knee current of the zener diode all has to be taken into account. In order to find the correct value of the zener diode (there are three different voltage levels to choose from), the relation between the voltage reference and the sampling circuit has to be understood: When the correct output voltage of the voltage regulator is achieved, the output of these two sub-circuits should have the same voltage.

3) Differential amplifier

The next natural step is to assemble the differential amplifier, although any of the three next steps can be done in any order. The differential amplifier is assembled in two steps. First two identical transistors are combined with a resistor. This resistor will be the common emitter resistor for the two transistors. This assembly gives a new unit, which in turn can be combined with two identical resistors that gives the two collector resistors. In the first step, the one resistor should have a value between 1kohm and 6.8kohm. If the resistance is lower than this value, the tester will return burnt plastic. If the resistance value is higher, a non-working circuit will be the result. In the next step, any values lower than 10kohm will return burnt plastic, while values larger than 68kohm gives a non-working device. Anything else is OK.

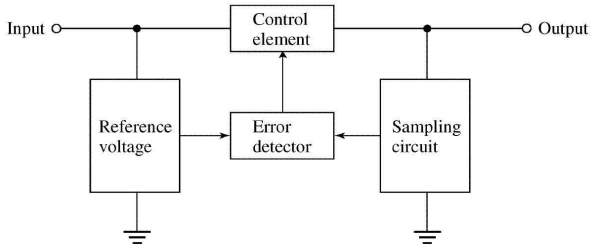

Fig. 2 Voltage controller

4) Voltage amplifier

The voltage amplifier is based on the voltage divider made earlier, in combination with a transistor of any kind, and two resistors. While this is done in two steps, the actual testing is performed on the final assembly. In order to differentiate between the collector resistor and the emitter resistor, it is stated and assumed that the emitter resistor is added first of the two resistors. Any resistor values between 1kohm and 10kohm are considered OK as long as the emitter resistor has a lower value than the collector resistor. Any resistor having a value below 1kohm gives burnt plastic. Anything else gives just a thing that does not work.

This circuit is further enhanced into a normal common collector amplifier by adding capacitors within certain bounds. Choosing the wrong capacitors cannot lead to burnt plastic, but the not working circuit.

5) Power amplifier

The power amplifier is supposed to be a normal class-B amplifier. This is simply made up of two complementary transistors and two identical resistors. The resistors should not be too small, nor should the transistors have two low current limits. This would lead to burnt plastic. Anything else having two complementary transistors and two identical resistors, gives a working circuit.

These three circuits will be combined to form an operational amplifier, and as the preceding steps are completed successfully, the assembly is assumed to be OK. This represents the error detector in fig. 2.

As a small sidestep, the players are encouraged to build a class-AB amplifier, and present this to “The Lone Guy somewhere in the hills around here”. If done correct, the prize is a very special t-shirt for the avatar and a piece of silver.

6) Rectifier

In addition to the circuits above, a rectifier circuit is needed. This should also have a filter capacitor of a certain size. The rectifier should be a normal bridge rectifier, and it should be able to handle a relative large current. This means that the only circuit allowable here is four diodes of the highest rating available. This should be combined with a capacitor with value no lower than the two highest capacitances available.

7) Differential amplifier

The next natural step is to assemble the differential amplifier, although any of the three next steps can be done in any order. The differential amplifier is assembled in two steps. First two identical transistors are combined with a resistor. This resistor will be the common emitter resistor for the two transistors. This assembly gives a new unit, which in turn can be combined with two identical resistors that gives the two collector resistors.

Fig. 3 In the shop

8) The final assembly

The final assembly according to fig.2 can be made, as all the elements are completed, in addition to the control element transistor. It is again assumed that as long as all the preceding steps are OK, so will the final assembly be.

IV. The Trials

A. The game

The development setup in this game followed on from the setup described in our previous studies.[3,14]

Below are shown some screenshots from the prototype. Fig.3 shows the student acquiring components from the shop. These components are later used in the construction of circuits. The other windows shown are starting top right and going clockwise: map, crafting, inventory, shop, chat, macros and messages from the system. Fig.4 shows the journal, specifying the current task, and their work window (Inventory).

Fig. 4 Working on assignment

In the prototype, the players have several ways of getting help. The first source of help will be given by the system. As the players are given a task, they are given a minimum amount of information apart from a problem description. Upon visiting the quest giver again that will either receive a small piece of information and/or a hint of where to find more help on solving the problem. This more help may be inside the game in the form of a wise man or looking up some web address, or simply a direct pointer to a chapter in the textbook. There has never been the intention of the authors to model all learning material inside the game. The game is intended to be a trigger and a driver to learn, not to be the sole source of information.

B. The experiment

The students in the second year electrical engineering degree at the authors university was offered the game as an addition to the usual activities such as lectures, laboratories, and tutorials in a module on analogue electronics.

The game was introduced to the students in a tutorial and they were free to download the game to their own computer for both online and stand alone use. It was not an requirement for the students to use the game, the students was encouraged to use it and the week after the introduction to the game there were no other activities scheduled, giving the students ample time to try out the game. It was observed that nearly all the students elected to install and try out the game just after the short introduction was complete. Due to fact that the students had an option for offline use of the game usage statistics from the game server are not reliable, feedback from the students reported that a significant amount of them had attempted to complete the game.

A note here is that in this trial, as in previous trials, there is a particular group of students that are not interested in using the game, arguing that they don't enjoy games and feel it more efficient to concentrate on traditional tutorials. This group tends to consist of what can be referred to the stronger students. From a general viewpoint the fact that these students not using the game is not a problem, since these students probably will do ok and are not the main aim for this experiment.

C. Results from the trials

The topics covered by the content of the game have been given as exam questions for this module since 2007, and has been comparable in level of difficulty and area of questioning. The exam results for the years 2007-2010 does not show any significant change from year to year and the result s for 2010 has been used in Table I. Results for 2011 are given in Table II. The exam results, as shown in Table I and II, show that the students doing the game performed significantly better than previous years.

As previously mentioned the students doing the module the autumn of 2011 was introduced to the game in between the lectures, while the previous year students did not have access to the game.

TABLE I
EXAM RESULTS 2010

Result	No of students	Percentage
Fail	5	12 %
Average	3	7 %
Above average	11	26 %
Full sore, or close to full score	24	56 %

The exams results for the class in 2010 for the questions in the exam connected to material presented as part of the game.

TABLE II
EXAM RESULTS 2011

Result	No of students	Percentage
Fail	1	3 %
Average	1	3 %
Above average	8	24 %
Full sore, or close to full score	24	71 %

The exams results for the class in 2011 for the questions in the exam connected to material presented as part of the game.

For us it is especially interesting that the reduction of students failing the topic covered by the game (12% to 3%), as this is was one of the stated aims of introducing the game: Getting the students who show less interest in the module, or are less eager or capable to study on their own to increase their effort in studying the module. There are also a marked change in better results overall in the topic covered by the game.

The students of the year 2011 were the first to break the continuous trend of 20-30% of the students failing this subject, when less than 5% of the students failed the subject. It is the author's belief that this can in part be contributed to the game, as can be seen in the exam questions with topics covered by the game, and in part to other activities introduced into the module covering other topics. These activities are more traditional and cover other topics within the module and are not the topic for this paper.

V. CONCLUSION

The aim for this experiment is to show a prototype for a system that utilises games-based technology to support virtual learning environments that are constructivist in nature and utilise narrative for the learning process and assessment included as a continued process during the learning, and to show that this, when used by the students has a positive impact on their learning. The experiment has shown that a group of students that are given access to a computer game with learning content as their tutorial show improved results in the exam compared to previous years groups.

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