

# A Game Design Framework for Vocational Education

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**Abstract**—Serious games have proven to be a useful instrument to engage learners and increase motivation. Nevertheless, a broadly accepted, practical instructional design approach to serious games does not exist. In this paper, we introduce the use of an instructional design model that has not been applied to serious games yet, and has some advantages compared to other design approaches. We present the case of mechanics mechatronics education to illustrate the close match with timing and role of knowledge and information that the instructional design model prescribes and how this has been translated to a rigidly structured game design. The structured approach answers the learning needs of applicable knowledge within the target group. It combines advantages of simulations with strengths of entertainment games to foster learner's motivation in the best possible way. A prototype of the game will be evaluated along a well-respected evaluation method within an advanced test setting including test and control group.

**Keywords**—Serious Gaming, Simulation, Complex Learning.

## I. INTRODUCTION

SERIOUS games, or educational games, have been developed for several decades under many pseudonyms, notably *business* or *management* games [1] [2], *policy* games [3; 4] or more generally *simulation* games. They include physical board and role-playing games that are at most computer-assisted, as well as computer-based games that rely on (high- or low-fidelity) simulations of physical and/or social systems. Serious games are known for allowing players to experience a certain context or system from which players can subsequently learn.

Following Muehl and Novak [5], when serious games are used for learning and training purposes, the model of the simulation should be as realistic as possible to get the best results in preparing the trainees for real-life situations. For reasons of such knowledge transfer from the virtual to the 'real' world, it is of crucial interest to design a serious game that is very much a like the 'real' world, a so-called "there-reality" or real virtuality [6]. Transfer research emphasizes that transfer is effective when the trained skills have similar logical or deep structures in virtual and in real world [7]. Failure to achieve the 'right' level of realism holds the risk that the player adopts a 'wrong' or different strategy than needed in real life [6].

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This topic is also related to the term of fidelity, which defines the degree to which a game emulates the real world and can be substructured in physical, functional and psychological fidelity [8].

Serious games increase motivation when designed as problem-centered trainings. A problem-solving approach compels learners to think about the content, to organize and use the information through actively constructing meaning and helps building long-lasting memories [9].

In the Netherlands, as it is in many European countries, professional education comes at different levels of training. Much focus in the literature has been on game-based learning at the university and for professional education level, where students typically have to acquire insights into real-world systems, get familiarized with and sensitized for bodies of theory and need safe experimentation environments, typically in the business and management domain [10; 11].

At vocational levels of professional education, students are typically very practice oriented. Theory in their perception is only there to apply in 'the real job'. Overcoming the motivational challenges, gap between theory and practice and soloist behavior regularly observed amongst these students would benefit not only the students, but also society at large as the number of students in this type of education greatly outnumbers the university students. Applications of serious gaming at this level of teaching are less common. Often they are a derivative from the approaches in higher education. However, different theories on learning apply at the different levels of education (see for an overview 12).

This paper describes a design approach developed for serious gaming for vocational education based upon the 4C/ID framework by Merriënboer et al. [13; 14] that handles what he calls 'Complex Learning'. His framework is ideally suited and widely accepted in the area of vocational education for technique-based professions.

Section II describes the complex learning framework with focus on the parts that are important for game design. Section III elaborates on the vocational education setting for serious gaming and introduces our test application area of mechatronics. Then we introduce our design approach based on the complex learning principles. Section V discusses the differences between our approach and other design approaches in the literature. We end with conclusions and further research to sketch the steps towards a full-loop testing in practice.

## II. COMPLEX LEARNING

Not only professionals, but also trainees in vocational education experience the increasing need of a strong relationship between theoretical knowledge and practical work. Work related and practice oriented learning and training

asks for specific design of instructional interventions to support the application of knowledge on practical tasks. The field of constructivist learning design with focus on problem solving [15] and the work on design principles of instruction by Merrill [16] are examples for instructional approaches as answers to these particular learning needs. The approach of complex learning, with its so-called 4C/ID model [13, 14] addresses three deficits of other instructional design models, which was the reason for us to choose this model as design guideline for the serious game.

First, this model focuses on the integration and coordinated performance of task-specific skills rather than on knowledge types, context or presentation-delivery media [13]. Starting from task-specific skills is a well-suited approach for vocational education in the technological domain. Second, the model provides a difference between supportive information for routine actions and just-in-time or procedural information, focusing on the performance, not on knowledge [13]. In designing a learning system like a serious game, one can use this distinction for embedding distinct types of information into the system, adjusted to the different needs of the learner. Third, the model recommends a mixture between more simple part-task and complex, whole task practice to support whole-task learning [13]. By following this advice, a combined approach of simple and complex problem solving is achieved with the main aim to support complex learning skills.

The idea of combining different levels of activities and learning is the basis of the 4C/ID-model of complex learning. It indicates that different skills are related to each other. The horizontal and vertical relationships between tasks of the same or a different difficulty level have to be taken into account when designing an instructional intervention like a serious game.

In general, the design model for complex learning described here, delivers four essential components for the design of learning environments, namely learning tasks, supportive information, procedural information, and part-task practice [13; 14]. In part IV, we describe in detail how these components are applied to our game design model. Primarily, we introduce the position of serious gaming in (vocational) education, the particular target group of our game and the setting in which the game takes place.

### III. SERIOUS GAMING IN VOCATIONAL EDUCATION

There are a number of definitions of serious games, the much broadest one includes all games with more than only the purpose to entertain, e.g. to train, support decision making or situational awareness processes. For many researchers and designers the term serious game has thus become an umbrella term for educational games, including simulation, business or policy games [see e.g. 17]. Serious games used for learning and training purposes transport instructional content that the learner should use in order to achieve intended learning goals, and that can be classified into four types: facts, procedures, concepts, and principles [18]. For our case, facts and concepts are the most important, but mechanic mechatronics also need knowledge of physical principles. Games offer a friendly

environment where students are able to play, probe, make mistakes and learn [19]. Serious games have some advantages compared to other technology-enhanced learning environments. Traditional e-Learning environments, which are packed with a huge amount of learning content, often fail to attract and motivate students using the material [20]. The dropout rates of some systems were enormous. As a result, new web technologies, first of all Learning Management Systems [21], were introduced to foster technology-enhanced learning by offering communication mechanisms, interactive and multimedia content, and context adaptive settings [22]. Serious games make use of visual, textual and auditory channels for feedback, challenges, and further components. They enable the player to enter fantasy worlds [9], together with the opportunity of a strong relationship to the real world.

Serious games are often applied in higher education and in business trainings, for example in health or safety settings [23]. The game described here is developed for technical vocational training, taking into account the specific target group of mechanic mechatronics. Typically, a mechanic mechatronics has to undergo a two years initial vocational training at secondary level. One of the important issues of designing the game is thus to keep it interesting and motivating over a period of two years. The students typically are around 16 and 17 years old and male (percentage of female students: 1,4). The daily work of a mechanic mechatronics is quite technical, and requires practical experience as well as profound knowledge of basic principles of mechanics and electronics. We assume that practical experience of machine use and crafting is best trained in practical settings, so the serious game developed is meant to complement the theoretical parts of the vocational training. For using the right machines in the optimal manner, mechanic mechatronics have to learn knowledge patterns, which are based on procedures and practical tasks. The game will cover different knowledge areas within different projects or levels, which are designed along the 4C/ID model for complex learning. We will describe this in detail in Section V.

### IV. PROJECT SETTING: MECHATRONICS

The authors jointly run a game design project in the domain of mechatronics education. The project is owned by a branch education institution, which involved a research organization, and a serious gaming studio. The education institution brings in the knowledge of what to teach to whom, the research organization the knowledge of design theory and evaluation, and the studio the design and technical know-how.

The project aims to deliver a game that lasts for 2 years, to be played during the full vocational education curriculum with 400 hours for playing the game within the two years. The first domain for application is the mechatronics program, a coherent program with components from metal works, electronics, pneumatics, hydraulics and logic/programming. Typically, the students find work as construction or service operation employee. The current curriculum is a combination of theoretical classes, taught in traditional classroom setting by a teacher, and practical classes in a learning work shop setting

that has all machines available. The game will replace a large part of the traditional theoretical classes by providing an active virtual environment in which the student will get the different sources of information at the right time and in the right format. An interesting game play should facilitate the constant participation of the students during 2 years. The practical classes will not be replaced, but enriched with content from the game. The main idea is that the student first makes an assignment in the game and after successful completion in the game will go to the physical learning workshop to accomplish a comparable task in real life. Therefore the game design does not only involve the game environment, but a full learning environment, including coupling with reality to actually facilitate the knowledge transfer.

#### V. DESIGN APPROACH OF A SERIOUS GAME BASED ON COMPLEX LEARNING PRINCIPLES

The approach we follow in the design aligns closely with the Merriënboer 4C/ID model on complex learning. In Section III, we already introduced the structure of this model. Our design approach follows the same structure, but some changes are made due to the specific needs of the target group.

The 4C/ID model focuses on the integration and coordinated performance of task-specific skills rather than on knowledge types, context or presentation-delivery media [13]. In the design method we translate this to a focus on what the student has to do to successfully finish a construction assignment. We created a nested approach in which any construction assignment can be split up to singular actions of the order of magnitude like 'select the correct size of bolt' or 'screw bolt X on screw Y'. Fig. 1 shows the nested design of Project, Task, Assignment, Procedure and Step.

Second, 4C/ID provides a difference between supportive information for routine actions and just-in-time or procedural information, focusing on the performance, not on knowledge [13]. In the game design there is a plethora of sources of information available. At the level of the Project, Task and Assignment, the player can get supportive information for routine actions. At the Procedure and Step level the player can get just-in-time and procedural information. In the definition of the procedures and steps the game designers set links to an existing expert system for the mechatronics sector, so that currently available and validated information can be re-used in the game. The aim of the combination of this part of the 4C/ID approach with knowledge patterns provided by the expert system is to "teach" the players to think like an expert. With the combination of supportive and procedural information, the user will get "just enough" information just-in-time, which is prerequisite to the learning and performance of the students [13] and where information can best be understood and used in practice [19].

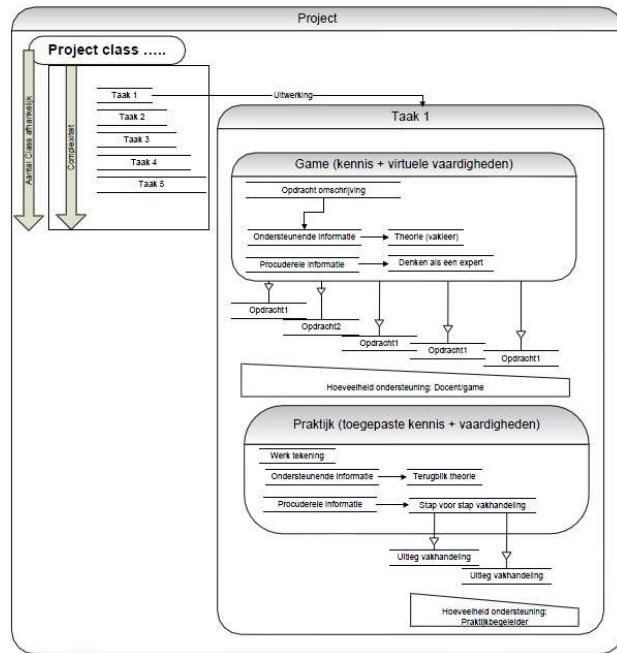


Fig. 1 Nested structure of game assignments

Thirdly, 4C/ID recommends a mixture between more simple part-task and complex, whole task practice to support whole-task learning [13]. In our game design method this is implemented through the nested approach, where in the game-play the participant navigates up and down through the complexity levels. Both automated (through recognition of the level of the participant) as well as manually, the player can pursue procedures in a step-by-step or in an unguided fashion.

Moreover, our approach to game design combines advantages of educational simulations with strengths of serious games. The game consists of two parts, which are strongly related to each other. The more educational, or simulation part of the game, represents a work place of a mechanic mechatronics. The environment is situated in a machine hall, containing all machines, tools and materials a real workplace also includes. It shows a high level of physical and functional fidelity. In the workplace, the students have to accomplish the projects that are designed along the 4C/ID-model of complex learning.

Strongly connected with this is the sandbox of the whole system. Here, students can use the work pieces tailored in the workplace. With accomplishing a task in the workplace, students will get a work piece or a reward to be used in the sand box. The sand box represents a leisure park with several attractions. Students can use their work pieces to develop their very own attractions like a roller coaster with water sprayers and individually shaped courses. Rewards can be used to buy additional underparts or to try out other students' attractions. This combined design approach is meant to answer the need of high functional and physical fidelity of a simulation game, simultaneously combined with a motivating fun-part of the leisure park sand box. Students always can enter and individually create own content, thus turning into producers of

the game instead of remaining simply consumers of any learning content [19]. The useful rewards are working as immediate feedback and thus also foster the motivation of the students [9].

A third part of the simulation game is meant to support student activity and navigation through the simulation game, to foster group activities and to enable teachers to assess the learning progress. This third part is called the profile page, which also functions as log-on page for the students. When logging on, the student can view his or her progress within the game, thus has an overview of the progress in the learning content. The student can choose whether he or she will progress with the next step in the game or to re-do any level again. Moreover, the profile page shows how many "points" the student has collected for the sand box. It will also provide access to a communication tool, like a mail or chat function.

#### VI. DIFFERENCES WITH OTHER DESIGN APPROACHES

In section II, we already showed the advantages of the 4C/ID model as design approach for a serious game. Nevertheless, this approach has not been used for designing a serious game before. Compared to other game design approaches, we still see quite some benefits of this approach.

A recent game design approach, the triadic game design model [24; 25], focuses on the three dimensions of reality, play and meaning of a serious game and illustrate why design dilemmas and trilemmas between these dimensions make it difficult to balance a serious game. It represents a very deep discussion of theoretical concepts. For our own project, this design approach seemed to us to be too abstract to put a game into practice. Furthermore, we needed an approach to transfer practical tasks and related knowledge into a long-lasting, complex simulation game system. The triadic game design approach offered no solutions to this specific problem.

The work of Kriz and Hense [10] discusses design and evaluation issues of simulations and games. Although they introduce a logic model of a serious game with input, process and outcome-variables, the model is very much focused on the ex-post evaluation of a game, seen as an intervention. The logic model provided is very abstract and has to be filled with individual criteria for each simulation game. Its aim is to gain evaluative knowledge on one particular gaming simulation [10], but the model does not contribute to an instructional design model for a serious game.

The contribution of van Staalduinen and de Freitas [26] gives insight in the relationship between learning theories and game design. Based on distinct instructional theories, they present an overview of game elements and their contribution to learning. Furthermore, a game-based learning framework is introduced, which serves as "a checklist and a reminder for designers of serious games" [26]. The framework shows aspects as learner specifics, pedagogy, representations and context, but it does not prefer any specific instructional approach. Eventually, it has not been tested yet.

#### VII. CONCLUSIONS AND FURTHER RESEARCH

The authors introduced a game design framework developed for vocational education application of gaming simulations. The design is based upon the 4C/ID framework by van Merriënboer [13; 14] that has a proven value for vocational education design. The close match with timing and role of knowledge and information that 4C/ID prescribes translates to a very structured game design. The framework is expected to yield games that have a closer alignment with the vocational learning goals of the teaching method(s) that a game might replace. The clear structure and recognizable tasks, steps and actions should lead to fast acceptance of a game amongst teachers, even if they are not familiar or positive about gaming for education in general. The lessons organized around a game based upon our framework can have a clear delineation, something that is often hard to do with current games.

The first application of the framework is a game for mechatronic construction education in The Netherlands at the vocational level. The first game prototype will be ready in Summer 2012. Next steps will also be to apply an evaluation model, based on Millers pyramid of competence assessment, to the simulation game. It will be tested within a setting with a user group and a test group. Both groups will get the same assignment at a three-days workshop. While the user group will play the game to learn about the assignment, the test group will get traditional, classical teaching. Observation and evaluation of the test will show how effective the game is at transferring the needed knowledge in mechanics mechatronics education.

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