Mecagenius®: An Innovative Learning Game for Mechanical Engineering*

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The present paper provides a description of Mecagenius®, a learning game to teach mechanical engineering at an engineering faculty. Firstly, the Mecagenius® game and learning content are introduced before practical ways of integrating this application in educational activities are explored in relation to the skills the teacher seeks to transmit knowledge. This is followed by a review of the literature on the educational effectiveness of serious games. Secondly, the learning game experience of Mecagenius® on a course is reported, providing evaluations from both students and teachers. Interviews with teacher and students together with the collected computer records allow for an assessment of the advantages and drawbacks of teaching and learning with this kind of tool. Through a qualitative analysis of students' game reports, the different strategies used in this educational environment are assessed.

Keywords: Serious game; learning game; learning; mechanical engineering; higher education; Mecagenius®

1. Introduction

Today, industrialists are confronted by the increasing complexity of their work environment and activities with the globalization of their markets, the geographical dispersion of industrial partners, pressures related to costs, the proliferation of information, reduced time to market and the emergence of co-designing practices involving suppliers. This has gradually led to Business Process Outsourcing, one of the most significant changes in design practices to have taken place during the first decade of the 21st Century and as experienced by many different professions [1]. Training the students who are to take on these challenges in their future professional lives in mechanical engineering has become increasingly difficult as a result of all these changes. In the fiercely competitive and global world of manufacturing on NC machine tools (NCMT), businesses have to produce ever more complex workpieces at ever greater speed without additional cost to the customer. Machine tools have become increasingly complex and costly both to acquire and to operate in order to guarantee manufacturing quality while also reducing machining time. In addition, the apprenticeship periods on such machines are now longer, making operator training more expensive. To further exacerbate matters, enterprises working in this competitive sector suffer from recruitment problems due to the decline in the number of applications to study science and technology degrees. In France, training in mechanical engineering suffers from a real image problem despite the fact that there are good job opportunities in the sector. In 2011, GIFAS (the French grouping of French aeronautical and space industries) announced that there were 13,000 highly qualified job creations in France but that 3,000 more could readily have been filled if the sector had not had to face recruitment problems. In order to respond to a real societal demand, it thus appeared to be a matter of urgency to ensure that training evolves towards new innovative and effective teaching aid products compatible with the high level of technical knowledge required in the field. Thus, to answer to the needs of the market and acquire a competitive edge, it will be useful to create artefacts tailored to the needs of the new generations (the so-called Y-generation), strongly imbued with a digital technology culture [2]. This explains the emergence of the learning game Mecagenius® [1], the fruit of combined efforts by computer specialists, mechanical engineers and didactics experts. This multidisciplinary project was financed in part by the French Ministry for the Economy, Industry and Employment within the scope of the Serious Gaming Call for Projects (Secretariat of State for the Digital Economy, 2009). The consortium now brings together one enterprise[2] as well as a number of research teams working in the complementary

[1] http://mecagenius.univ-jfc.fr/fr/accueil

disciplinary fields of mechanical engineering[3] and information technology[4], and learning game, e-learning[5] and didactics[6] specialists. One of the innovations involved using the possibilities offered by digital technologies to combine the mechanics of gaming and learning within a virtual workshop.

Innovation in terms of research within the project does not merely reside within the design of the learning game Mecagenius®. By stimulating the desire to appropriate knowledge, this innovation is also likely to convince a broad swath of students averse to existing teaching methods and much more in phase with their definition as "digital natives" [2]. Serious games have really taken off over the last few decades and now show a growing number of initiatives; solutions have already been successfully tested and deployed in various other projects and fields [3–5]. But the innovative feature of the present project also lies in its implementation and integration for apprenticeship purposes. The question we sought to address was as to whether it is relevant for students and teachers at an engineering faculty to use Mecagenius® as a factor to facilitate learning and so boost the potential for all involved to accede to mechanical engineering apprenticeships. Indeed, a gradual mutation in teaching and training skills can be observed. The role of the teacher is evolving and, through the serious game, involves finding or creating the resources best suited to attaining the set objectives, making them more readily accessible to learners and integrating them through relevant scenarios. It appears necessary to accompany the stakeholders out in the field in deploying Mecagenius® so as to help them make this new method their own. A certain number of tools and instruments able to answer to these needs therefore had to be constructed. The specific nature of this experimentation is precisely in that it brings learning game designers, researchers in didactics and professors from an engineering faculty to work together on the same project. The objective is to get real participatory innovation based on integration of the Mecagenius® learning game going within a proven training curriculum at an engineering faculty.

2. Mecagenius® presentation

2.1 What is the learning game Mecagenius®

The term Serious Game refers to games whose primary goal is other than mere entertainment [7]. The objective of serious games is to teach or learn while also having fun thanks to computer applications [6]. The final goal of a serious game is to learn, but the fun side acts as a catalyser. It transforms apprenticeship by contributing the two fundamental ingredients of pedagogics: action and emotion. The learning game could well be defined by the following equation:

Game + Teaching Scenario + Feed-back = Learning Game.

Mecagenius® is a learning game designed to discover a manufacturing workshop, learn to implement NC machine tools, machine workpieces and optimise production. Mecagenius® fosters active apprenticeship in an immersive and interactive virtual workshop. The students have the opportunity to discover the basic concepts of manufacturing and mechanical engineering. The 216 teaching activities scripted in Mecagenius® were designed by teaching experts and were studied to guarantee success in the learning process.

2.2 Mecagenius® design

The design of Mecagenius® relied both on skills baselines, the needs expressed by mechanical engineering professors and many years of teaching experience of a panel of teachers. Priority was given to design centred on the end user of the tool and right from the start the experience of mechanical engineering professors was integrated into the design process [8] while also remaining open to technical progress in the mechanical engineering field. Mecagenius® is a learning game to serve classroom apprenticeships with the overriding goal of teaching the key concepts of mechanical engineering, learning them while also having fun. The apprenticeship process is intended to be game oriented and interactive. A fictional universe some time in a relatively distant future was imagined from the real life context of a mechanical engineering industry situation. The scenario hinges around a wrecked spacecraft having landed on an unknown planet. Various missions are assigned to the players as they take part in mini-games where equipment and materials are awarded for good performance so they can manufacture parts to repair their vessel. Mecagenius® offers more than two hundred activities with their accompanying scenarios inside three great chambers in the crashed spacecraft. Players are led to explore one after another of them to carry through their mission. First they have to acquire a minimum level technically and enough money to invest in using the machine-tools and obtain the various rewards needed to move on to the next chamber The player will find all the conventional elements of a game, with scores, levels, experience bar, talent tree, number of lives, stopwatch, etc.

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The designers favoured apparent freedom of interactions to acquire experience that can later be brought to bear in the real world of the workshop. Mecagenius® can be seen as a virtual companion to apprenticeship through action in the process of producing a technical artefact. Its design uses Adobe Flash technology for greater accessibility and offers more than two hundred scripted activities, each lasting three minutes on average and covering all levels of training (beginner, intermediate or expert) for machining operators through to qualified engineers. For each level, activities are organised in line with a pre-established educational trail whose parameters can be set and that can be adapted to various training contexts. Two modes of utilisation are offered. The first, in game mode, follows a narrative scenario where the learner is guided through the three main rooms of a space vessel that has crashed down onto a remote star with ten models for activities. For each of them, a library of resources is renewed with each new use. In addition, customised teaching accompaniment is offered the learner according to the activity, with help and feed-back. The second mode of access is in training mode, with the teacher able to access all activities in a targeted manner, building his or her own emerging course structure in relation to the teaching context and the target audience. Mecagenius® also offers the teacher monitoring tools, as with the display of individual or collective results, progress monitoring, detailed marks after each game is completed and the overall scores achieved. The students-players can access their own profiles that give a summary of the activities performed in each category (see Fig.1).

2.3 Examples of Mecagenius® mini-games

Mecagenius® allows various topics in the field of mechanical engineering to be covered, as with the identification and architecture of machine tools, running an NC machine tool, manufacturing methods and production. For example, in a mini-game relating to manufacturing methods (see Fig. 2), the

Fig. 1. Player-student profile.

Fig. 2. Manufacturing methods mini-game.

player must associate surfaces with machining operations (facing, turning, profiling and cutting) and sequence them to obtain the final workpiece required. According to the level chosen (beginner, intermediate or expert), various constraints can come in to make things more difficult, for example by asking the player to select the geometries or names of the cutting tools required to perform each operation.

Another example is provided by the mini-game relating to the architecture of the machine tools where the player has to recognise the typology of the machines by acting on the numerical controls and then matching the corresponding code with the XYZ/ABC axes. Here too, the level of difficulty will vary according to the chosen level, going up to 5-axis machine tools with 12 elements to be positioned on the reference (see Fig. 3).

2.4 Research into didactics on Mecagenius® uses

Advances made in digital technologies now offer teachers the opportunity to diversify the media they use for teaching purposes. One of the underlying postulates when using these technologies is based on the idea that present-day learners were born into the digital era, have mastery of a whole panoply of related techniques and are well versed in the use of hardware like the laptop, the cellphone and the game console [2]. Nowadays, the use of serious games in education is promising and can place students in an environment more propitious to learning thanks to a perfectly integrated combination of entertainment and educational content characteristics. Theories based on apprenticeship have highlighted the fact that students commit to the learning process and are encouraged to take part actively to improve specific educational outcomes [9, 10].

Within the scope of the present project, research work in teaching science involved firstly taking part in various stages in the design of Mecagenius® and secondly identifying and grasping the processes implemented by the stakeholders—the teacher and the students—when using Mecagenius® [11]. A new approach was proposed in the present study to take a closer look at the uses made of this learning game by the stakeholders as also the management of knowledge and development of skills within the scope of teaching and learning mechanical engineering knowledge and know-how. This work contributes to the construction of scientific knowledge in all its diversity and provides insights into the learning process adopted from an on-site analysis of the use of Mecagenius® in a teaching environment [12]. These action-based research works aimed to offer or use models, methods and tools to design, set up, run and analyse these learning scenarios. This involved emphasising the scripting of learning situations and their evaluation.

The initial exploratory educational science study was conducted in the Ile-de-France region and focused on the design and educational uses of Mecagenius® [11]. This experiment's educational objective was firstly to implement the methodological tools developed in previous research conducted into the ways teachers use Mecagenius® with their students. The present article looks at how educational strategies use this learning game in class work in order to explore the real potential Mecagenius® has to offer and then goes on to consider possible uses that may help improve our understanding of the learning mechanisms for the sciences in a real educational context. This first exploratory study was primarily designed to test the protocol for the next stage in the Mecagenius® experiment to take place in the Midi-Pyrenees and Aquitaine regions. Finally, this exploratory study represents one of the few hands-on experiences of its type in higher education engineering.

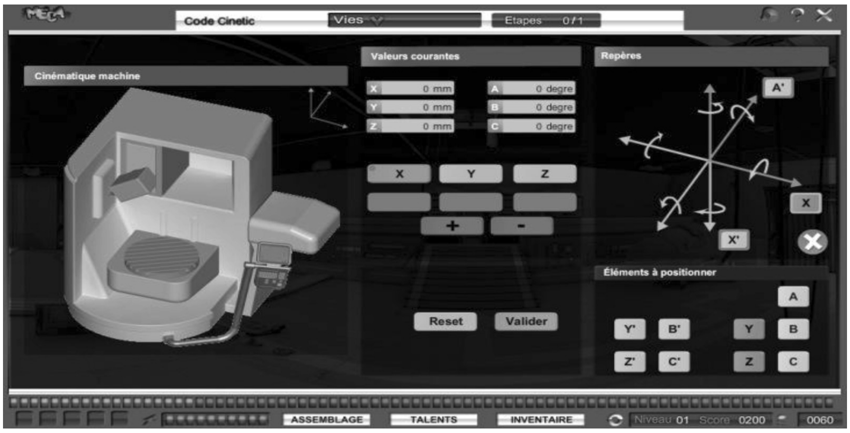

Fig. 3. Mini-game relating to the typology of NC machine tools

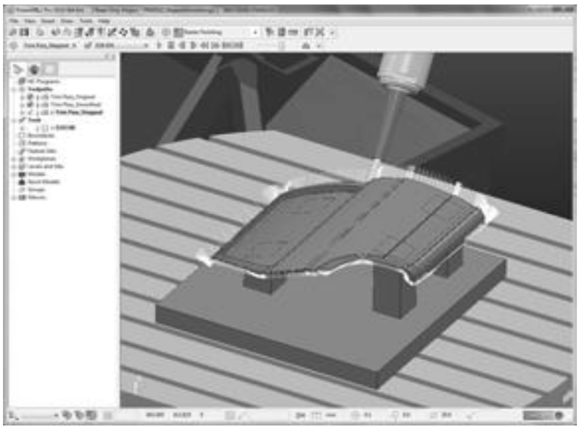

Fig. 4. Example of simulation in Powermill[7].

Fig. 5. Delmia machining[8].

3. State of the art

The present section introduces research work into serious games in the field of mechanical engineering and more precisely mechanical manufacturing by removal of material. Over the last few years, many research and industrial laboratories have developed tools to simulate the behaviour of a machine tool during the different stages in machining.

3.1 Machine simulation off-the-shelf tools

Within the scope of training sessions on NC machine tools, two types of simulators are now available on the market:

- The machine-based simulator: a calculator identical to the NC machine tool calculator considered controls displacement of a point on the screen, as it would control displacement of the tool during machining. This type of simulator can only simulate the machine under consideration.
- The software-based simulator (Fig. 4): using a virtual rough, a program simulates in computer form the various forms of machining sequences ordered by the CN program.

A state of the art provided in previous works [13, 14] gives examples of these different types of simulators. Sinutrain could be mentioned in this context for example as a simulator on a machine base. Meanwhile software based NCSimul and Vericut simulators can be used to display 3D animations on NC machining processes. In addition to validating cutter paths, they also allow programmed tool paths to be optimised by increasing the chip flow. These are tools to assist machining optimisation.

In addition, all CAM software routines include a simulation function for the machining programmed. The figure below reproduces a simulation with Powermill. Simulations with CATIA®, SolidWorks® or TopSolid® are of the same type. The objective in all cases is to allow a tool path to be validated, not to train the operator.

All these tools are NC machine tool simulation tools only and cannot be considered to be training aids. Nor is there any suggestion of a game aspect to their use. They do not therefore answer to our stated needs.

3.2 Virtual production off-the-shelf tools

CAD/CAM general software offers virtual simulation tools. Dassault Systèmes offers the DELMIA technology, a vision of the real world in 3D to create, validate and optimise activities in the workshop and production processes before physical implementation

Delmia machining aims to boost manufacturing quality by realistic simulation of machining. For example, Delmia assembly allows you to sequence assembly in the design phase or validate product upgrades in a process context. But Delmia is not a training tool. It aims at enhancing business profitability. Furthermore, it is addressed to expert users.

3.3 Simulation tools and serious game

These works share the objective of seeking to respond to the need to take into account the various parameters involved during the machining process. Two main types of NC machine tool simulators are available on the market; the machine based simulator allowing movements of the machine under consideration to be simulated and the software-based simulator that gives a computerised simulation of the various stages in material removal commanded by the Numerical Control (NC) program. The obvious advantage for the user is to be able to gain access to a world of extremely costly NC machine tools and be able test things out even in crisis scenarios (breakages, extreme conditions, etc.)

7 https://delcam.com/languages/de/news/press_article.asp?releaseId=918
8 http://www.3ds.com/products-services/delmia/products/nc-programmers/extended-milling-machining/

without the risk of provoking costly errors. A number of research papers [13, 15] stress the limits to such artefacts that merely simulate cutter paths through reading the program. They fail to simulate a machine as a whole even though they do help to provide a better understanding of the theoretical concepts. In addition, there is no fun side to these representations.

Looking at things from a teaching-apprenticeship perspective, simulators are not yet suited to remote training situations and still pose real problems of accessibility. They are also designed for experts in the field: only a technician with sufficient knowledge to use a real machine can really get to grips with the simulator. Although there is a wide range of developments covering NC machine tool simulation, few works address serious games in this area.

Extending the research perimeter, it can be seen that the only existing serious games mostly concern the mechanical engineering design field [16]. These sometimes include constraints in terms of total development cost, time and quality [17]. In some instances, undergraduate students in mechanical engineering are given the task of writing computer programs relating to a car race around a racing track [18]. No such serious games seek to consistently take up the models used by machine tool simulators. There also appears to be a lack of serious games working towards development of the skills required for mechanical manufacturing and machining. Over the last few years, innovative pedagogical solutions have been implemented within the scope of teaching projects [19, 20]. However, such projects are mainly based on collaboration between a number of students and the strategy for collaboration does not involve a game scenario.

Furthermore, there is a paucity of research work on the didactics of serious games in mechanical engineering in engineering faculties.

4. Pedagogical approach and experimentation objectives

This experiment concerned students at level L3 (third year university undergraduates) and level M1 (postgraduates in their fourth year at university) at Arts and Métiers ParisTech engineering school.

Various versions of Mecagenius® were developed. Each of them was evaluated to different degrees in a teaching environment. The industrial version of Mecagenius® provided the point of departure for experimentation in 2 French regions: Île-de-France and Midi-Pyrénées. This series of experiments was financed by these regions and supported by the local education authorities and Aerospace Valley and ASTech competitiveness clusters. Experimentation started in February 2013 and continued through 2014, in partnership with the Paris Arts et Métiers ParisTech Campus and a number of research laboratories devoted to mechanical engineering[9], didactics[10], psychology[11] and sociology[12]. The evaluation conducted allowed the various uses made of the package by teachers and students to be compended and helped in the development of digital teaching applications tailored to the needs of wide range of educational institutions. This collaboration helped achieve the final goal of building methodological tools for the full potential of this learning game to be realised.

The panel for the pedagogical experimentation of Mecagenius® as pursued on the Paris d'Arts et Métiers ParisTech campus was made up of 89 students at level L3 and M1 (respectively 46 and 43 subjects) (Table 1). The learning game was used in practical sessions lasting 7.5 hours for the undergraduate students and 3.5 hours for the M.Sc. students and the groups remained small (24 students maximum). The mean age was 21.7 years.

The 89 subjects represent a student population of diverse origins. The main training courses represented were BTS (technician's diploma), DUT (technology institute diploma) and preparatory classes for the Grandes Ecoles as well as some isolated degree courses (B.Sc., etc.). Table 1 shows that among the L3 population, there was a balanced distribution between people having already received instruction in mechanical manufacturing and the others: respectively 22 and 24 persons. In M1 training, a clearer preponderance of students never having practiced this subject can be seen: just 6 students out of 43 had some grounding in the subject. Overall, out of the studied population, it can be observed that 31% of students had prior knowledge in mechanical manufacturing and 69% had none. This diversity, which might have been interpreted as an obstacle for imparting knowledge, allowed the Mecagenius® tool's potential to be illustrated through the customised learning process it offers.

This training set-up was retained precisely due to the extreme variety of levels within the student year. This disparity in knowledge among the students is due to their different origins (as with the IUT Mechanical Engineering, BTS in Product Design, etc.). In teaching science terms, these differences meant that pedagogical progress had to be adapted to each individual. Mecagenius®'s extreme flexibil-

[9] Institut Clément-Ader, Toulouse et laboratoire Conception de produits et innovation, Paris.
[10] UMR EFTS Education, Formation, Travail, Savoir, Toulouse.
[11] Trigone-CIREL, Lille.
[12] Centre d'Etude et de Recherche Travail, Organisation, Pouvoir, Toulouse.

Table 1. Origins and mechanical background of the student population

	L3		M1		TOTAL	
	Mech. Knowl.		Mech. Knowl.		Mech. Knowl.	
	Yes	No	Yes	No	Yes	No
BTS	8	3	0	8	8	11
DUT	9	20	3	27	12	47
CPGE	5	0	3	0	8	0
Others	0	1	0	2	0	3
	22	24	6	37	28	61
					31%	69%

L3: third year university undergraduates; M1: postgraduates in their fourth year at university. BTS (technician's diploma), DUT (technology institute diploma), CPGE (preparatory classes for the Grandes Ecoles)

ity, with its three levels of difficulty in the game, gave the participants the opportunity to choose their own learning pathway and their own basic level starting point. In addition, there was the choice of exercises the students were to do to make progress in the game.

The practical works topic, as handed out at the start of the session, provides for five stages presented on Fig 6. Firstly, the teacher gives an introduction to the game, explaining the initial narrative scenario and the final objective of Mecagenius®. The second stage sees the teacher hand out customised identifiers and passwords to the students so they can connect up with the tool. The subjects then connect up in game mode and choose their game level in relation to their capabilities (beginner, intermediate or expert). The fourth stage leaves the students free to operate in the Mecagenius® world, with no constraints, so as to take full control. Then, half way through the time slot allocated to the practical session, the student switches to the guided game, then connecting to "training" mode. A series of 30 exercises, identified by the teacher in relation to the expected skills, is then conducted to allow for customised acquisition of knowledge. Note that each exercise can be repeated unlimitedly, with the parameters for the assessment changing after each failure. Practical work evaluation is performed taking into account the student's score, the assemblies made in Mecagenius®, and the virtual money (MecaGold) made during the session. Teacher's intervention is coloured in dark grey (T); student's one in light grey (S) and each stages' duration is presented.

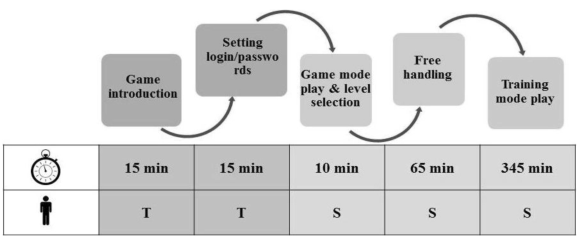

Fig. 6. Experimental protocol synthesis on a 7.5h session.

The aim of the research team was to collect both qualitative and quantitative data to understand how teachers and students use Mecagenius®. Introducing Mecagenius® within a learning sequence requires some reorganization. First, it appeared necessary to define new protocols to identify how the teachers are to be employed during the lessons. To this purpose, two questionnaires were developed and printed out, the first being a pre-test questionnaire containing three parts (biographical information; a mechanical engineering knowledge target and the statement of pedagogical intention) and the second a post-test questionnaire for feedback on the activities. The second concern was to understand the dynamics in which students act and react to the learning games proposed by Mecagenius®. Informal observation of the students during the class was conducted but in addition a tool was implemented in Mecagenius® to trace the various actions and scores of the gamer students. These macro-data types (level of play, number of games played, scores, types of error, time spent on the game, number and dates of connections) were analysed

The main objectives of this experimentation were:

- To validate the tool's pedagogical relevance
- And evaluate the students' interest in this new innovative pedagogical method.

5. Data processed and results

5.1 Data processed

The data processed included:

- The time spent on the game (total time, and dates of first and last connection),
- The rate of success per exercise,
- Information on the student's learning pathway and on their training.
- Semi-directive interviews with the reference students for each of the classes were also conducted.

5.2 *First results*

The data gathered from the experimentation described in the previous section were then analysed. Firstly, considering the practical work sessions, the main advantage the students derived was the sense of freedom they felt due to the fact that they could make mistakes without causing material damage, operate in a virtual workshop without the overriding presence of the teacher and feel free from the risks that are always inherent in a "real" machining workshop.

5.3 *Analysis of connection times*

Analysis of the connection times was conducted individually. Indeed, each of the accounts opened for the students was accompanied by a game time counter. Extraction of these gaming times was performed so as to be interpreted to see whether the students had replayed Mecagenius® outside the practical work sessions. This indicator, which the students were not informed about, is essentially based on the notion of gaming pleasure. For 89 subjects, similar training profiles are to be seen between those who replayed on Mecagenius® outside practical work sessions and the others. Those who replayed among the M1 subjects did so mainly to improve. This behaviour was not observed among the L3 panel, although this may well be explained by the fact that they spent 7.5 hours on Mecagenius® as against 3.5 for the M1 students and may well have felt that they had had enough. For both groups, an attraction for this learning system was clearly felt. Connections outside the compulsory sessions were observed, and even some reconnections after the final evaluation for the module.

Figure 7 below shows, among the 89 subjects, the proportion of those who replayed outside the compulsory sessions. It can be seen that almost one third of students reconnected—a highly encouraging result that confirms the interest aroused in our students by this learning game.

Among the 31% having replayed, the real time spent so doing outside the compulsory sessions was analysed. The results are shown in Fig. 8 below. It can be seen that 43% of subjects spent one hour or more replaying Mecagenius®, and 10% even spent 4 hours and more doing training on the game. These results are extremely positive and show the enthusiasm aroused by this new type of teaching method.

5.4 *Analysis of success rates per exercise*

As outlined in the paragraph devoted to the pedagogical approach and experimentation objectives, Mecagenius® introduces exercises identified by the teacher as being appropriate to the skills to be acquired, allowing for a targeted acquisition of

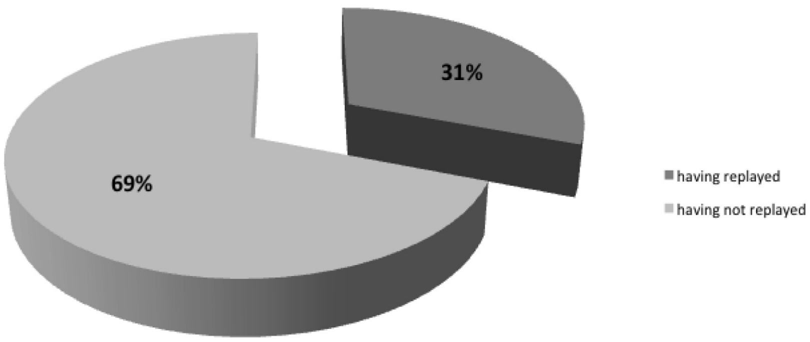

Fig. 7. Proportion of students having replayed Mecagenius®.

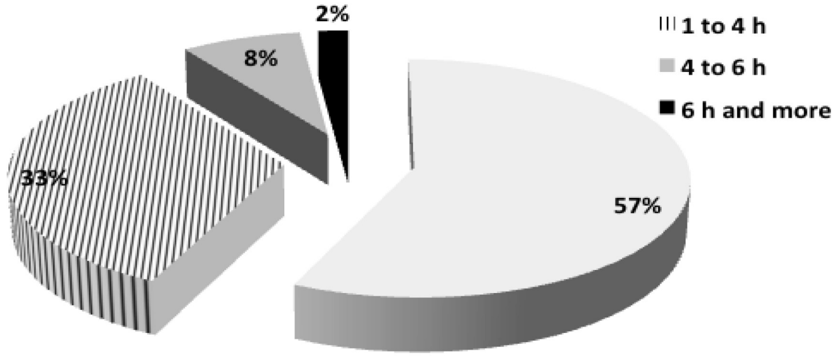

Fig. 8. Time spent in addition by students having replayed on Mecagenius®.

Table 2. Variables recorded for 46 students of Licence 3

Student ID	Identification Exercise	Object Production Ex.	Machine Tool Architecture Ex.	Best Training Level	Score	MecaGold
1	16	3	2	4	2800	715
2	39	13	6	8	6500	2840
3	15	2	2	5	3650	105
4	21	3	5	3	2500	85

knowledge. During practical work session, a set of variables has also been recorded for the 46 students of Licence 3 (see Table 2). These variables will help us to define some correlations between final exam results and performance during practical work sessions.

The final examination was conducted extracting the results from 15 Mecagenius® games in order to test the students' acquisition of knowledge. These games were chosen by the teacher in relation to the desired skills from among the 3 major game families: 5 identification games, 5 production object games and 5 machine tool games.

Following this exam, it can be seen that the results are encouraging. Studying the connection times, it emerges that the students in greatest difficulty (i.e. those who lacked grounding in mechanical manufacturing) connected up again several times before the exam with the aim of enhancing their training. To summarise, the average mark for the exam was 16.2/20 (min. = 13/20, max. = 18/20) for the 46 subjects in LICENCE 3, with a standard deviation of 1.2. For the MASTER 1 subjects, the average came to 14.4/20 (min. = 9.5/20, max. = 19/20) with a standard deviation of 2.4. These values clearly show the transmission of knowledge as correctly performed by Mecagenius® whatever the student's training background. Indeed, the averages are substantially equivalent and fairly high. Furthermore, the standard deviations remain fairly low meaning that the overall level is satisfactory, with few deviations whatever the training background. These results highlight the fact that the strategies adopted by these students lead them to select their own experiences, thus fostering the learning process as an integral part of their educational project.

Then, a correlation matrix of the whole set of practical work variables has been performed. It is interesting to note that exam mark appeared significantly correlated to the amount of Mecagold earned during the session ($r(46) = 0.411$, $p = 0.005$). This result validates the fact that educational objective and purpose of serious games are aligned.

Finally, a number of students reconnected even after the exam. It can reasonably be deduced that they wanted to continue using Mecagenius® for entertainment.

5.5 Analysis of semi-directive interview

At the end of each practical works session, two students were chosen from each panel (L3 and M1) for them to give their views as to the learning experience they had been through. The interviews were recorded and the data collected then retranscribed.

The user interview is a method used to collect oral data from individuals or groups in order to derive information from specific facts or representations. The relevance, validity, and reliability of this information are assessed based on the goals of that data collection. Each interview takes place within a specific context. Interviews must be prepared beforehand, planning which central topics are to be addressed and in what order. This allows the

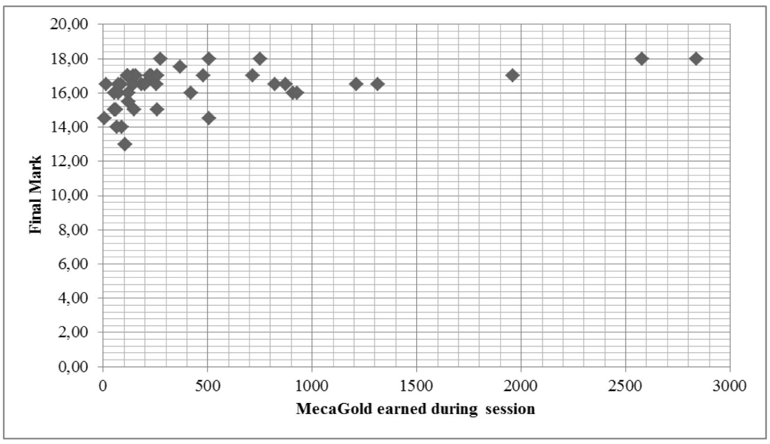

Fig. 9. Exam mark awarded and number of MecaGold earned by the L3 students.

interviewer to gradually steer the interviewee's feedback towards specific topics of interest and ensure that series of interviews with different people retain a specific internal coherence. The main types of interviews include the directive interview, the semi-directive interview, and the free (open) interview [21]. Considering our goals, the type of interview that seemed to suit our needs best is the semi-directive interview. It allows us to collect precise data within a reasonable length of time (each interview lasted about 15 minutes) and fosters a genuine dialogue between the interviewer and interviewee, while preserving a framework that is tailored to the goals of the project.

The topics addressed in these interviews were: quality of Mecagenius®, the learning feeling and then a "feedback" part where the students were free to give their views. Following these interviews, the recorded comments were grouped together and then an analysis was conducted to identify the terms most frequently used by the interviewed students. Thus, the three expressions most often employed were first of all "fun learning", then "innovation" and then "autonomy". Here are two verbatim statements made:

- "This tool's really interesting to give an initiation to mechanical engineering and make students want to get out onto "real" machine tools. It looks like this learning game isn't there to compete with but rather to be complementary to workshop activities".
- "I really liked the fun learning method".

The students' real taste for this new learning method and attraction for its novel features can clearly be seen here.

Finally, the teacher running the practical work sessions noted that it was difficult to get the students to take a break, which is to say the least unusual and confirms the test population's strong interest in the product.

6. Discussion

Can the discipline of mechanical engineering be learned in a fun way?

The present research offers insight into the use of Mecagenius® in education. In our previous research we studied the ways teachers use this learning game with their students. The findings highlight the contrasting forms of integration of this learning game as a part of teachers' usual practice. Some failed to use the full potential of Mecagenius® with the teacher's approach going against the initial aims as originally planned by the designers. For example, some gave away the solution to a problem when trying to explain how the game works. The teacher's role is essential in the learning experience and so guidance is required to help them use the full learning potential of Mecagenius® in engineering schools. The whole learning experience in this serious game has been made more effective thanks to the concerted efforts of the learning game designers, researchers into didactics and the teachers at an engineering faculty.

The relation between learning game and students shows how Mecagenius® can be used as a shared artefact for knowledge acquisition. The environment that emerged around Mecagenius® in constructing knowledge was examined and an understanding of the uses of learning games provided new opportunities for learning perspectives in the field of mechanical engineering.

The authors agree with Gee [22] that serious games can provide new forms of learning, where different pathways to knowledge can be chosen. Students logged in again after practical sessions and on average they put in over two extra hours. From the collection of Mecagenius® traces, the results show different learning strategies used by the two groups of students. There is seen to be a very real attraction for the learning system. Indeed, a number of connections running up close to the exam date were noted, suggesting that Mecagenius® was seen to be useful for revision purposes. Here, students put the learning goals above the game goals.

Finally, it is interesting to note that the disparity in knowledge observed at the start of the course work was not reflected in the exam marks at the end. This observation can be explained by the fact that those students facing the greatest difficulties were those who spent most time on Mecagenius® outside lessons. It can therefore be deduced that work on Mecagenius® enabled differences in levels between students to be reduced as part of a general upward trend. It can be concluded that the Mecagenius® learning game effectively contributed to the building of knowledge in mechanical engineering among the students. In addition, Mecagenius® gave students the opportunity to target the knowledge they needed most, an especially interesting result as, to our knowledge, no other study has yet shown that a serious game really allows skills to be developed.

Considering the students' behaviour during the game sessions, the hypothesis can be argued that it is Mecagenius®'s flexibility that allowed the weakest students to do the most exercises in the areas where they felt unsure of themselves. This assumption remains to be proved, but further work could usefully be devoted to developing tools that strongly focus on the needs felt by the student. The learning experience in Mecagenius® is all the more effective in that students retain considerable freedom when playing this learning game.

However, even if Mecagenius® was designed from a combination of game-play and practical technical scenarios that suggest it could almost be self-sufficient in furthering a training objective, certain limits need, however, to be recognised. Some students, for example, were seen not to have found in Mecagenius® adequate feedback enabling them to "play" and "win" in the apprenticeship game. The retrieval of computer records on game actions in play-tests allowed certain player strategies over time to be analysed [12]. This set of results suggests that mini-game feedback is not sufficient for weak students even though they may find some help and solutions there. One response to this lies in improving targeted teaching accompaniment with extra assistance and feedback being offered to the learner. For such students to be able to overcome certain obstacles to learning, the teacher must offer additional pathways and provide guidance.

The approach needs to cater for the teacher-pupil dialectic, with a strong emphasis on providing effective guidelines for the teaching staff who will continue to play an essential role in facilitating learning with Mecagenius®, steering the students through. This survey of the possible classroom uses of Mecagenius® strongly suggests that the teacher will play a decisive role if the impact of Mecagenius® on the development of students' mechanical engineering skills is to be optimised. However, prior research [11] also reveals that too directive and interventionist an approach by the teachers can also undermine the fun side of the game and the students' freedom to find their own way around the different mini-games that go to make up Mecagenius®, subduing their interest. It was shown that teachers sometimes remain reticent about the idea of letting their students experiment with Mecagenius® and that they took it on themselves to point out the solutions that would allow a game to be won. This form of close guidance goes against the ideas informing the initial design of the *serious game* that envisages precisely that students can work through trial and error and even improvise various possibilities of response to the problems posed by the mini-games. It would appear relevant for the future teaching staff using Mecagenius® to be accompanied and informed of the implementation procedures for the teaching situations in order to take advantage of the full potential of Mecagenius® in classroom situations. Knowledge of the different possibilities the game has to offer to open the way for new pathways to learning is a prerequisite. Effective professional training should encompass this so that the teachers can continue to invent and further develop high potential teaching aids. In addition, the construction of tools for teachers (user guides, software allowing the corresponding mini-games to be matched with the targeted skills and examples of possible uses) will make Mecagenius® easier to deploy.

7. Conclusion and future work

One of the key issues for competitiveness in the manufacturing sector lies in the education and training of future young engineers. Sustained by the rapid development of the new Information and Communication Technologies, innovative approaches to manage knowledge and nurture skills are needed to overcome students' declining interest in the sciences and engineering.

The present article showed that such innovation does not simply lie in what a mechanical engineering learning game has to offer but also in the way it is used. Serious games have the enormous advantage of breaking with conventional learning methods, allowing the learner to become immersed in a particular, scripted environment. Beneath the entertainment value Mecagenius® represents are hidden theoretical models and learning scenarios reserved for the initiates. The number and wealth of activities available offer a host of teaching opportunities that can help develop in the players clearly identified and referenced mechanical engineering skills. It should also be emphasized that this acquisition of knowledge is pursued, at least in part, independently, outside course work sessions, thus opening up possibilities of blended learning.

Technical innovations must not, however, lead necessary pedagogical innovations to be neglected. It is important to anticipate the organisational transformations imposed by these new technologies. For example, the wealth of resources available can also overwhelm the teachers and thus present an obstacle to using Mecagenius® even though they have already received training on how to use it. It is therefore important to provide for accompaniment of teaching staff on start-up and help them to choose activities to match the centres of interest addressed in training.

Use of Mecagenius® also demonstrated that a customised follow-up of the students during training made for greater efficiency and optimised training time. Finally, from a user perspective, Mecagenius® was greatly appreciated and aroused a real feeling of pleasure in most students. The great majority wished to continue using Mecagenius® in future courses.

Studying the ways Mecagenius® is used in class also illustrates the essential role of the teacher in optimizing the impact of this learning game on the development of the students' mechanical engineering skills.

Finally, the results of this analysis showed an encouraging set of guidelines for the development of serious games in the field of mechanical manufacturing. This experimentation also pinpoints a number of areas for improvement in Mecagenius® as for example in better evaluating the player's progress through the game (tracking*)*.

This research work offers an insight into the possible use of learning games when teaching mechanical engineering at an engineering faculty with very high level students. It would now be of interest to extend this study to other types of training (training for M.Sc., B.Sc., at high school and in vocational training) and in other countries or regions. The final objective is to offer use of the game as tailored to the training concerned and suited to the level of the player.

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