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Motivating the learning of science topics in secondary school: A constructivist edutainment setting for studying Chaos

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ABSTRACT

In this paper, we present an Edutainment (education plus entertainment) secondary school setting based on the construction of artifacts and manipulation of virtual contents (images, sound, and music) connected to Chaos.

This interactive learning environment also foresees the use of a virtual theatre, by which students can manipulate 3D contents (parameterized models of expressive faces called "Talking Heads"), in order to realize a computer performance on the explanation of Chaos concepts.

After an entry assessment of subjects' information on Chaos, 30 high school students aged between 16 and 18 have manipulated real and virtual objects related to Chua's circuit. Then they have written a script on Chaos topic, manipulated the Talking Heads for the realization of a virtual theatre performance, and filled a Chaos knowledge questionnaire and a motivation test. The control group (30 students) has attended traditional lessons on Chaos, and compiled the same tests. Results enhance the great potentiality of the realized setting for science education and motivation. In particular, very positive results in learning, as well as an increase of motivation linked to interest/enjoyment and competence, have been demonstrated.

1. Introduction

In recent years, the necessity of learning complex scientific contents as well as the opportunity to use innovative media at school, have lead to the design of educational settings and environments by which learners can be motivated and actively engaged in the process of skill development (Bertacchini, Gabriele, & Tavernise, 2011). In fact, some researches stress that motivation, which is associated with positive learning outcomes in many studies (Curry, 1990, 1991; Logan, Medford, & Hughes, 2011; Pintrich & Schunk, 1996), is not well implemented in the majority of educational courses. Especially intrinsic motivation is often neglected even if, in the "society of knowledge", different kinds of motivation for learning are increasingly demanded (Bilotta & Tavernise, 2012; Brooks, 2011; Hamlen, 2011; Huang, 2011; Lancioni & Chandran, 2009). Furthermore, in recent times, this need of activating motivation has been particularly relevant for the acquisition and increment of young generation's literacy in science (Liu, Horton, Olmanson, & Toprac, 2011; Milner, Templin, & Czerniak, 2011). In fact, science learning can involve learners' emotional-cognitive side, especially if subjects are properly motivated to carry on personalized and creative activities as the development of scientific artifacts (Bilotta, Bertacchini, Gabriele, & Tavernise, 2011; Bilotta, Gabriele, Servidio, & Tavernise, 2007), also using different multimedia tools as images, sound and music. Thus, current advances in Information and Communication Technologies have already provided novel tools and strategies for the learning of educational contents in an entertaining way (Bilotta, Gabriele, Servidio, & Tavernise, 2008; Owston, Widerman, Sinitskaya Ronda, & Brown, 2009), as Games-Based Learning applications (Bourgonjon, Valcke, Soetaert, & Schellens, 2010; Kiili, 2005; Paraskeva, Mysirlaki, & Papagianni, 2010). Some of these tools have become cognitive amplifiers for supporting the educational process and the approach of young generation to scientific topics. This new kind of learning has been called "Edutainment", thanks to the mixture of the two terms "education" and "entertainment" (Bilotta, Gabriele, Servidio, & Tavernise, 2009). Hence, in hands-on laboratories, users have an active role in engaging education settings, learning by doing (Aldrich, 2005), and their participation has a positive emotional connotation (Astleitner & Wiesner, 2004). In fact, as some studies confirm, there

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is significant effect of emotions on both mental effort investment and level of satisfaction (Um, Plass, Hayward, & Homer, 2011; Um, Song, & Plass, 2007).

According to the constructivist approach, direct contact with objects and consequent manipulation encourage learners to think, to formulate hypotheses and to test their hypotheses (Bednar, Cunningham, Duffy, & Perry, 1995; Gärdenfors & Johansson, 2005; Kafai, 2006; Kafai & Resnick, 1996; Papert & Harel, 1991). Thus, students can better understand and remember the topics, feeling a positive sense of success when the task is completed (Jonassen, 1999; Palmer, 2005; Wing-Mui SO, 2002). Manipulation can also be virtual: the visualization of a scientific content on a computer screen, associated with a real-time virtual interaction, can support the comprehension of complex phenomena (Pantano & Tavernise, 2009, 2011). Moreover, students have the opportunity of different interactive personalized hands-on paths, adapted to their necessities (Naccarato, Pantano, & Tavernise, 2011).

Regarding Chaos, one of the most important focus of contemporary science research (Brown, Berezdivin, & Chua, 2001; Chua, 1992; Chua, Kocarev, Eckert, & Itoh, 1992; Matsumoto, Chua, & Komuro, 1985; Shil'nikov, 1993), its value in education has been identified (Cronbach, 1988), even if it has constantly been considered a subject for University students or specialists. After some initial study (Cziko, 1989; Markham, 1998; Pouravood, 1997; Trygestad, 1997) on the relationship between learning and Chaos, an important research has been carried out by Gandhi, Muthuswamy, and Roska (2007), who have introduced Chaos to high school classes. The researchers have used a software simulator of Chua's circuit and the software "Osqoop", that has turned students' computers into virtual oscilloscopes. A non-conventional didactic environment has also be planned by Bilotta, Bossio, and Pantano (2010), in order to involve high school students in an engaging and appealing learning of stimulating Chaos-related ideas. Moreover, an experimentation with adults is in progress (Bertacchini, Bilotta, Gabriele, Pantano, & Tavernise, 2012). In this view, the aim of the present study is to demonstrate that the exploration of specific emergence-related concepts in a hands-on environment, out of regular school programmes, can powerfully engage and motivate also learners without a strong scientific background.

2. Research topic: Chaos and Chua's circuit

Chaos theory considers non-linear dynamical systems with deterministic behaviour, that evolves in an apparently random sensibility to initial conditions (Alligood, Sauer, & Yorke, 1996). Unlike random series, these systems evolve in the same way for a given set of initial conditions and parameters values; hence, chaotic systems can create a number of unpredictable form and shapes, known as strange attractors. It is impossible to witness this kind of evolution in real-world settings, but it is possible in digital simulations. In fact, Chua's circuit, a physical device able to reproduce chaotic behaviour, can produce a large number of chaotic structures of many different patterns and size (Bilotta, Pantano, & Stranges, 2007; Chua, Wu, Huang, & Zhong, 1993a,b; Bilotta, Di Blasi, Pantano, Stranges, 2007). Therefore, Chua's circuit is considered a universal paradigm for studying Chaos, "the first real physical system where Chaos is observed in laboratory, confirmed by computer simulation, proven mathematically by two independent methods" (Matsumoto, Chua, & Ayaki, 1988).

Chua's circuit displays many of the defining characteristics of a chaotic system, as: sensitive dependence on initial conditions; strange attractors; many routes to Chaos; fractal basin boundaries. The state equation for the circuit is determined by seven parameters. Chua et al. (1993b) have demonstrated that this is equivalent to a "family" of symmetrical odd equations with 21 parameters.

Equations for Chua's circuit can be used to both define the basic behaviour of a dynamical system and detect changes in its qualitative behaviour, when modifications in parameter values produce a bifurcation. In fact, systems evolve through different qualitative behaviours, represented by various shapes; these shapes can also be transformed into sounds.

3. Research participants

The experimental sample consisted of 30 high school students ($N = 30$), aged between 16 and 18; the control group consisted of 30 high school students ($N = 30$) of the same age. In each group, 15 were female and 15 were male.

Both groups included 4th-year subjects from 6 secondary classes of the same school, randomly assigned to the experimental or control group. Table 1 shows students' mean age and standard deviations.

Mann–Whitney *U* test has indicated no statistically significant differences between the research groups in respect to age and gender.

All subjects were comfortable with computers and have used technology applications in other instructional activities. The research has been carried out in the structured context of the educative environment to which the students belonged, delimiting the research field to a specific area (the science laboratory). Experience has coexisted with other school activities and courses, and conditions have been the same for experimental and control groups: laboratory and traditional lessons have taken place in the same location, day of the week, hour. In particular, tests were group administrated by researchers according to objective formats in order to avoid extrinsic sources of error; therefore, preliminary conditions have been rigorously predisposed. Moreover, students knew that participating in the study did not affect their grades.

Table 1
Information on research participants: mean age and standard deviations.

	N	Age mean (16–18)	SD
Experiment	30	16.06	0.56
Control	30	16.08	0.55
Boys-experiment	15	16.07	0.59
Girls-experiment	15	16.04	0.53
Boys-control	15	17	0.51
Girls-control	15	16.06	0.51

4. Research methodology and tools

The research has included three stages for the experimental group: a) the entry assessment of students' information on Chaos, followed by the manipulation of real and virtual objects related to Chua's circuit; b) the writing of a script (students could choose between the story of the genesis of Chua's circuit or the easy explanation of Chaos concepts) and the manipulation of parameterized models of expressive faces ("Talking Heads") for the realization of a virtual theatre performance on the topic; c) the administration of a Chaos knowledge questionnaire and a motivation test. Manipulation of virtual and real contents has had a duration of 6 h.

Regarding control group, students have attended traditional lessons on Chaos. Firstly they have compiled the entry test on Chaos knowledge, and then they have attended 6 h of traditional lessons, using only textbooks and still-pictures. They did not manipulate real (Chua's circuit) or virtual (i.e. Talking Heads) contents. After these lessons, students have compiled the Chaos knowledge questionnaire and the motivation test.

Results obtained by experimental group have been compared to those obtained by control one by using SPSS version 18. Non-parametric statistical tests were used to analyse the data provided by knowledge assessment. Thus, having the great advantage of possibly being used for small samples of subjects, the Mann–Whitney *U* test has been used in this study ($N = 30$). In particular, Mann–Whitney *U* test and Wilcoxon signed ranks test were employed to measure pre-post change in students' knowledge and to test if there were any differences between the control and experimental classes. Moreover, Mann–Whitney *U* tests were used to assess differences in levels of knowledge between groups, ranked on a scale of 1–15 (15 being the highest and 1 being the lowest). Wilcoxon matched-pairs signed rank tests were used to assess if there was an increase in knowledge within the individual groups. Multiple regression analysis has been used both to make valid projections concerning Chaos post-test scores, taking into account motivation and pre-test scores, and to determine what of the subscales of the motivation test was the strongest predictor. Mann–Whitney *U* test has also been used to investigate gender differences in motivation.

4.1. The first stage: manipulation of real and virtual objects

After the administration of an entry test on the research topic, students have been divided in 6 groups. Each group has had a kit for the construction of Chua's circuit, and instructions; the kit consisted of:

- a printed circuit board (Fig. 1);
- the circuit components to add to the printed circuit board according to the instructions.

Regarding the instructions, the conversion of the Chua circuit diagram to a breadboard layout has been leaded by the following simple rules:

1. When putting parts on a breadboard you must concentrate on their connections, not their positions on the circuit diagram.
2. Start the wiring with the Integrated circuit first. Place it in the centre of the breadboard and work round it pin by pin, putting in all the connections and components for each pin in turn.
3. Probably the most difficult part in wiring up Chua's circuit is the non-linear element (Chua diode): pictures will show how you can realize the current voltage characteristic.

After the construction, students have checked the circuit functioning, connecting it to a computer endowed with the software "Osqoop", able to turn a computer into virtual oscilloscope, already used by Gandhi et al. (2007). In particular, Osqoop is a multi-platform open source software oscilloscope able to be connected to various hardware data sources as well as to provide real-time signal processing through a plugin architecture. In this study, a microphone has been plugged in the Line-In of computers and the voltage waveform (time series) and/or double scroll strange attractor has been visualized on the screen. In fact, varying the potentiometer between the two capacitors it is possible to observe the evolution route to Chaos and listen to the sound of Chaos through the computer's speaker.

Then, chaotic behaviour has been reproduced, simulated and visualized on a computer screen thanks to the software Chaos Explorer (Fig. 1), that has been conceived, designed and created for this study. The virtual manipulation of the mathematical parameters has allowed the creation of different attractors, 3D images, music and sounds.

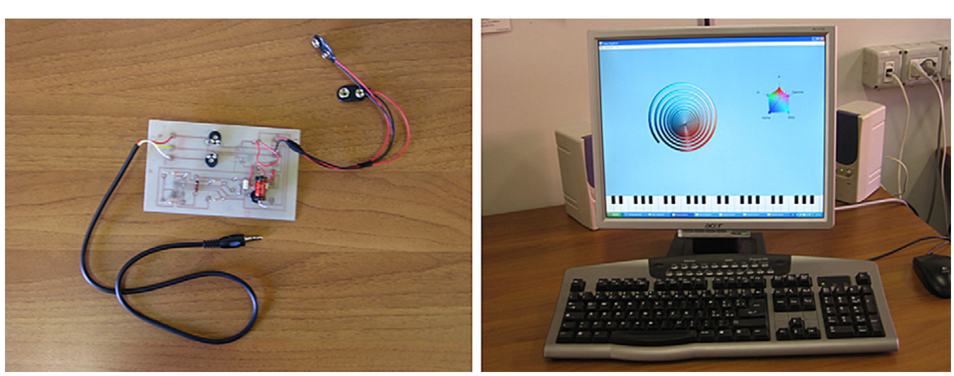

Fig. 1. The printed circuit board and the interface of Chaos Explorer.

In Chaos Explorer a mathematical model simulates Chua's circuit; this mathematical model is a system of three differential equations in three unknowns. The data derived from the simulation of the model are encoded and converted into images, sounds and music through a series of computer algorithms. The evolution of the three variables over time is simulated using a numerical integrator implemented with the fourth-order Runge–Kutta method. An allowable range of values has been selected for each parameter; moreover, a collection of basic configuration, giving rise to a number of interesting attractors, has been provided. Therefore, when one of the five parameters changes, the attractor shape varies significantly.

The manipulation of the parameters is achieved through a very simple and intuitive interface. In fact, if the vertex of a star configuration is moved, the attractor shape changes (Fig. 2). Thus, very small modifications of parameters change radically the structure of the obtained attractor. Moreover, the attractor shapes can be saved as JPEG images or as 3D models in VRML format.

4.2. The second stage: the realization of a virtual theatre performance on Chaos

The ad-hoc built software Face3D has been used to realize a performance of parameterized Talking Heads in a Virtual Theatre. In particular, the groups of students have chosen to realize a script on the genesis of Chua's circuit (Bertacchini, Bilotta, Laria & Pantano, 2012) or the easy explanations of Complexity concepts.

Hence, after a short tutorial on the use of Face3D software, students have had to:

1. arrange the script in a group writing laboratory;
2. audio record the script;
3. select the virtual actors from a library on the basis of the content to perform;
4. synchronize the recorded files with the facial expressions of the virtual actors;
5. realize the performance.

Therefore, this stage has foreseen the "manipulation" of:

a. the script;
b. 3D head models of virtual actors;
c. audio files: students' voice recording and virtual manipulation in the software for the synchronization of standard facial expressions (neutral, anger, surprise, sadness, fear, joy, disgust, attention) with pre-recorded files of speech;
d. the performance in a Virtual Theatre interface.

The software has been designed and implemented by Evolutionary Systems Group (ESG, http://galileo.cincom.unical.it/) at Università della Calabria and consists of three Graphical User Interfaces: 1) Face3DEditor for selecting the 3D expressive faces of the researchers who have invented Chua's circuit or important scholars as Poincarè or Lorenz; 2) Face3DRecorder for animating the Talking Heads (Fig. 3), and 3) Virtual Theatre for the performance of the synthetic actors (Fig. 3).

However, since human faces are able to show minute changes in a very fast way (Bertacchini, Bilotta, Cronin, Pantano, & Tavernise, 2007; Adamo, Bertacchini, Bilotta, Pantano, & Tavernise, 2010), the software allows a rapid alteration of agents' emotional expressions (Bilotta, Pantano, & Tavernise, 2010). Moreover, a random movement of head and eyes can be adopted to provide a very realistic blinking to the animated heads. Regarding the audio files, the richness of voice characterisation and intonation is very important, providing a realistic human feature to the virtual objects (Bilotta, Bertacchini, Laria, Pantano, & Tavernise, 2011). Among the characters used in this stage there have been Chua, Cantor, Lorenz, Poincarè, Julia, Matsumoto, Zhong, Ayrom, Matsumoto's assistants, a narrator (Fig. 4). Each character has been reconstructed by ESG on the basis of a set of pictures imported in Face3DEditor.

4.3. Administration of research questionnaires

Both quantitative and qualitative data have been collected for the purpose of triangulation (Creswell, 2009), measuring:

- students' understanding of the scientific concepts linked to Chaos, examined by 15 closed-ended questions, using a pre- and post-questionnaire;
- students' motivation to learn science through the proposed Edutainment setting – examined by a 1-to-7 Likert-type questionnaire adapted from the Intrinsic Motivation Inventory (IMI);
- students' opinions on positive and negative aspects of the learning experience.

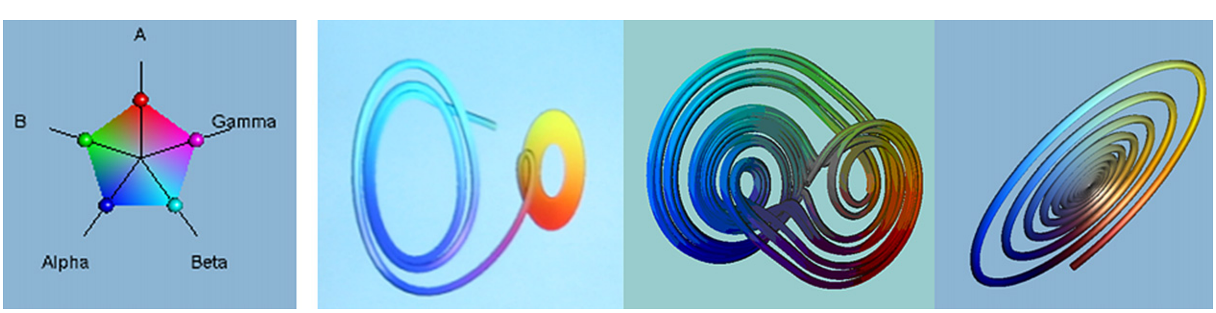

Fig. 2. The star configuration in Chaos Explorer and some attractors coming from Chua's circuit.

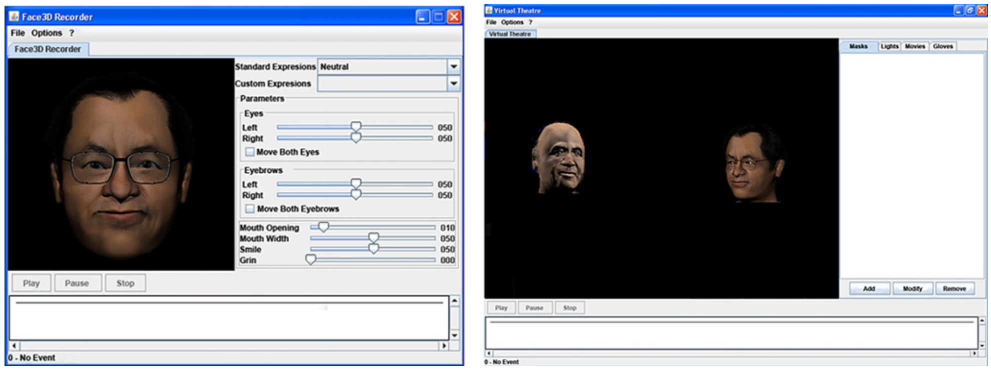

Fig. 3. The interface Face3DRecorder, used for animating the Talking Heads, and the Virtual Theatre.

Therefore, the present study has included three questionnaires: an entry test, a Chaos knowledge questionnaire and a Motivation test with some additional open questions. Regarding the first one, it has been designed to collect some personal data (age, sex, class), and assess the level of Chaos knowledge possessed by students before the experimentation. Then, upon completion of the real and virtual manipulation of stage 1 and 2 for experimental group, and traditional lessons for control group, participants have completed a post-test designed to assess whether there has been an increase of knowledge.

Regarding the Chaos learning questionnaire, knowledge questions have not been identical to the pre-test but very similar, with the aim to ensure that students did not learn from the previously asked questions present in the pre-test. 15-multiple choice questions have addressed both factual knowledge and application questions. As regards to the score, 1 point has been attributed for each correct answer and 0 for each incorrect one, for a maximum of 15 points.

A shorter version of Chaos knowledge questionnaire has been used in a previous study on the same topic, with a similar sample by Bilotta et al. (2010). Each question had four answer choices. Examples of the questions are the following:

1) What are the characteristics of Chaotic systems?
   - ☐ Only initial conditions
   - ☐ Only the variation of parameters
   - ☐ Initial conditions and the variation of parameters
   - ☐ I don't know
2) What does "Butterfly effect" mean?
   - ☐ Butterflies fly chaotically
   - ☐ Weather depends on the state of health of butterflies
   - ☐ When there are butterflies, it rains
   - ☐ Small variations in initial conditions can provoke a large effect
3) What of the following sequences does represent a route to Chaos?
   - ☐ Equilibrium point, limit cycle, bifurcation, double scroll
   - ☐ Double scroll, saturation
   - ☐ Bifurcation
   - ☐ Equilibrium point, limit cycle
4) When does bifurcation happen?
   - ☐ When chaotic system halves the possible solutions
   - ☐ Chaotic system has a constant number of possible solutions
   - ☐ Chaotic system doubles the number of possible solutions
   - ☐ Chaotic system deletes the possible solutions

Fig. 4. Some Talking Heads selectable in Face3D interfaces.

Regarding motivation, twenty-five items from the seven-point Likert scale IMI (e.g., Deci, Eghrari, Patrick, & Leone, 1994; Plant & Ryan, 1985; Ryan, 1982; Ryan, Connell, & Plant, 1990; Ryan, Koestner, & Deci, 1991; Ryan, Mims, & Koestner, 1983) have been used to evaluate students' motivation after manipulation (experimental group) or the traditional lessons stage (control group). The instrument has been used in a number of studies related to intrinsic motivation, assessing participants' interest/enjoyment, perceived competence, effort, value/usefulness, felt pressure and tension, and perceived choice. It has been reported as reliable and valid by McAuley, Duncan, and Tammen (1987).

In this research, four subscales on a five-point Likert scale (with 1 being not all true and five being very true) have been used (please see Appendix A). Their Cronbach's alpha values have been calculated for this sample: interest/enjoyment (seven items = a = 0.83), perceived competence (six items = a = 0.71), effort/importance (five items = a = 0.72), and value/usefulness (seven items = a = 0.73). The same subscales have been used in similar studies (Liu et al., 2011). The test as a whole had an alpha value of 0.72.

However, in IMI, the interest/enjoyment subscale is considered the self-report measure of intrinsic motivation; thus, although the overall questionnaire is called the Intrinsic Motivation Inventory, it is only the one subscale that assesses intrinsic motivation.

In three of the four subscales some statements were negative; they were marked with (R), and were recorded for statistical analysis. Moreover, at the end of the IMI, two open questions have been added: "Please indicate the positive aspect(s) of your experience" and "Please indicate the negative aspect(s) of your experience". This description of different characteristics of the activities in students' own words has been requested in order to produce a study beyond the quantitative analysis, enriched by the nuance of personal opinions.

5. Results

5.1. Learning effectiveness

Mann–Whitney U tests indicated that there was no significant difference in Chaos knowledge levels in the pre-tests between the experimental group and the control one. A Wilcoxon matched-pairs signed ranks test showed that the scores for experimental group, after the constructivist manipulation, were significantly higher than the scores of the pre-test ($Z = -2.065$, $p < 0.001$). The mean score on the pre-test for the experimental group was 1.23 out of 15 (SD = 1.25) and on the post-test (Chaos knowledge test) was 13.6 out of 15 (SD = 1.04).

Regarding the control group, the mean score on the entry test was 1.8 out of 15 (SD = 1.09) and on the post-test was 11.5 out of 15 (SD = 1.65). A Wilcoxon matched-pairs signed ranks test shows that also the scores after the traditional lessons on Chaos were higher than scores of the pre-test ($Z = -2.567$, $p < 0.001$).

A Wilcoxon matched-pairs signed ranks test indicates that the difference in knowledge post-test scores in the experimental group and the control one was also significant ($p < 0.001$).

Fig. 5 shows the comparison score – frequencies between experimental and control groups.

Gender differences have also been examined, since literature indicates a male bias towards computer-based learning (Mitra, LaFrance, & McCullough, 2001; Mitra, Lenzmeier et al., 2001). However, the correct responses in the knowledge test have increased significantly from pre-test to post-test (experimental group and control group) for both male and female students.

Therefore, the lack of a significant dissimilarity in post-test knowledge scores between male and female, as well as the presence of the only statistical significant difference between experimental and control group, imply that the only difference in students' score can be explicated by the participation in the Edutainment setting, and not by gender.

Table 2 shows students' mean score and standard deviations.

5.2. Motivation questionnaire

Regarding the analysis of the relationship between experimental group's learning post-test scores and motivation ones, controlling for the effect of the pre-test scores, a multiple regression analysis has showed a significant R^2 of 0.61, $F(2, 27) = 21.5$, $p < 0.01$. Thus, motivation test scores, obtained after Edutainment activities, can be considered as a predictor for Chaos post-test scores: $\beta = 0.37$, $t(27) = 2.5$, $p < 0.01$.

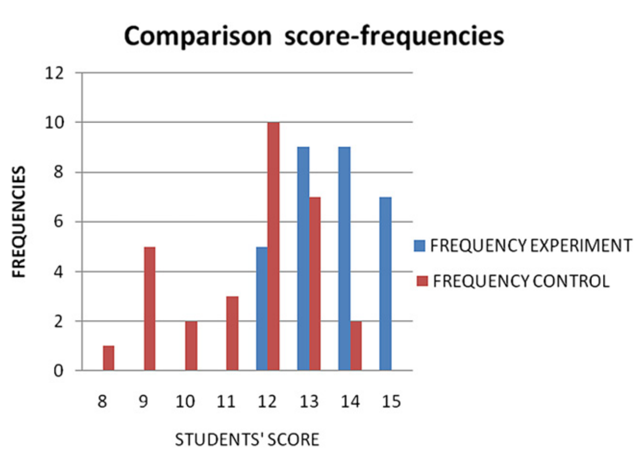

Fig. 5. The comparison score – frequencies shows a major frequency of high scores in the experimental group.

Table 2
Students' mean score and standard deviation.

	N	Pre-questionnaire		Post-questionnaire	
		Mean (0–15)	SD	Mean (0–15)	SD
Experiment	30	1.23	1.25	13.6	1.04
Control	30	1.8	1.09	11.5	1.65
Boys-experiment	15	1.46	1.24	12.9	0.74
Girls-experiment	15	1	1.25	14.3	0.72
Boys-control	15	1.33	0.81	11.73	1.75
Girls-control	15	2.26	1.16	11.27	1.58

Moreover, with the four subscales of IMI as predictors, an additional multiple regression analysis has showed a R^2 of 0.54, $F(4, 25) = 7.4$, $p < 0.01$. The subscale of "Perceived competence" has resulted as the strongest predictor: $\beta = 0.59$, $t(25) = 3.5$, $p < 0.01$. A significant relationship between Chaos knowledge scores and the subscale "Interest/Enjoyment" has also been noted: $\beta = 0.23$, $t(25) = 1.65$, $p < 0.01$. Exploring the relationship between each subscale of IMI and Chaos post-test scores, a simple regression has then confirmed a significant relationship between the subscale of "Perceived competence" and Chaos post-test scores: R^2 of 0.46, $F(15, 17) = 24.27$, $p < 0.01$; $\beta = 0.7$, $t(17) = 4.9$, $p < 0.01$.

Regarding the analysis of the relationship between control group's learning post-test scores and motivation and pre-test ones, a further multiple regression analysis has showed a R^2 of 0.8, $F(2, 27) = 1.15$, $p < 0.01$. As in the case of the experimental group, students' motivation score has resulted as a prediction factor for Chaos test scores: $\beta = 0.29$, $t(27) = 1.46$, $p < 0.01$. However, using the four subscales of IMI as predictors, the subscale of "Effort/Importance" has been the strongest predictor.

In this view, the scores obtained by experimental group in the subscales "Perceived competence" and "Interest/Enjoyment" mostly contribute to the relationship between motivation and learning scores, whereas the scores obtained by control group in the subscale "Effort/Importance" is positively related to the learning test results.

Regarding gender differences in motivation, the scores obtained by male and female subjects in each group (experimental and control) have been analysed. Regarding experimental group, the Mann–Whitney U tests show that there is a significant difference in the scores obtained by male and female subjects in effort/importance subscale ($p = 0.028$, $p < 0.05$). No significant differences have been found regarding the other subscales. Regarding control group, there is a significant difference in the scores obtained by male and female students in interest/enjoyment subscale ($p = 0.004$, $p < 0.05$); no significant differences have been found regarding the other subscales.

Fig. 6 shows the mean obtained by male and female students in both groups, in the different subscales of the IMI: 1 = interest/enjoyment; 2 = competence; 3 = effort/importance; 4 = value/usefulness.

There has also not been a significant difference in the scores obtained by male and female subjects between the groups.

5.3. Qualitative data findings

At the end of the motivation test, some questions have asked students' opinions on positive and negative aspects of Chaos learning experience. In particular, subjects have answered to open ended questions on what they thought were the positive and negative aspects of the Edutainment setting. The answers have been mostly concise, ranging from encouraging positive opinions to categorically negative. However, they have not been largely various. Several subjects of the experimental group have positively highlighted the interactive nature of the proposed activities ("I liked the interaction with others", "I liked group work"), also commenting on the way of understanding Chaos concepts ("I get a lot of information", "I enjoyed the use of computers", "I played as I usually do with videogames", "the computer-based activity was engaging"). However, the most remarkable sentences have regarded the intention to use the acquired concepts in the final assignment of last school year, even if the subject Chaos was not a part of the ordinary school curriculum (in Italian school system a short thesis linking all the studied topics is required before the attending of the final examination in the last secondary school year). Students have also commented the negative aspects of the activities: regarding stage 2, two boys have picked up on the limitations of having few characters to use in the virtual theatre, and almost all the girls have complained about the total absence of female characters to use as actresses. Moreover, shyness in the realization of audio-recording has been orally underlined, but not reported in the questionnaire. No negative aspects of stage 1 have been pointed out. Thus, qualitative results of this study confirm that the majority of the students have been motivated to use the proposed setting to learn science topics, as shown in this statement: "it has been different from science lessons, it was very funny!".

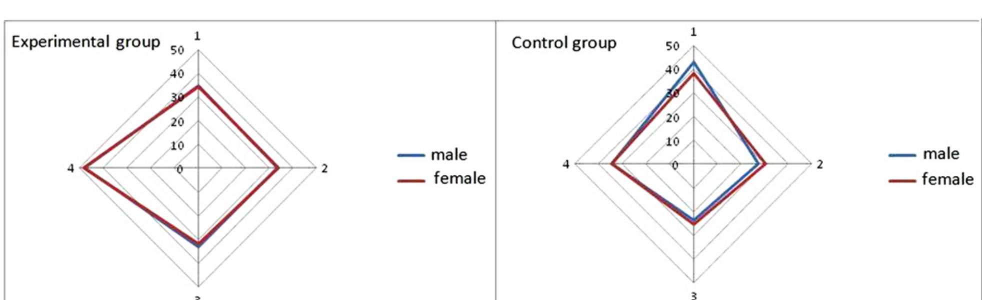

Fig. 6. The mean obtained by male and female students in the different subscales of the IMI.

Regarding the control group, students were not as supportive as those of the other group. A half has agreed that the lessons on Chaos were interesting, but only 5 subjects have declared that the activity has sustained their engagement. Moreover, only 4 students have been interested to participate in a similar activity, even if almost all have agreed that lessons on Chaos could be used to increase skills also at secondary school level. Some of the comments have been the following: “quite long”, “too hard”, “too much additional work”. One student indicated that the lesson did not hold his/her attention: “the topic does not interest me, I have a history test after this lesson”.

6. Conclusions

In recent years, traditional teaching methods have been viewed as outdated (Hainey, Connolly, Stansfield, & Boyle, 2011). Some of the advantages and disadvantages of traditional approach have been discussed by Bonwell (1996) and Davis (2001). Some of the main differences concern the passivity of traditional methods as opposed to the active education of the experiential learning, that consists of a learning cycle: concrete experience, reflective observation, abstract conceptualization, and active experimentation (Kolb, 1984). However, in traditional method, teachers have full control of the learning experience and can communicate their enthusiasm, also providing a model of professionals' behaviour in managing problems and answering questions. Moreover, a significant difference is that traditional methods are proven, while new ones are still to be proven.

In this research work, an Edutainment setting has been ideated and realized, in order to teach a science topic that usually is supposed too difficult for high school students: Chaos. In fact, this subject is usually taught at University level and only specialists study it. An experimental class in which students had to physically build Chua's circuit has been conceived; the proposed construction has involved the manipulation of circuit components, the identification of the correct elements to use, and the positioning of them on a predisposed breadboard. The cognitive aspects have regarded the participants' understanding of the functioning of the circuit diagram, and the learning of the role of the individual components as well as the importance of the connections between them. In particular, in the constructivist setting subjects have been encouraged to: a. manipulate and become familiar with circuit components; b. connect the components to the breadboard, using instructions; c. advance hypotheses concerning the role of specific components in the functioning of the circuit; d. share knowledge and information about the process within the group and with the other groups. The experimental setting has also foreseen a virtual manipulation of specific elements: by using the interface of the software Chaos Explorer, students had the opportunity to deeply understand the evolution of dynamical systems through computer simulation, creating changes in the patterns derived from Chua's circuit, known as strange attractors. Thus, students' manipulation has leaded to the realization of different kinds of dynamical configurations through the changes in the mathematical model of the physical system. However, virtual manipulation has also concerned the translation of the simulated dynamical systems into sound and music. In this way, students have been encouraged to: a. visualize Chua's attractors on the computer screen, observing how configuration manipulations change the shape of the patterns; b. use the software to convert the attractors into sounds; c. create musical compositions, based on the attractors.

In the stage devoted to the creation of a virtual performance, students have created a script. Their understanding of Chaos concepts has thus been organized through the use of narrative thinking. Manipulation has involved the use of Face3D software, synchronizing audio files of the scripts with facial expressions of Talking Heads. Moreover, virtual performances on the explanation of Chaos concepts have been realized. In this case students, divided in groups, had to: a. write and record a text on Chaos; b. select the Talking Heads from a library, on the basis of the text, and manipulate them; c. realize the virtual performance, actively working in groups.

The findings of this study emphasize not only very positive results in learning for experimental group, but also a motivation linked to interest/enjoyment and competence. In particular, both experimental and control group subjects have appreciably increased Chaos knowledge from pre-test to post-test; moreover, quantitative data have showed no evident difference in male and female students' performance. However, regarding motivation scores, a significant relationship has been found between experimental group's learning post-test scores and motivation ones. In particular, the significant relationship between Chaos knowledge scores and the subscale “Interest/Enjoyment” suggests that the more a student enjoys himself/herself, the higher are Chaos learning scores. This implies that characteristics supporting intrinsic motivation should be planned and included in the design of learning environments, taking into account the relationship between enjoyment, motivation, and learning. Also qualitative results show that engaging experiences are a crucial element for the teaching/learning of science topics (summarized in the following statement: “it has been different from science lessons, it was very funny!”). Furthermore, a significant relationship between the subscale of “perceived competence” and science knowledge post-test scores suggests that a challenging learning experience positively impact motivation. Regarding the analysis of the relationship between control group's learning post-test scores and motivation and pre-test ones, the significant scores obtained in the subscale “Effort/Importance” recall hard work linked to learning, as well as the control of the educational process (summarized in the following comments: “quite long”, “too hard”, “too much additional work”). Hence, thanks to the qualitative analysis of results, this research has showed what secondary school students find engaging and motivating in a computer-based learning: problem solving, play, and socializing. In fact, regarding this latter, results show that subjects are interested in collaborative work groups. Therefore, designers of new educational settings (especially those devoted to science learning) should consider the incorporation of this feature for the promotion of intrinsic motivation. Moreover, a great effort should be provided to the arrangement of a coherent edutainment path from grammar school to University based on the use of advanced tools, as well as a reasoned, rational, and articulated concurrence with school contents. Finally, the present research results are in alignment with the outcomes obtained by using other learning environments (Liu et al., 2011), but the arrangement of the Edutainment setting has here foreseen the manipulation of real and virtual objects. Therefore, further research in this direction is recommended.

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Appendix A

Adaptation from the Intrinsic Motivation Inventory (IMI).

Interest/Enjoyment

I enjoyed doing this activity very much.
This activity was fun to do.
I thought this was a boring activity. (*R*)
This activity did not hold my attention at all. (*R*)
I would describe this activity as very interesting.
I thought this activity was quite enjoyable.
While I was doing this activity, I was thinking about how much I enjoyed it.

Perceived Competence

I think I am pretty good at this activity.
I think I did pretty well at this activity, compared to other students.
After working at this activity for awhile, I felt pretty competent.
I am satisfied with my performance at this task.
I was pretty skilled at this activity.
This was an activity that I couldn't do very well. (*R*)

Effort/Importance

I put a lot of effort into this.
I didn't try very hard to do well at this activity. (*R*)
I tried very hard on this activity.
It was important to me to do well at this task.
I didn't put much energy into this. (*R*)

Value/Usefulness

I believe this activity could be of some value to me.
I think that doing this activity is useful for learning Chaos.
I think this is important to do because it can help me to learn Chaos.
I would be willing to do this again because it has some value to me.
I think doing this activity could help me to learn Chaos.
I believe doing this activity could be beneficial to me.
I think this is an important activity.

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