DEEPER COMPREHENSION OF BASIC ENVIRONMENTAL ISSUES THROUGH SERIOUS GAME

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ABSTRACT

During the last three decades we observe growing use of ecodesign, but we observe also misuse of ecodesign methods, leading often to time and financial loss. In coherence with several failure analysis and with our observation, we base our work on a hypothesis: Misuse of ecodesign is often caused by lack of basic comprehension of environmental issues: Non linearity of the processes, their inertia and their excessive costs.
Building on this hypothesis, we decided to enhance our education program with an innovative serious game. The goal is to achieve comprehension of the basic environmental issues. Innovation of the game lies in revealing to students at the end of the game, that the fictive initial situation of the game corresponded to a starting point of a real catastrophe. Students can thus not only compare their decisions with those of real leaders, but also to understand how and why bad decisions were taken.
Experiments indicate that students who played the game tend to evaluate environmental problems, while those who followed a lecture tend to describe them. This trend (going further than to a description) seems to be useful in decision making and in deployment of ecodesign methods.

Keywords: Ecodesign, Design education, Sustainability, Serious game

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1 INTRODUCTION

This Since more than 30 years, ecodesign has become an dominant topic in all the areas of the industry and has spread exponentially for the last ten years, as showed by the growing number of Environmental Product Declarations. (Ibáñez-Forés et al., 2016; Toniolo et al., 2019) Besides decreasing environmental impacts, eco-design also brings strategic and economic benefits. (Prendeville et al., 2017) shows, on a long-term observation of one particular company, how dealing with ecodesign dilemmas helps growing more sustainable and steady business models. (Plouffe et al., 2011) shows direct economic benefits related to ecodesign. Those benefits coming either from improved marketing, added value or from saving energy, materials and reducing logistics.

Nevertheless, like any other approaches, ecodesign does not always lead to the desired outcome and various authors have tried to find the reasons of such failure. Some of them have focused on imperfections in ecodesign methods such as (Polverini and Miretti, 2019) who propose to take systematically into account externalities, product lifetime and material consumption. Others suggest improving the circular economy and innovating ecodesign methods instead. For example, (Hinchliffe and Akkerman, 2017) report unclear links between the resource value and energy efficiency and (Bundgaard, Mosgaard and Remmen, 2017) add the need to increase methods' standardisation. Yet, (Plouffe et al., 2011) finds that simple lack of rigour in methods implementation is a common aspect of ecodesign projects' failure.

Most of the methods are based on simply requiring a good understanding of basic environmental issues. However, according to our observations during various industrial projects, the users are often engineers and managers with only a minimal training limited to one or two ecodesign methods.

Even engineering schools start often with teaching methods rather than the basics of environmental issues.

A typical situation can be illustrated by (Piekarski et al., 2019) describing a promising approach of university-industry cooperation. Their method focus on teaching LCA and ecodesign with emphasis on methodology instead of environmental issues fundamentals. Even the very well-designed toolkit to support ecodesign integration in engineering programmes by (Verhulst and Van Doorsselaer, 2015) assume that students already have a good grasp of environmental issues.

Nevertheless, (Luttropp and Lagerstedt, 2006) brought "The Ten Golden Rules" in order to prevent misuse of ecodesign methods. Their objective was to help engineers who know less about environmental issues to adopt a simple set of rules and priorities in order to take the right decisions when it comes to it.

In the french education system, a proper understanding of environmental issues is not yet well established. The secondary education program called STI2D (Sciences, Industrial Technologies and Sustainable Development) is the one teaching the most ecodesign. Unfortunately, it's limited to the bare definition of sustainable development and introduction to the methodology of Lifecycle Assessment (LCA). (B. Marti - A. Richet - B. Dufeu, 2019)

If the engineering programmes focus on methods, how can an engineer take the right decisions? According to our observations, it is not common for engineering students to know basic concepts such as: How long does it take before seeing negative impacts when a large amount of toxic liquid infiltrates the soil? What is the role of microorganisms and invertebrates in natural water purification? Or what is the risk of losing half of floral biodiversity?

In this work, we build on a hypothesis that **engineers and managers sometimes misuse ecodesign methods due to lack of knowledge in basic environmental issues**.

2 IMPLEMENTATION IN PRACTICE

If the logic of most ecodesign methods is based on the Lifecycle Assessment methodology, it seems appropriate to look at what the decision-making in LCA look like and what its requirements are. According to (Baumann and Tillman, 2004), LCA practitioner should define goals consistent with the prescriber's environmental and commercial policy. This part seems to rely entirely on the practitioner's good understanding of environmental issues and how they are related to the prescriber's environmental policy.

In 2017, based on our observations coming from an interaction with four industrials, we have re-evaluated our goals in the environmental excellence-teaching module. Instead of 4 hours of LCA

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theory that, in our opinion, was unlikely to develop any competence in assessing environmental impact, we tried to enhance a better understanding of environmental issues.
We observed that engineers tend to see environmental issues as linear processes explaining why they expect them to be easy to observe and to quantify.
Therefore, based on personal experience from collaboration with industrials, participation on the Czech Development Agency project (Remediation of Environmental Burdens Caused by Pesticides in Moldova, 2013) and on literature (Zavialov, 2005; Tianhong, Wenkai and Zhenghan, 2010; Sutton et al., 2016), we propose three principles that need to be taught to students :

1. Environmental processes are complex and non-linear. They are hard to understand and their variations should be taken with caution.
2. Both environmental deterioration and remediation are long processes with a high inertia. They tend to become visible with years or decades of delay and might as well last decades or even hundreds of years.
3. Environmental deterioration goes usually along with part or complete loss of environmental services, representing very high economic losses. These losses are usually a lot higher than the economic benefits coming from the previous harmful activity.

After this re-evaluation, we have observed our students had better perspective and improved capacity to grasp environmental impacts. Besides, according to (von der Heiden et al., 2013) teaching abstract concepts is more efficient through experiencing than through lectures. He also shows that a serious game can bring such experience.
That is the reason why we decided to develop a serious game for our students. Thanks to a brainstorming session, we came up with the idea of re-playing real events to increase the positive response to the serious game. Therefore, this innovation hypothesis is defined as follows: **Acquisition of new concepts through a serious game shall be reinforced by confronting student's choices and behaviour to a real event.**
For practical reasons, we chose the disaster of Aral lake as real event to be re-played by students. The event represent very well the three principles we aim to deliver:

1. The disaster went through non-linear evolution that is why it illustrates very well the complexity of natural processes.
2. Technical aspects (irrigation systems) causing most of the disaster, were put in place decades before the first negative consequences could be easily observed on the lake.
3. Deterioration of the lake seems to be irreversible and present huge financial losses in the area as well as concerned states: Uzbekistan and Kazakhstan. Besides, the consequences are not only economic and strategic but also social and environmental. These impacts cover very well all the aspects of sustainable development.

Given this event is very well documented it is possible to make a parametric model of the Aral lake's disappearance, thanks to a personal interest and visit of the area, we could use lots of material collected directly on site: photos, videos, testimonials. .

2.1 Methodology

This work aims at helping both managers and engineers to get more perspective in the area of environmental impacts, the final objective being for them to use ecodesign methods correctly.
To achieve that, based on our observations and on literature research, we designed a serious game, comparing student's strategic choices to the real past event of Aral lake disaster. There is a risk that students might know about the Aral lake disaster and try to avoid it since the beginning. Therefore, we decided to place the students in a fictive context and reveal the reality at the end of the game.
Specifications we set to the serious game were:

- Students shall experience a new situation with uncertain results. They shall not recognize they are dealing with the Aral lake disaster.
- The fictive lake disappearance has to be close to the real events.
- Students need to face the problems of non-linear behaviour, inertia and severity of the impacts

The first point was achieved by presenting the game as a socio-economical development of a fictive state of "Grand Coloredo" situated in the United States. Just as the situation in Uzbekistan is linked to the production of cotton, "Grand Coloredo" faces advantages and problems of a fictive culture "Colzon" typical for this fictive area.

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The Grand Coloredo was designed with similar dispositions as those of Uzbekistan. Especially hydrology needed to resemble, see Figure 1. Therefore, the northern mountains of the state give birth to two big rivers, just like Amu Darya and Syr Darya comes from the Pamir and Tian Shan mountains. Those two rivers feed endorheic Alan Lake like similar to the Aral lake.

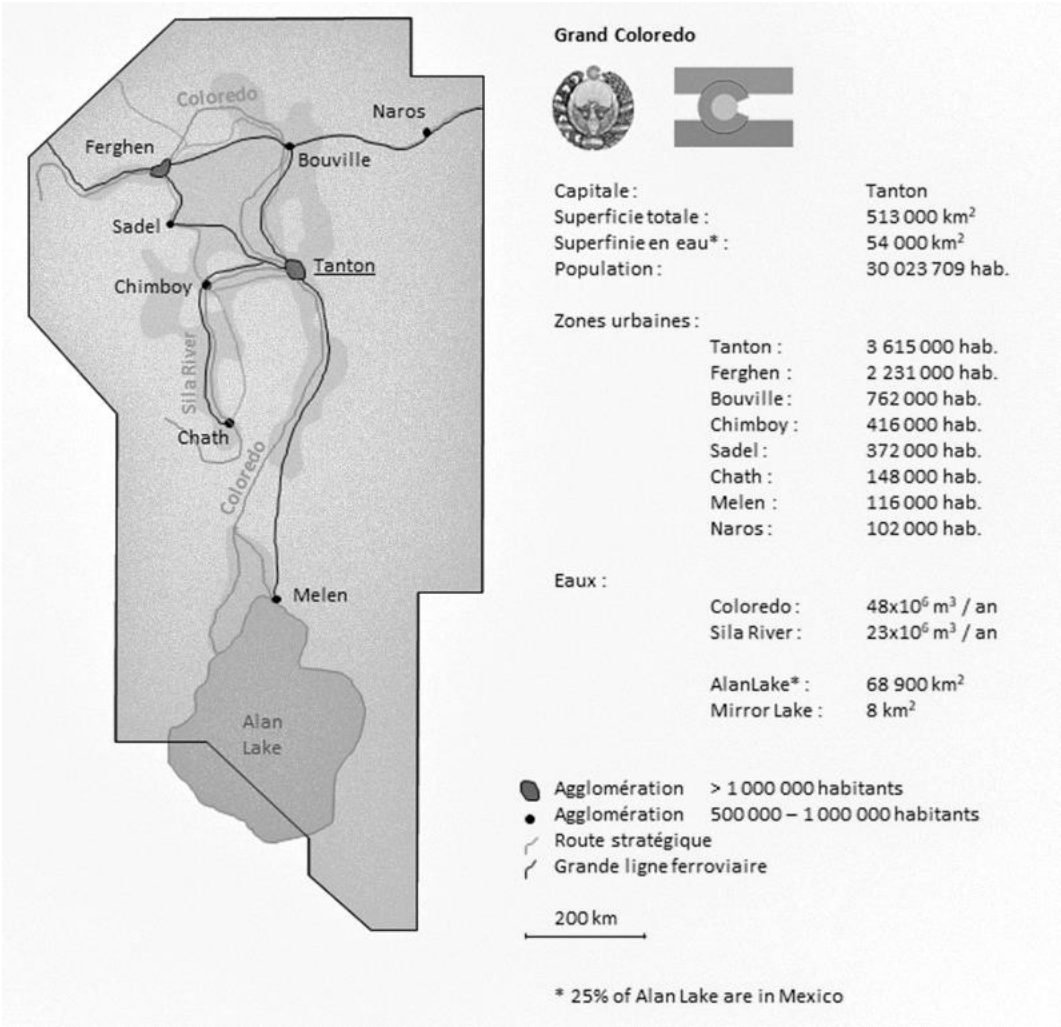

Figure 1. Map of the fictive state with detailed strategic information for players

We paid a lot of attention to the hydrology model. We have based the disappearing on the data from Physical oceanography of the dying Aral lake (Zavialov, 2005) as shown on the Figure 2.

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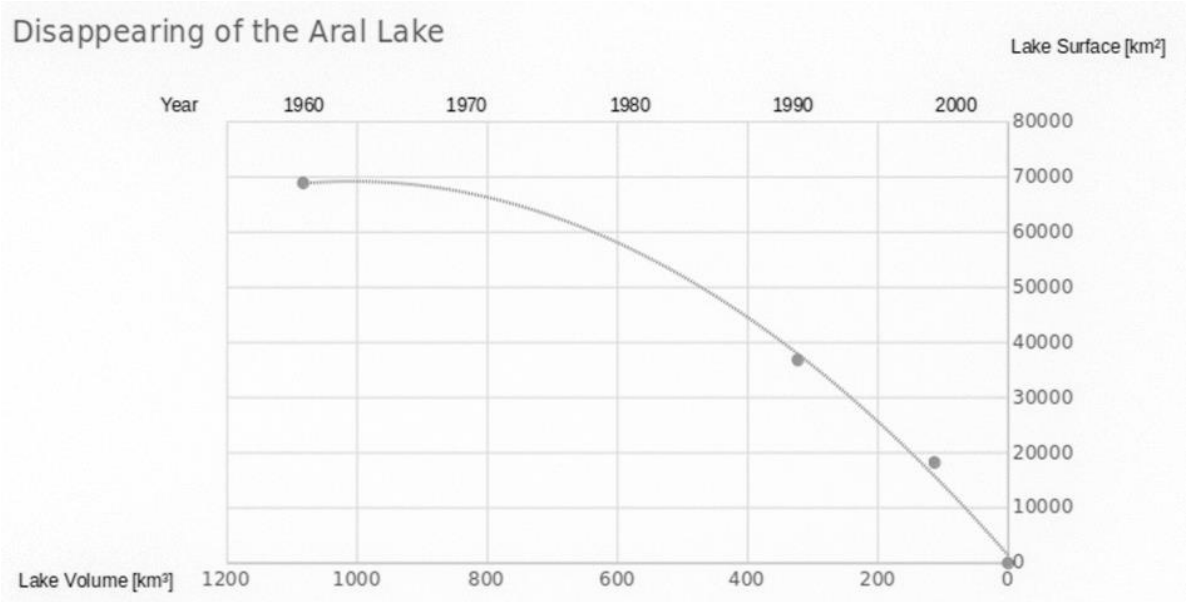

Figure 2. Approximation of Aral lake's disappearing with indication of time, surface and volume. The graph illustrates well how around 1970 the surface variation could barely be noticed even though the lake had already lost about 30% of its volume. This was one of the aspects we wanted our students to experience

The curve is not exact but it gives a good non-linear model of the Aral lake behaviour during the years. The model is especially interesting because it indicates the surface variation in function of volume changes. Volume can then be modified by varying water income and evaporation. In addition, just like in Uzbekistan, we take into account losses due to the infrastructure (security evacuation of dams) and growing infiltrations when irrigating the desert soil.

The game itself is organized by turns where the players plan a 5-years budget because playing in turns is simple and corresponds to the Soviet 5-years planning.

The way the players organize budgets influence the future evolution of their state. A parametric model, dependent on previous investments and with variable inertia, represents each sector (Health, Industry, Infrastructure…). For instance, an increase in pesticides use boosts quickly agriculture productivity but provokes economic losses within a 10-years delay.

Most of the parameters are estimated to maintain a certain level of difficulty to the game whereas the hydrology parameters remains the same.

At the moment, the parametric models are Excel sheets and require a teacher operating. It is a suitable solution for the game prototype so the teacher can work as a source of information as well as modify the parameters each time the players tend to try unexpected modification. For example, a subvention to an industry in a particular district, instead of general automatically distributed subvention.

Initially, the game was designed for 30 students in which 5 students represent the government and the others 25 are citizens with limited possibilities to influence the government's activities. Every 2 turns the government can be replaced through elections.

The game lasts approximately two hours including introduction, reveal of the true identity of Grand Coloredo and following discussion.

2.2 Experimentation

Experimentation was a rather uneasy part of this research project. Out of the four experiments originally planned last year, only two could take place and even those were disrupted by external factors like strikes and the global pandemic of 2020.

In the experimentation, we wanted to verify the second hypothesis (Acquisition of new concepts through a serious game shall be reinforced by confronting student's choices and behaviour to a real event.) We decided to measure through an exam how well the students acquired two non-intuitive concepts mentioned earlier:

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Firstly, the interdependence between the different consequences of environmental disasters (social, economic and of course environmental) and secondly the inertia of such consequences that is to say how late they show.

2.2.1 First experimentation: one group of 6 students

The first experimentation was planned for a class of 30 students of engineering program at Arts et Métiers Paris on the 16th of December 2019. The whole month strikes had paralysed public transports and we could perform the experimentation only with the six most motivated students who came.
We have recorded the whole game on video for further analyse of the students' reactions.
The six students quickly adopted the game's rules and contributed to their country's development. They have well played their roles, trying even to give advantage to their fictive characters native region.
They managed to keep up a good economic situation but just like the leaders of Uzbekistan, they ended up draining the Alan Lake.
Revealing the true identity of the game's location and history of the Aral lake's disaster triggered an emotional reaction among students which is rather unusual during lectures. It might facilitate good memorization of the serious game.
This first experience led us to think the game's concept was efficient even though it was tested on a non-representative sample of students.

2.2.2 Second experimentation: Group of 9 students and control group of 8 students

The second experimentation took place on the 19th of February 2020 at the IUT-A, Université de Lille for students in ecodesign bachelor program.
This time, we have decided to observe a potential gap between the serious game and traditional lecture, both still having the same teaching objective. Students were divided into two groups : one of 9 persons and one of 8 persons. One group played the government of Grand Coloredo and the second group had a lecture on the key factors of environmental issues: Complexity and non-linearity, inertia and excessive costs.
In order to identify differences between the game's and the lecture's impact, all the students have taken the same test at the end of the day.
It is difficult to anticipate what differences can happen between the two groups, that is why we decided to ask the students a large open question allowing us to analyse their intuitive reactions.
The question each student had to answer to was: What are the links between the economical, environmental and social aspects?
This time, students managed to avoid draining the lake by refusing irrigation projects that seemed too large to them. This might be explained by their previous education in eco-design.

3 RESULTS

On the first experiment, we could only observe a certain potential in better transmitting around environmental management issues. Students were discussing their approach and they seemed surprised to have the same results as the real Uzbekistan leaders. This session has confirmed a possibility to play the game in a smaller group.
The second experimentation allowed quantification and we aimed at verifying if a gap between the serious game and traditional lecture existed.
Table 1 shows responses of students to questioning after the serious game/lecture.

Table 1. Responses to the second experimentation

Responses to the question: What are the links between Economical, Environmental and Social aspects?	
Students of bachelor program "Ecodesign" at IUT-A, University of Lille, 12/02/2020	
Test group : 9 students who played the serious game : Evolution of Grand Coloredo	
1x	Student **points out** responsibility of actors to respect each of the three aspects
3x	Students **points out** responsibility of actors to keep the three aspects in a reasonable balance
4x	Students **points out** dependencies between the three aspects and comment on how complex it is to manage them.

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1x	Student **describes** issues of each aspect
Control group : 8 students who followed a lecture on environmental issues of sustainable management	
1x	Student **points out** dependencies between the three aspects
3x	Student **describes** issues of each aspect
4x	Student **describes** the three aspects as pillars of sustainable development and add note about existence of eco-design.

Although the students did not provoke the fictive disaster, they discussed the fact, that in reality the disaster did happen and might have been avoided with more careful decisions.
It is not surprising that students in ecodesign program did not give any wrong answer in the test, it is an interesting point that most students who played the game, tend to give judgement or evaluation in their answer. The others incline to a description. Four students out of nine highlighted the responsibility in decision-making and four others warned about complexity of management when taking into account such heterogeneous aspects.
The fact no one commented on the inertia of consequences may be due to two issues. For one, the question did not clearly mention the relation between decisions and consequences. In addition, the students probably also go for the "correct answer" more than making their own evaluations.
In an open discussion, three students noted that their point of view did not change after playing the game. One student remarked that the game helped reinforce his perception of how important and complex it is to achieve balance between the pillars of sustainable development. The other five students had not thought whether to change their point of view.
The control group responses indicated lesser achievements of the lecture's teaching goals. We expected from the students a higher tendency to give judgement or evaluation since the lecture was already a revised version with several practical examples. And previously we had a very positive feedback to this lecture from students in engineering program at the University of Strasbourg.
The second experimentation tends to confirm the serious game advantages compared to a traditional lecture. However, it could not fully confirm or reject our second hypothesis. (Acquisition of new concepts through a serious game shall be reinforced by confronting student's choices and behaviour to a real event.) In further experimentations, we aim to compare also with a fully fictive serious game in order to verify the hypothesis.

4 PERSPECTIVES

Our observations indicate a good potential of this serious game despite the difficulties to get more quantitative results. It seems that the concept of copying a real situation helps to provoke an emotional reaction among students. In addition to logical understanding of the consequences, students seem to realize that environmental problems are not really caused by bad intentions or incompetence. They appear due to lack of perspective and pressure to get quick results.
The game need more experimentations in order to validate or refuse the hypothesis. We plan to experience the game once in spring and once in autumn 2021 with students of engineering program at the University of Strasbourg. We plan to compare their performance to previous students in order to evaluate if there is any positive impact on their choices. Therefore, we plan this experimentation before beginning of a practical course on ecodesign.
Meanwhile the game itself needs serious improvements. The parametric models could be improved in order to reflect more closely the reality. Present version does not take into account any demographic evolutions, inflation or environmental impacts of industry. The advantage of this game lies in availability of all the necessary data. Getting it very close to the reality is only a matter of time, motivation and resources.
The game could also get a user-friendly interface, intro and ending, so it would not need a teacher in the future. In this perspective, we have launched investigations in order to develop a web-based experience of the experiment, in order to promote the exercise towards a larger public. Nevertheless,

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the goal is not to develop a full e-learning experiment but to develop sequences in hybrid learning, with a coaching and feedbacks with teachers that can be online. Due to the relative complexity of the LCA process, authors think that in order to have more efficiency while teaching LCA; face-to-face interactions are needed in order to have a better understanding of the underlying concepts.
Another perspective can be found in the topic of the fact that results of LCA must contain error. In this way, integrating errors functions and giving some inputs in order to reduce these errors (integration of error analysis algorithms, machine-learning methods…). (Yang, Frangopol and Han, 2021)
If the concept of serious game reviving the real events proves its efficiency in education, it could be extended to other domains, like security, quality management, maintenance.

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