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Insertion of sustainability performance indicators in an industry 4.0 virtual learning environment

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Abstract

Despite the profound impact caused by the technological revolution of the 20th and 21th centuries, many training practices, especially in formal education, have experienced little change. More holistic and self-sufficient means of education and training are necessary to meet the needs of manufacturing industry, incorporating success factors besides technical knowledge and economic viability, and one of the tools capable of delivering are serious games. One relevant concern when developing these tools is how to assess the learner's development and which goals to set as the learning challenge. To address this matter, this article contains a review of the sustainability assessment theory, focusing mainly on the social and environmental dimensions, and discusses the possibilities for incorporating theses metrics in a virtual learning environment both regarding their role for learning and motivation, their learning advantages and disadvantages as well as their relation to real practice, all in the context of the fourth industrial revolution. It aims to illustrate the usage of sustainability awareness as a learning outcome and the incorporation of sustainability indicators as tool to promote this development.

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Keywords: Serious Games; Sustainable Manufacturing; Sustainability Assessment; Technical Education

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1. Introduction

Highly skilled workforces have been a key factor to companies and countries successes for a long a time, and this shows no signs of changing. In an economy where machines are being developed to perform a wide range of tasks of different complexity and are capable of intercommunicating, the very definition of highly skilled worker will change in many areas. Coupled with the fast-paced evolution that has kept going for decades in the manufacturing environment training and education will keep or perhaps increase their importance in the foreseeable future.

There are many challenges to address in the education and training needs some of them more recent then others. The overly technical and fragmented technical-focused teaching that engineers are normally exposed to has been one of the main concerns for almost a century [1,2], and to face it more holistic approaches to learning are being used, among them the usage of games and simulations [3–5]. In a traditional context, learners would have different subjects to address different topics and new learning needs may be dealt with by creating a new subject and adaptation of the existing ones. When working however, solving problems is central and the subject or area divisions in acquiring or developing knowledge for this purpose are blurred. To decrease the distance between learning and working environments, more holistic methods of educating are being used.

Problem, project and case based learning are some examples of more integrated approaches, however, despite their many advantages, all of those require tutors and a significant amount of preparation time to be effective. Common ways to solve the external time demand are recorded classes, videos, books, texts and online courses but many of these commonly fall into the fragmented approach. The need to incorporate learning practices that are more closely related to real practice, especially regarding the competences they develop, is clear specially in engineering and technical context [2,6]. Due to their interactivity, adaptability potential, and the experience-focused approach, virtual learning environments, simulations and serious games are some of the candidates to address these three issues: education-work distance, fragmented subjects, staff time-constraints. The education-work distance can be reduced by creating environments that represent the usage of learned concepts in relatable work experience. This closer relation makes it difficult to create overly fragmented topics. While the initial cost of developing these learning environments is high, they can be massively reproduced with a greater potential for interactivity and adaptation to different difficulties.

To develop a truly holistic approach, the education and training practices cannot limit themselves to dealing only with technical matters and content, they must transcend concepts and incorporate other concerns that are relevant not only to manufacturing and industry, but to the society at large [7–9]. Manufacturing industries are not concerned only with producing goods and the costs involved, but also about the impacts that the production and products have for their clients, machines, consumers, the environment and society, be it from a legal or moral standpoint. A sustainable future depends on sustainability awareness, both social and environmental.

Incorporating sustainability assessment in the very technical and management education is a way to present applied sustainability concepts. While broader sustainability awareness focused courses do have their place, the direct insertion of sustainability issues and practices integrated in technical subjects can provide a more tangible understanding on how to apply them, in the training of the professionals who should do so. The main objective of this article is to present ways to incorporate sustainability learning outcomes through the usage of KPIs in an industry 4.0 serious game and learning environment considering motivational effects, in-game function with its advantages and limitations.

In section 2 the ideas of sustainability assessment will be discussed based on the literature to establish feasible indicators and practices to incorporate in the learning environment. Section 3 describes the virtual learning factory, its goals and comparison with other education practices. The fourth section describes the various approaches to incorporate these factors in serious games, virtual learning environments and in the proposed virtual factory. Finally, the last section brings the conclusion and other considerations.

2. Sustainability Assessment and Industry 4.0

Much data is collected to assess the performance of organizations regarding many different areas. Some of them are common and widespread, such as financial health or production efficiency, but others still require further development to establish themselves. Environmental and social sustainability indicators are a developing research topic and much discussion on best practices and results are still ongoing [10–13].

One of the key difficulties of sustainability indicators is their unconstrained nature. While factors such as financial situation and production parameters are mostly well defined, environmental and social factors transcend the organization´s borders and that of suppliers, customers and manufacturers. Considering this, it is understandable the lack of consensus and the gap between research and market practices regarding assessing sustainability [10–12,14].

Among the many practices for assessing sustainability, some division can be made. Typically, sustainability is divided in three dimensions, Social, Environmental and Economic, being the focus of this article the first two. For the environmental dimension there are already decades of research with some well stablished indicators even though many of them are not yet incorporated significantly in industrial practices [15]. In the social side of sustainability there is a lack of metrics due to difficulties in converting qualitative characteristics into directly measurable variables [15], however new attempts to address this matter aim to set scales of perceived success according to preset criteria [13,16,17] often require a qualitative quantitative conversion that leads to a more difficult implementation.

The categorization proposed by [11] divides sustainability KPIs in five dimensions of which “Social Well-Being” and “Environmental Stewardship” are of special interest for the discussion since the others regard economic and financial factors. Each dimension contains factors and descriptors under which the KPIs are placed. Compared to other analyzed articles, the social set of KPIs proposed by [13,17] are divided mostly in agreement with the categorization described in table 1, but [17] includes supplier characteristics (certification, commitment and initiative) and [13] includes indicators regarding supply-chain and location that are also not addressed directly addressed in [11]. On the environmental dimension the number of described KPIs increase significantly, and the proposition of the categorization does incorporate the most significant factors by creating a division into “Emission”, “Pollution”, “Resources Consumption” and “Natural Habitat Conservation” and is in agreement with [10,18]. “Product and Services (e.g. reusability)” and “Compliance (e.g. environmental fines)” [14] as well as “Legal Aspects” [13] and “Technique/Process” [15] can be included by considering in the categorization by considering the entire product life cycle and the local government goals toward sustainability.

Table 1. Environmental and Social sustainability indicators’ categorization

Environmental Stewardship	Social Well-Being
Emission	Employee
• Effluent	• Health and Safety
• Solid Waste	• Development
• Air Emission	• Satisfaction
• Waste Energy Emission	
Pollution	Customer
Hazardous Substances	• Health and Safety
• Green House Gases	• Customer Satisfaction
• Ozone-depleting Gases	• Customer Rights
• Other Pollutants	
Resource Consumption	Community
• Water Use	• Product Responsibility
• Material	• Justice
• Energy	• Development
• Land Use	
Natural Habitat Conservation	
• Biodiversity	
• Habitat Management	
• Conservation	

Adapted from [11]

While there is still much to be developed regarding this indicators and suitable tactics for incorporating them in manufacturing environments, many of these indicators have been around for more than a decade and especially environmental sustainability indicators are regarded as more well developed. Industry 4.0. design principles however can interfere in the way they are acquired and how to act on their improvement [19].

Industry 4.0 is an ongoing process of industrial development that explores factors such as machine to machine communications, vast amounts of data and always connected intelligent manufacturing plants [20,21]. The six design principles proposed by [22] (interoperability, decentralization, virtualization, real-time capability, modularity and service-orientation) will be considered to discuss how this industrial change can affect the sustainability KPIs usage.

From these six principles, modularity and interoperability may have the lowest impact regarding KPIs measurement since their main concern is internal machine operation and compatibility. Real-time capability changes the speed of response of the systems and accelerates corrective implementations. Decentralization can significantly alter the spread of the indicators accessibility and create hubs leading to different data granularity and more individualized responses. Virtualization and service orientation may influence KPIs in more throughout manner.

Service Orientation changes the relation manufacturing companies have with their products. One of the most significant example already in the market are short duration car rentals. To offer this service companies must control many KPIs (how much fuel it has, its fuel consumption, the rate of usage, the state of maintenance, when to stop it for repairs…) not only for analysis and business intel, but for in the very core of the business [23]. Service Orientation also relates directly to many of the sustainability performance indicators categories. Regarding environmental indicators, the higher use levels of the products (due to sharing and service offerings) can create direct improvements in pollution, emission and resources usage indicator. On the social dimension, eliminating the initial capital barrier (for cars, power tools, professional equipment, working spaces etc.) can make many assets available to a larger portion of the population, especially considering lower income families and individuals. This can also lead to increased durability of goods, since it is in the company best interest to make them available as service longer. Compared to products where the consumer pays, owns and has liberty on maintenance practices, service oriented products and service product systems aim to supply the functionality, which places continued operation capacity under the manufacturer/ service provider responsibility. The billing methods can also require specialized data collection, possibly including number of hour of usage, fuel and/or energy consumption, usage of consumable material etc. Summarizing, service orientation can lead to improve in data acquisition and longer life span of produced goods.

Virtualization changes the way KPIs can be followed up, separating them from location and if implemented to higher degree promotes significant changes in granularity. With the concept of virtual twins, the access to information and collected data from the manufacturing ground or even the supply chain at large may change the way KPIs are collected. Coupled with service orientation, this can lead to both direct action on the current state of the assets and a deeper understanding of consumer habits, increasing even more the potential improvements.

Put together, there are significant changes to how performance indicators will work in internet of things and industry 4.0. reality, however this means that there are also many opportunities for improvement. Working to educate on the best-known principles can accelerate seizing this potential.

3. The Virtual Learning Environment

The key difference between a simulation and a game are the goals [4]. Simulations can be used for learning and give their users a deep understanding about the simulated process [24], but simulations software do not incorporate objectives or limited resources. By adding these elements into simulation, they start to become a game.

To promote the learning of industry's 4.0. design principles, practices and impacts on the production, a virtual factory learning environment is currently under development. The chosen concepts have been taken from the literature on the subject. This environment will contain both explanatory and content related "tours" as well as challenges, or serious games, with different learning outcomes as goals. This environment will be as an example in this section and the next to exemplify the usage of different strategies for incorporating the KPIs in the challenges.

The different challenges are designed to achieve different outcomes and promote learning in a self-sufficient way. To understand virtualization, a player may have to set the communication between machines or use the virtual twins to make decision. For modularity, the learner may have a pool of different machines as resources, each with their functionalities, and create an assembly line layout built from these modular sections. In a more holistic scenario, the player may lead the change from an automated industry to an industry 4.0. paradigm. All these cases can use sustainability indicator as a concurrent factor to create secondary learning outcomes.

As a strategy, these serious games can be used in an academic as well as in industrial contexts. In an academic context, these tools can be more thoroughly explored for discussion and as mean to test the application of learned concepts. For an industrial environment, they can be used as learning assets, having some advantages over both written material and corporate courses. Among the main advantages of a learning environment are interactive content, visual representation of concepts, time saving (especially in the lower cognitive levels of Blooms [25]), active learning that enables reaching cognitive levels and increased motivation levels due to gamification concepts usage.

In general, the learning environment and other serious game implementations can be important learning tools, be it on the strategical, tactical or operational level. To use these tools to incorporate sustainability aspects to industry 4.0 learning environment, there are two main paths, either develop games that have sustainability teaching in industry as their main goal or incorporate sustainability when creating challenges and games with other learning outcomes. Both can be efficient, but the second is more holistic approach.

To discuss the motivational effects of different ways to incorporate KPIs in-game, the motivation taxonomy proposed by [26] which divides, from more externally motivated to more intrinsically motivated: External regulation, introjection; identification, integration and intrinsic is used.

4. In-game incorporation of sustainability aspects

There are many possible approaches to incorporate sustainability learning outcome in serious games challenges, this article deals with the usage of measurable KPIs. When considering a virtual learning factory environment, some of the indicators become more suitable than others as goals, rules or restrictions. While it is possible to design challenges and presentations that incorporate any of the indicators categories, they should be considered regarding the desired learning outcomes.

Of the discussed indicators, those related to legislation are better suited, in the proposed virtual factory, to be in-game rules for the sake of simplicity and because the possibility to be successful in-game by breaking the law is far from the main learning focus.

The easiest indicators to implement virtually are similar to the easiest to implement in the real world. It is much easier to rate a given machine energy consumption than to quantify the training impact in a worker's qualification. Despite this similarity, it is still much easier to measure them in a virtual environment since models can be implemented based on research with little regard to peoples' subjectivity or time spent answering and analyzing surveys.

In the "Environmental Stewardship" category (see table 1), the main indicators of the first three categories (emission, pollution, resource consumption) can be easily implemented being the biggest difficult to model in significant and didactic feasible features for machines that are yet to be created. The fourth indicator however (Natural Habitat Conservation) is more difficult to address since it is very location and industry dependent. Based on the learning outcomes exemplified in section 3, this set of factors are likely to be ignored, or of lesser importance, to most of the challenges.

On the "Social Well-Being" side of the table 1 there are many variables that are outcome dependent. If the outcome is role of human workers in industry 4.0 then the employee subcategory is central, if not, it gets more difficult and lateral to talk about their development and satisfaction. The customer indicators however are much more central when considering service oriented production systems and these indicators can be implemented (through virtual models) as a complement to many other learning outcomes. Community, however may not even be modeled in the learning environment for many the project outcomes, and while product responsibility is more closely related to the discussed issues, the other two may not be used in many of the challenges.

As discussed above, for each desired outcome, the most suitable indicators to verify how good is the player's decision-making process must be selected. There is however another dimension to this problem: which function will these indicators have in-game.

Table 2. In-game Function of KPIs usage characteristics

In-game function	Motivational Effect	Advantages	Disadvantages	Examples

Pre-requisite for proceeding or success	From: External regulation – if the player is only interested in proceeding. To: Identification – if the player is motivated by the game itself and understands the importance of this achievement to proceed.	By forcing the player to reach the required results, it is expected that his or her decision-making process is directed towards achieving this goal.	She or he may just perform the minimum level required and will not be stimulated to reach even better results.	Ask player to decrease resource waste by a given amount as the level final goal Increase labor income/ safety/ renewable energy usage by a given amount to proceed
Pondered (scored) pre-requisite for proceeding or success	From: External regulation – if the player is only interested in proceeding. To: Identification – if the player is motivated by the game itself and understands the importance of this achievement to proceed.	Contributing to the required score to proceed, this also puts significant pressure in achieving the required result in a forceful manner.	Depending on the mathematical participation in the required score, players may not consider sustainability factor or overuse them. This can be challenging to balance	Accumulate a company value of x: the company price is calculated based on economic, production and sustainability KPIs.
In game feedback factor	From: Introjection – if the player feels proud of getting a good score. To: Intrinsic – the player wants to get a better score just to get a better score.	This works as a feedback on how good the player decisions were. If multiple topics are presented in this manner it can deliver valuable information on where to improve. Also, player can get motivated to learn more by retrying the challenge, which rewards effort.	Each of the factor of the grades must be implemented distinctively and the game must have a built-in scale of results, which can be difficult to balance.	In the end of the level or challenge the player gets a score card containing her or his results regarding different factor (e.g. Economic: A, Social: C. Environmental: A).
Resource related reward	From: External regulation – if the player is only interested in more resource for proceeding. To: Identification – If the player is interested to achieve the best result.	Since the resources are useful to the player to achieving other results, he or she will have more reasons to pursue the objective. Also, since the resource is an in-game variable the player may seek better results on the principle of the more the better.	This is also an Extrinsic motivation to tool that may be difficult to balance. While small incentives may be related to real practices (like better interest rates on loans for more sustainable companies) an exaggeration to make it feasible as a reward may easily become unrealistic	If the sustainability results are above a certain level, the selling price of products increase. The player gets access to new marketing strategies based on their environmental results.
Resource unrelated reward	Intrinsic	Giving rewards in game can motivate players to participate and do well for the game itself.	Since they are not mandatory they can easily be ignored.	Badges for achieving good sustainability results, Changes in environments such as more plants in the gardens or gifted plants in the office. New dialogues and in-game recognition such as compliments from co-workers

To better deal with learning curves and learning objectives, some challenges may be subdivided into levels where achieving certain results may enable players to proceed, making the control of this advancement one of the possible functions for the chosen KPIs. This function, the first item of table Table 2, places achieving the required results regarding the indicators the defining factor for progression, similar to final grades in traditional courses, it determines whether there will be repetition, and as such may be faced as a mere obstacle. A company that has to improve their waste management to get a certification is a relatable example that is transferrable to a virtual learning environment where a KPI by itself is a measure of success.

The same logic can be used by pondering different indicators in a composed score, and defining this score as the result, a function described in the second line of the same table. Instead of focusing in only one factors, the consideration of multiple success measures is more related to common industry practices where an optimal point balancing many constraints is aimed at. Few, if any, organizations, can use sustainability KPIs as their sole measure of success outside of specific situations, making this approach broader than the first.

Another in game function for KPIs, is a “In game feedback factor”, where in the end of a level, or other suitable milestone, the player may also be given a feedback (be it a grade, score or result text) on how well are his in-game results in respect to any of the outcomes’ areas. While talking to clients, a player can be complimented by their efforts for the environment or the local community with the dialog changing depending on his or her level of success. Since this is not directly required, it draws from more intrinsic levels of motivation.

The item “resource related reward” means that by maintaining or achieving superior results in one area a player can be given more resources to improve his chances in the challenge. A bonus payment, useful for the challenge main goal (or proceeding requirement), for achieving a certain threshold in a KPI is one example of this in-game-function.

The last item is resource unrelated rewards which consist of side elements that do affect directly the game play but can give the player the feeling of achievement and of control of the virtual environment, which can have a significant impact in motivation. More kids playing in the gardens, a new object on the player´s table, an award that can be accessed in the main menu or other consequences of the player´s result are some examples of how to use this function.

It is important to note that if any of the in-game functions described in table 2 has the intention to be used for grading purposes, a direct external regulation or introjection (depending on the student) incentive is added to the description

5. Final Remarks

The importance of incorporating sustainability assessments in manufacturing context is a well-known fact. To decrease the gap between theory and practice and better illustrate the usage of these indicators in actual decision-making situation, this article has proposed their implementation in a serious game learning environment. By incorporating sustainability KPIs in the functions described in Table 2, they become goals that share space with economic and improvement challenges in this environment, creating space for designing learning material that actively addresses this gap.

The proposed in game functions for inserting KPIs in the virtual learning environment can be useful as means to understand the motivational and learning impacts about their strong and weak points and considering their conceptual connection to real industries. If their incorporation is made in verisimilar manner, they can become to promote awareness and attention to environmental practices.

To fully understand and validate the proposed model, the implemented KPIs should be put to test both in academic and industrial environments to assert if they do or do not alter in-game sustainability results, if they affect motivation to look and decide based on these indicators and if the connection is seen between the virtual-world decision making and that of the manufacturing reality.

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