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Developing Systemic Thinking through Gamification with Invention System Kits: Case of an Aircraft Assembly Line*

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Abstract: developing countries like Colombia have understood that education is an effective strategy in closing social inequality gaps to improve population's skills. In the last decade, coverage in higher education went from 30 to 50 percent. One of the most important factors in this achievement is Colombia's transition to peace, increasing the development of the population towards higher levels of competitiveness and education. In consequence, it is necessary to reinforce the development of competences, to encourage systemic thinking that allows the solution of problems from a holistic view and achieves effective solutions in the improvement of the local industry. During this study, an applied ludic strategy involving an airplane assembly line made with Lego blocks is created, looking for an effective and practical education framework in teaching the attributes that generate impact in a production line of goods; in this way, students can be involved in a clear and creative manner in their search for solutions. This project was developed by member professors and students from an engineering education institution in Bogotá, Colombia. The results show that through gamification, students develop skills to take decisions leading to increase the production's competitiveness from a systemic thinking view.

Keywords: action learning; case method; learning; strategy education.

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Desarrollo del pensamiento sistémico con ludificación a través del uso de sistemas de invención: caso de estudio de una línea de ensamblaje de aviones.

Resumen: los países en desarrollo como Colombia han entendido que la educación es una estrategia eficaz para cerrar las brechas de desigualdad social y mejorar las habilidades de la población. En la última década, la cobertura en educación superior pasó del 30 % al 50 %, siendo uno de los factores más importantes en este logro, la transición de Colombia a la paz, incrementando el desarrollo de la población hacia mayores niveles de competitividad y educación. En consecuencia, es necesario reforzar el desarrollo de competencias, fomentar el pensamiento sistémico que permita la solución de problemas desde una visión holística y que logre soluciones eficaces en pro de la mejora de la industria local. Durante este estudio, se crea una estrategia lúdica aplicada que involucra una línea de montaje de aviones hecha con bloques Lego, buscando un marco educativo eficaz y práctico en la enseñanza de los atributos que generan impacto en una línea de producción de bienes; de esta manera, los estudiantes pueden participar de forma clara y creativa en la búsqueda de soluciones. Este proyecto fue desarrollado por profesores y estudiantes miembros de una institución de educación de ingeniería en Bogotá, Colombia. Los resultados muestran que a través de la ludificación, los estudiantes desarrollan habilidades para tomar decisiones que conduzcan a aumentar la competitividad de la producción desde una visión sistémica del pensamiento.

Palabras clave: aprendizaje de acciones; método de caso; aprendizaje; educación estratégica.

Pensamento sistêmico por meio da ludificação com pacotes do sistema de invenção: caso de uma linha de montagem de uma aeronave

Resumo: os países em desenvolvimento como a Colômbia vêm entendendo que a educação é uma estratégia eficaz para fechar as brechas da desigualdade social e melhorar as habilidades da população. Na última década, a cobertura do ensino superior passou de 30 % a 50 %, sendo um dos fatores mais importantes nesta conquista a transição da Colômbia à paz, aumentando o desenvolvimento da população a maiores níveis de competitividade e educação. Em consequência, é necessário reforçar o desenvolvimento de competências, fomentar o pensamento sistêmico que permita a solução de problemas sob uma visão holística e que consiga soluções eficazes em prol da melhoria da indústria local. Durante este estudo, é criada uma estratégia lúdica aplicada que envolve uma linha de montagem de aviões feita com peças da Lego, a fim de encontrar um referencial educacional eficaz e prático no ensino dos atributos que geram impacto em uma linha de produção de bens; dessa maneira, os estudantes podem participar de forma clara e criativa na busca de soluções. Esse projeto foi desenvolvido por professores e estudantes membros de uma instituição de ensino de Engenharia em Bogotá, Colômbia. Os resultados mostram que, por meio da ludificação, os estudantes desenvolvem habilidades para tomar decisões que levem a aumentar a competitividade da produção sob uma visão sistêmica do pensamento.

Palavras-chave: aprendizagem de ações; método de caso; aprendizagem; educação estratégica.

INTRODUCTION

In the last years, the National Development Plan of Colombia has established education to be one of its three fundamental pillars so that the education system's levels of quality and equality improve. However, today's numbers show an enduring difficulty regarding this issue (Consejo Privado de Competitividad, 2016). Because of this, Colombia is expected to have become the best educated country of Latin America by 2025 (António Alfonso, 2013) and thanks to the peace process and its subsequent agreements, an important increase in the education budget is seen. This is expected to improve the fund management and distribution. Consequently, a strong social commitment arises with a high involvement of the business sector and educational institutions to increase the number of registered students in all levels and to provide education services throughout the country (Organisation for Economic Co-operation and Development (OECD), 2016).

This transition stage that is taking place in the country prompts a need to offer alternative and effective learning environments for comprehensive education, especially in engineering. To meet this requirement, systemic thinking is recognized as one such approach which allows to improve decision-making for different actors of productive systems, focusing on heightened performance of activities (Seddon & Caulkin, 2007). Additionally, recent studies show that involving simulation games as teaching and learning strategies favours the comprehension of economic, environmental, and social issues regarding the decisions made in a productive system (Müller, Reise, Duc, & Seliger, 2016).

Developing systemic thinking in engineering students for decision-making through active learning promotes better results by perceiving the elements of a company in an interconnected manner, which is a key aspect that an engineer must face in the working world. Therefore, this project is based on the use of an airplane assembly line consisting of different workstations and built with Lego Mindstorms EV3, as a ludic way to teach and develop competences. The use of Invention System Kits has proved to be highly effective as a complement in the teaching and learning processes in several knowledge fields. That is why this material was chosen to be implemented at Escuela Colombiana de Ingeniería Julio Garavito, an engineering education institution located in Bogotá, Colombia, to develop decision-making competences based on a systemic approach for industrial engineering students.

Firstly, background about this research field is presented along with a bibliographic review on the methodologies used in the field of gamification. Similarly, a brief overview about the present situation of Colombia in topics related to engineering and higher education is presented. The following section shows the methodology used for this project to end up with the results and future research suggestions based on this process.

▪ BACKGROUND

Getting students involved in their learning process seems to be one of the biggest challenges of current education, especially in universities. This is due to the rapid technological development and innovation that offer opportunities to enhance the contributions of the scientific community through theory, tools, and new applications employed in higher levels of decisions (Murray, Åström, Boyd, Brocket, & Stein, 2003).

According to the OECD (2016), there were about 288 higher education institutions in Colombia in 2016 (universities (28%), university institutions (42%), technological institutions (18%), and technical institutions (13%)), which offer over 10,000 academic and vocational programs. However, by 2013 only 33 higher education institutions (11.5%) were awarded a High-Quality Accreditation; likewise, only 813 (8.5%) academic programs out of 9,608 available had such an accreditation. In recent years, Colombia has shown significant improvement in several fields; for example, Colombia now has a higher education coverage above 50%, which is significantly better than 2016 which recorded only 30% (Organisation for Economic Co-operation and Development (OECD), 2016). Colombia's advantages are plentiful: young population, abundant natural resources, and an open economy. In addition to this having signed the peace agreement which ended the long standing internal armed conflict has become a competitive advantage for the country in several aspects.

In this respect, Colombia is considered to be the second most biodiverse country, only topped by Brazil, for its potential to foster research and industry (Gross, 2014), due to the abundance of species in both flora and fauna (Rivera-Méndez, Rodríguez, & Romero, 2017); in the agricultural sector due to food production and secondary products (Ibanez, 2016), especially for the widely known Colombian coffee (Alzate, et al., 2017); and the energy sector, due to its capacity to generate electricity for all the population using only half of its potential for wind power capacity, although only 0.4% of it is used (Edsand, 2017). Furthermore, by having coasts both on the Atlantic and on the Pacific oceans, Colombia holds a strong logistic potential (Consejo Privado de Competitividad, 2016), because it can take advantage of its geographical location and resources to implement fluvial means of transport, through the navigability of the Magdalena River (Castro Escobar, 2008); land means, such as the existent railroads (Nieto, 2011); and maritime means, by allowing the creation of multimodal systems of interoceanic transportation of goods providing safer and faster passage on Colombian soil (Hoffmann, 2008).

In the field of education, Colombia has created different methodologies to explore interactive and educational contents, stimulating and motivating students to learn concepts by interacting with information, tools, and materials. A study pursued by Universidad de Córdoba in Colombia performs a ludic simulation to analyse the traditional production method and the Theory of Constraints (TOC) production method to manage multitasking environments. It consists of recreating a scenario by simulating a real productive environment, which allows showing and comparing a productive system with multitasking processes. Likewise, it recreates applied processes to TOC, wherein students play a role in the productive system that allows them to assimilate the characteristics of every method and to become capable of identifying the advantages of one over the other. The ludic aspect is developed in the process of motorbike assembly and building a production line station (Marín-González, Montes-de-la-Barrera, Hernández-Riaño, & López-Pereira, 2010).

Moreover, Lego Mindstorms has been widely used in recent years in different areas (Repenning, 2013). Examples of such use are the multiple applications of Lego NXT, Segway or M3DITRACK3R. The first Invention System Kit with visual programming was called Legosheets, an educational software for learning, which can run simulations with mechanical devices programming and design (Gindling, Ioannidou, Loh, Lokkebo, & Repenning, 2002). One of the main examples in the education field is Lego Mindstorms NXT, used in lab experiments and students' competitions, within a framework of real-time programming and mainly for robot competitions. The goal of these types of games is to encourage design and experimentation with simulation, as a motivating platform to introduce different competitions. To achieve this, basic LabVIEW models are made in lab practices implementing the Lego Toolkit and command programming (Gomez-de-Gabriel, Mandow, Fernandez-Lozano, & Garcia-Cerezo, 2010).

Another example of Invention System Kits is Segway, a self-balancing two-wheeled vehicle produced by S.A. Segway. This device is propelled by two electric engines in its base, with a main regulator and four sensors (for example, the ultrasonic sensor is used to warn about possible collisions ahead, and the light sensor to provide angle). Real-time programmed simulation is useful mainly to clarify the theoretical concepts in physical simulations, since they are experimented and developed by students (Rodríguez, Guzmán, Berenguel, & Dormido, 2016).

In the medical field, M3DITRACK3R has a medicine management model using its time of prescription and dosage, to help reduce skipping medication unintentionally, common among senior patients. The proposed model uses Lego Mindstorms EV3 Kit allowing patients to introduce the medicine followed by a touch sensor that determines the duration of the medication (one touch sets the timer at 12 hours and two touches sets it at 8 hours). The device can dispense water and medicine at the pre-set time and, using a smartphone, collect essential data to check on patients, such as current location of seniors. However, it is not particularly efficient for users that are not technologically savvy (Chelvama, Zamina, & Steeleb, 2014). In addition, “technology in the broadest sense has become a key driving force for firms, industries, and the global economy. Governments and universities worldwide are pushing for education programs that produce more “entrepreneurial engineers” who are “bilingual” in the sense that they possess dual managerial and technical competences” (Verzat, Byrne & Fayolle, 2009, p. 356).

These are some of the challenges and opportunities that today’s students, in engineering and other knowledge fields, will face to achieve higher competitivity at the international level. That is why it is necessary to develop educational strategies that allow learners to become competent professionals capable of reaching new knowledge through the implementation of ludic and didactic systems; which is a widely used and proved efficient teaching model.

Therefore, regarding the Colombian context there are still opportunities to enhance research on education strategies using gamification. This study aims at contributing to this research field from a qualitative perspective.

▪ THEORETICAL FRAMEWORK

A distinguishing element in teaching is the training of systemic thinking in students for problem analysis and solution in an efficient manner, based on ludic games with a systemic approach that allows for the development of critical thinking skills. In this research, specific issues are analysed, such as systemic thinking and simulation, , through different successful strategies: gamification, considered to be an efficient tool for developing problem-solving skills, decision making, research, multitasking, collaboration, and creativity (Freitas, et al., 2012). Besides, the systemic approach fosters cognitive independence, integrity, and creative character, encouraging the development of a competent personality (Michelena, 2017).

It can be a natural, engineering or company system. A production plant is a subsystem of a company and, in turn, the company is a subsystem of the market. Systemic thinking focuses on seeing the systems as a whole and how the interrelationships between their parts generate their behaviour (Seddon & Caulkin, 2007). Ballé et al. (2006) consider manufacturing operations as social systems. This implies that even the most automatized plants critically depend on people for their operation. Therefore, if the role of the social system is critical, the importance of learning is even more relevant. Particularly regarding an assembly line, in order to solve the challenges of the cycle time or lead time in the configuration, not only the ability to solve problems is required but also the skills to investigate, find the root cause and implement measures that counteract the emergent behaviours not desired in the productive system (Ballé et al., 2006). The above requires seeing the system as a whole, from a holistic point of view, making the best decisions.

Gamification is “a process of enhancing a service with affordances for gameful experiences to support user’s overall value creation” (Huotari & Hamari, 2012, p. 19), that has been focused on elements of systemic games, with the objective of having a support9* system for decisions and helped by the creation of experiences. Hamari and Koivisto (2015) also define it as a technology that attempts to promote individual motivations in different activities, through the introduction of game design characteristics to motivate and support people towards different individual and collective behaviours, using emotional mechanics. Therefore, gamification can be studied in different spaces, education for example, to analyse the potential of learning new technologies, fostering students’ development, and improving comprehension, with educational environments as a pedagogical methodology (Schneckenberg, Ehlers, & Adelsberger, 2011).

A teaching strategy to enhance students’ critical thinking in their learning process is the application of tools and methods such as simulations, a technique used to improve logical reasoning by solving complex problems (Choi & Kim, 2017). Through gamification as a procedure for game design and teaching methodology, this technique holds great benefits for innovation in education, since organized games generate spaces to reach creative thinking skills (Werbach & Hunter, 2012); besides, it also allows to acquire basic knowledge and skills for decision making. Lego Mindstorms EV3, as an Invention System Kit, has a user-friendly interface for programming with basic robotics components; it makes it possible to design with a study control approach, for teaching how to develop advanced software or simulated production (Lew, Horton, & Sherriff, 2010). Previous research shows that the use of Lego (Roth, Schneckenberg, & Tsai, 2015), a method of innovation and gamification based on the combination of pieces and sequence of steps, leads to foster creative and intuitive thinking for decision making. Results show the potential of ludic activities to facilitate group discussions during the early stage of innovation, with the goal of stimulating creativity.

A study made by Nailya, Anna and Aida (2015) shows that universities should consider the following fundamental principles in the teaching strategies used in the educational process for fostering systemic thinking through gamification and multidisciplinary projects: (a) priority of training through action, (b) wide-range learning, (c) multiple solutions comparing and (d) choice-based education structure.

To achieve a meaningful teaching and learning experience through gamification, the starting point should be the theory for the development of a game concept, from this principle, Taspinar, Schmidt and Schuhbauer (2016) claim that all attempt at gamification and autonomous learning should be focused on meeting the needs of both parts: learners, also known as players, and teachers, who transmit a knowledge; a methodology aimed at developing the model to be implemented.

METHODOLOGY

The methodology of this research is grounded on the one used by Nailya, Anna and Aida (2015) in four (4) pre-set steps and a fifth (5) step was included for the performance analysis. It was selected because it suggests highlighting the types of skills and knowledge that are more relevant for professionals to identify, analyse and define meaningful elements of a problem so that it can be solved effectively and with sound reasoning. Besides, it is founded on the quality of decision making and an approach towards students' systemic thinking development in the teaching process, allowing them to obtain a competitive advantage. The interest for this study is to explore from a qualitative approach the students´ development of systemic thinking when making decisions in order to improve an airplane assembly line. Within the framework of this study, those steps are performed as follows:

Step 1: Priority of Training through Action

This step consists of encouraging students to identify themselves with the type of task, to use the ability to recognize previously learned theoretical principles for problem solving, and to take responsibility for the results and impact level of their actions.

A ludic strategy is designed for the project; whose primary activity's goal is to build an airplane assembly line with Lego blocks using Lego Mindstorms EV3 sets. This assignment allows students to understand and develop in a practical manner the concepts learned about the development of a production line and the factors that play a role in it. Firstly, understanding cycle-time as the time it takes to complete to develop a product from the beginning of its production until its conclusion, distributing it as activities that either assign the product an added value or not. Secondly, takt time defined as the time or pace needed to produce a product to meet customer demands. Finally, a single line production system defined as an effort to manufacture a single specific product. The activity is performed by 3 engineering students that belong to the research seedbed of the education institution sponsoring the research project titled: *Simulation of production systems as a tool in the development of competences for decision making under a systemic approach*. Overall, the activity aims to foster systemic thinking in the actors through decision making, that allows the development of a product according to pre-set specifications and proposals, achieving their preparation for Step 2.

Students have the possibility to develop the activity by using their knowledge and preferences, considering the established limitation such as creating a single line that assembles Lego airplanes and making a programming that allows for easy modification and utilization. To measure the results obtained in this first step, the checklist shown in Table 1 is proposed. This checklist is filled in by 3 expert teachers who accompany the educational process of the students.

Table 1. Step 1 Checklist. Source: Own creation.

<table>
<tr><th colspan="4">Checklist</th></tr>
<tr><td colspan="4">Assembly line simulation for systemic thinking development through gamification using Invention System Kits.</td></tr>
<tr><td rowspan="3">Students’ names</td><td colspan="3"></td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3"></td></tr>
<tr><td>Passed/Failed</td><td colspan="3"></td></tr>
<tr><td colspan="2">Design</td><td>Check</td><td>Comments</td></tr>
<tr><td colspan="2">Functional prototype</td><td></td><td></td></tr>
<tr><td colspan="2">Optimization of Lego Mindstorms EV3 sets (quantity)</td><td></td><td></td></tr>
<tr><td colspan="2" rowspan="2">Functionality of the single line for the other stages of the process</td><td rowspan="2"></td><td></td></tr>
<tr><td></td></tr>
<tr><td colspan="2">Semi-automation of line</td><td></td><td></td></tr>
</table>

Step 2: Wide-Range Learning

The second stage aims to foster capabilities in the students to make decisions and to propose solutions to a given problem. For the project, a practical case is built, which describes the context (problem that needs solving) and invites other 3 students from the engineering program who are interested in expanding their knowledge about the topics in a practical and ludic manner, to solve the context (the first group of students, belonging to the research seedbed, will now be referred as leader students). The case contextualizes the need to improve the airplane assembly line to meet the customer’s demands. The challenge assigned for the second group of students is to select the best production configuration available based on the proposals given by the leader students in Step 1, observing and measuring the cycle-time, the efficiency, and the idle time of every station. Here, the use of knowledge and decision making on the side of the students plays a strategic role. Students receive the form in Table 2 to fill in their calculations and analyses.

Steps 1 and 2 seek to develope knowledge in the student through gamification. For Step 1, leader students generate knowledge about the construction of a single line for assembling Lego airplanes, which requires full understanding of concepts regarding constructing and programming Lego Mindstorms EV3 sets, for the line to be semi-automated and to have the expected performance. Students in Step 2 strengthen their knowledge about cycle-time, efficiency and single line in a ludic way.

Table 2. Form to Fill in Calculations and Analyses Step 2. Source: own creation.

<table>
<tr><th>Daily production</th><th>17 airplanes/day</th><th colspan="2">Time available (hours)</th><th>8</th></tr>
<tr><td colspan="5">$$Efficiency = \frac{\sum operation\ times}{number\ of\ stations \cdot cycle\ time}$$
$$Cycle\ time = \frac{Expected\ produced\ units}{Available\ time}$$</td></tr>
<tr><th colspan="5">Production rhythms</th></tr>
<tr><td colspan="2">Operation Change</td><td>1</td><td>2</td><td>3</td></tr>
<tr><td colspan="2">Operation E</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Operation G</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Operation I</td><td></td><td></td><td></td></tr>
<tr><th colspan="5">Case Analyses</th></tr>
<tr><td>Cycle-time 1 (min)</td><td></td><td colspan="2">Cycle-time 2 (min)</td><td></td></tr>
<tr><td>Cycle-time 3 (min)</td><td></td><td colspan="3"></td></tr>
<tr><td colspan="2">Calculation 1</td><td colspan="3">Calculation 2</td></tr>
<tr><td colspan="2"></td><td colspan="3"></td></tr>
<tr><td colspan="5">Calculation 3</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>Efficiency 1 (%)</td><td></td><td colspan="2" rowspan="2">Efficiency 2 (%)</td><td rowspan="2"></td></tr>
<tr><td>Efficiency 2 (%)</td><td></td></tr>
</table>

Step 3: Multiple Solutions Comparing

This step attempts to educate students to be able to provide and compare different solutions for the problem, relating economical and technical traces.

Through gamification, guest students in Step 2 were expected to identify what problems arise in the assembly line based on the calculations and analyses performed in the previous step and, from that point, to provide and compare different solutions to decrease the cycle time and thus making the line as productive as possible. The capabilities that students are expected to develop are:

- Analytical skills to identify and provide solutions for a problem situation present in an industry, considering all the elements of the system.
- Teamwork capabilities.
- Ability to apply previous knowledge for joint decision making to improve a system's behaviour.

To assess the development of the students regarding the above-mentioned capabilities, Table 3 proposes a checklist for the expert teacher to evaluate the students' development during the ludic strategy real-time observation.

Table 3. Checklist Step 3. Source: own creation.

Checklist		
Assembly line simulation for systemic thinking development through gamification using Invention System Kits.		
Student's name		
Pass/Fail		
Capabilities	Check	Comments
Analytical capabilities to identify and provide solutions for a problem situation present in an industry, considering all the elements of the system.		
Teamwork capabilities.		
Apability to apply previous knowledge for joint decision making to improve a system's behaviour		

Step 4: Choice-Based Education Structure

Lastly, this methodology sets activities that provide different opportunities for students to apply their skills and competences. For this project, especially, to round up the ludic strategy, students propose and implement a plan that improves the assembly line's performance. To achieve this, students are autonomous, guided by their own knowledge and the tutoring of expert teachers and leader students. This activity aims to strengthen, and evidence practical knowledge acquired during the ludic strategy complementing their training process in the *Industrial Facilities Design* academic course from the industrial engineering curriculum. To assess the activity's performance, Table 4 proposes a form where students must fill in and compare the initial results of cycle-time, stations' idle time, and single line efficiency, versus those obtained with the implemented strategy. Results are delivered to the expert teacher who checks whether the practical case goal was achieved during a focus group session.

Table 4. Form to Fill in Calculations and Analyses from Step 4. Source: Own creation.

<table>
<tr><th colspan="3">Assembly line simulation for systemic thinking development through gamification using Invention System Kits.</th></tr>
<tr><td>Student’s name</td><td colspan="2"></td></tr>
<tr><td>Fulfilled objective</td><td colspan="2"></td></tr>
<tr><td>Topic</td><td>Initial</td><td>Proposed</td></tr>
<tr><td rowspan="2">Operation E (min)</td><td rowspan="2"></td><td></td></tr>
<tr><td></td></tr>
<tr><td rowspan="2">Operation G (min)</td><td rowspan="2"></td><td></td></tr>
<tr><td></td></tr>
<tr><td rowspan="2">Operation I (min)</td><td rowspan="2"></td><td></td></tr>
<tr><td></td></tr>
<tr><td rowspan="2">Efficiency (%)</td><td rowspan="2"></td><td></td></tr>
<tr><td></td></tr>
<tr><td rowspan="2">Cycle-time (min)</td><td rowspan="2"></td><td></td></tr>
<tr><td></td></tr>
<tr><td rowspan="2">Produced airplanes/day</td><td rowspan="2"></td><td></td></tr>
<tr><td></td></tr>
</table>

Due follow-up of each step enables students to develop systemic thinking, as well as decision making skills, evidenced through ludic, teaching, and development of the competences mentioned in the methodology.

Step 5: Performance Analysis

According to the authors Kumar (2014) and Trochim y Donnelly (2006) qualitative research can be analysed with different criteria than quantitative research. Below is the proposed alternative criteria and its comparison with traditional criteria.

Table 5. Traditional and alternative criteria for judging research. Source: Adapted from Kumar (2014)

Traditional criteria for judging quantitative research	Alternative criteria for judging qualitative research	Description of the alternative criteria
Internal Validity	Credibility	Credibility is establishing that the results are believable from the perspective of the research participants.
External Validity	Transferability	It is the degree to which the results can be generalized or transferred to another context. In these criteria the researcher can make a description of context and assumptions around to the research in order to improve and ensure the transferability.
Reliability	Dependability	It consists in ensuring that we would obtain the same results if we could observe the same thing twice. Therefore, the researcher can document the changes that occurred in the investigation and how they affected the investigation to ensure dependability.
Objectivity	Confirmability	The degree to which the results could be confirmed by others; the researcher can document the procedures to check and recheck the data throughout the study.

To ensure the performance of this qualitative research and its corresponding analysis, these four criteria were used.

On the other hand, the sample size was selected using the concept of saturation point described by Kumar (2014), which consists in collecting data to the point where no new information is obtained. This criterion is decided by the researchers.

RESULTS

This section shows the results found after developing the methodology with the pilot group of students. The findings allow infering the impact that ludic-based teaching strategies have on engineering education and learning, which could eventually be studied with larger groups of participants. Overall, by being involved in the ludic strategy, students evidenced the development of systemic thinking, which allows them to grow improved technical skills and better understanding of relevant concepts for their social and professional development.

Step 1: Priority of Training through Action

During the first stage, based on the initial specifications, leader students build a Lego airplane assembly line with a simple elaboration process and a ludic approach that captures their attention. All of this through previous research of production systems, specifically a single-line system, since it provides an easy development of the assembly line and the activity carried out in the second step. This system sets up a determined number of consecutive stations and flexible programming for its development by using Lego Mindstorms Education EV3 sets.

Lego provides a software for Mindstorms Education EV3 sets, which is user-friendly and allows grabbing action blocks from a list, placing them on the developing program and for example changing motor value or location depending on the hardware to be programmed, as shown in Figure 1.

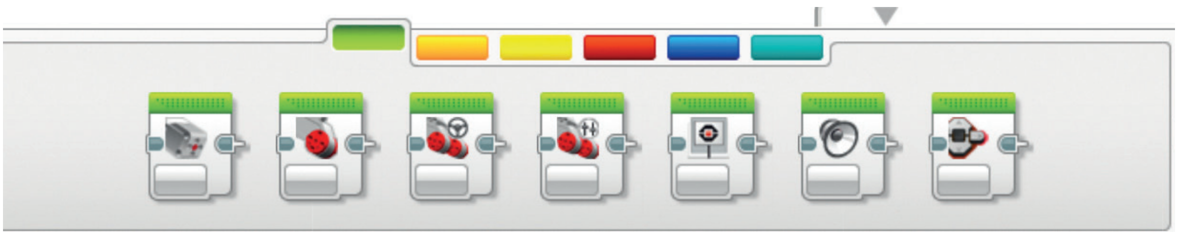

Figure 1. Programming Blocks. Source: Software Lego Mindstorms Education EV3.

Considering that the students who were part of the assembly line development have previous knowledge about programming and facilities design, 4 semi-automated stations are established using the following hardware: 2 programmable bricks, which allow correct airplane assembly, 1 big motor, which allows assembly line movement and the automated arm performance, 5 medium motors which place the pieces in the appropriate place and subsequent proper assembly, 1 touch sensor which enables the first station and the assembly line, connection cables and assembly pieces, 3 types of programming to set simulations that provide more opportunities for analysis and correct functioning of the assembly line.

Figure 2. Assembly Line. Source: Own creation.

The airplane is made with the following blocks (see Figures 3 and 4): Yellow block: fuselage, White block: tail plane, Blue block: body, Gray block: cockpit, red block: wings

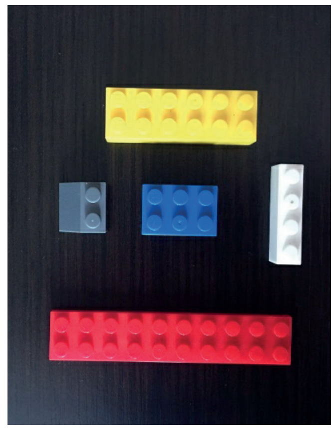

Figure 3. Airplane blocks. Source: Own.

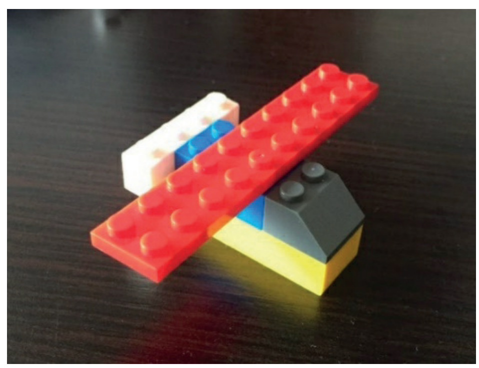

Figure 4. Assembled airplane. Source: Own.

Stations are divided as follows:

- First station: It oversees assembling the fuselage and the tail plane through a mechanism developed to position the pieces in the correct place to lock them together.
- Second station: The body is supplied manually and then the pieces proceed to assembler number 1, which locks all pieces correctly (see Figure 5).

- Third station: The cockpit is manually supplied and then the pieces proceed to assembler number 2, which locks all pieces correctly.
- Fourth station: The wings are manually supplied and then the pieces proceed to assembler number 3, which finishes the assembly process (see Figure 6).

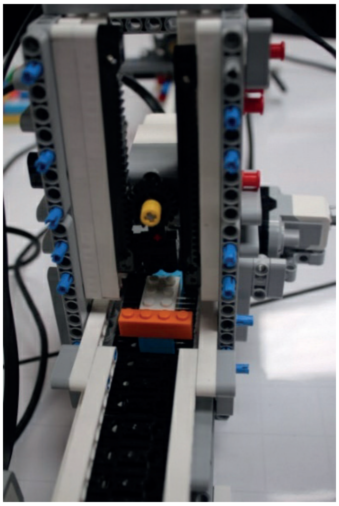

Figure 5. Assembler 1. Source: Own creation.

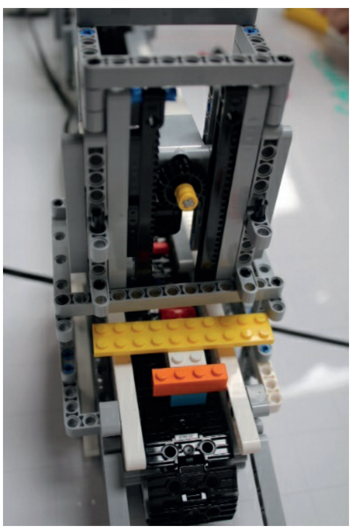

Figure 6. Assembler 3. Source: Own creation.

Based on the prototype or assembly line constructed, expert teachers assess the activity developed by the leader students using the checklist (see Table 1), which includes the revision and analyses results pertinent to each aspect listed. Among the findings, experts highlight the achievement of an activity that can motivate students to learn all expected concepts in a practical manner through the developed line. This line complies with the initial requirements: first, its semi-automation for a correct development of the activity; second, Lego sets optimization since students had 4 bricks at the beginning and 2 at the end; third, having a fully functional prototype easily understandable and usable. The line's functionality is clear for the development of Step 2, so the proposed objectives are achieved as confirmed by experts.

Step 2: Wide-Range Learning

To contextualize guest students, a practical case is delivered that details information about the assembly line, such as the precedence diagram, each station's description accompanied by pictures and technical data of the assembly line as shown:

- Number of airplanes expected by the customer: 17.
- A workday is 8 hours long, restricting it to a maximum of 12 hours a day.
- Soldering machines times are standard, so they cannot be reduced.
- The sequence of activities of both the assembly line and the operators cannot be modified. Changing this configuration can cause longer times and production errors.

Likewise, students are informed that their results will be assessed per the following criteria:

- Diagnosis: correct calculation of the current situation, that is, cycle-time and line efficiency with the initial conditions.
- Shortage: number of airplanes that are not produced compared to the customer's needs in an 8-hour workday (takt time vs proposed cycle-time).

Once the practical case is exposed, leader students perform a functional sample of the airplane assembly line, through a simulation done under pre-set conditions in the initial programming of each brick that composes the system for the sample.

After the initial sample of the assembly line's functioning, each of the 3 different configurations starts simulating so that students can face the challenge of selecting the best configuration available based on the proposals made by the leader students in Step 1. Students are eager to face the challenge and run all calculations based on the directions they receive in the form of educational aids such as formulas (see Table 2). During the activity, they show interest in cooperating to work successfully as a team and beat the challenge. Students claim that there are some difficulties in understanding the concepts of cycle-time and takt time, corroborated by a reduced analysis in theory and use of necessary equations to find the solution to the challenge, which are worked out with the support of the leader students and expert teachers. The practice that the ludic strategy provides generates a deeper analysis by students, who, in the end, can apply the information provided in a better manner for correct calculations of the required data in the system diagnosis.

During the development of the activity, it is evidenced how the prototype's easy operation encourages students to make decisions in an assembly line. After running the 3 simulations, leader students and expert teachers assess the performance of guest students by using the two previously explained criteria: Diagnosis or run calculations and shortage or undelivered units to the costumer. The following results are found:

- Diagnosis: after briefly clarifying the provided equations, students manage to run the required calculations for cycle-time, takt time and expected units correctly, which prompts their decision-making and select the pace of production that meets the required conditions.
- Shortage: students analyse the different paces of production, finding shortages in two of the proposed simulations, this provided background knowledge to select the most efficient production.

Step 3: Multiple Solutions Comparing

Along with the results of Step 2 and the experience during the development of the activity, students make suggestions to improve the assembly line. During the discussion of the proposals, students recognize relevant factors that could generate errors in the development of the activity, both in theoretical aspects as well as in the practical ones, since many of the proposed solutions are related to the number of pieces that the airplane assembly line can process simultaneously thus finding that there is a potential to optimize the process. Additionally, they identify difficulties to initialize the necessary brick's programs and suggest the design of an interface that allows both bricks to be activated simultaneously to avoid drawbacks when doing the ludic strategy.

Students elaborate improvement proposals such as this:

> "Based on what was seen in the simulation, I detected a poor layout and organization of raw materials along the conveyor belt, since it was in a single place and operators had to find the necessary piece and go back to their workstation, which is why a 5S methodology is proposed where operators take care of their workstation order and cleaning along with an improvement of the location of raw materials to decrease dead times. I also suggest that while the operator is assembling the pieces, the soldering of the next stations is working so that the line's production is doubled".

Based on the students' proposals, experts assessed the activity with the checklist (see Table 3), verifying the performance of the capabilities by the students. Because of this, experts corroborate the application of students' knowledge under the tutoring of leader students, making evident the compliance of the proposed objectives for this research, wherein students strengthen their knowledge about facility design and programming as they develop skills to develop systemic thinking for decision making.

Step 4: Choice-Based Education Structure

Students propose a strategy to improve the assembly line's performance and proceed to make the pertinent changes to optimize production. During the process, they aim at reducing times in each assembly station and identify different problems or inconvenient in reaching the minimum cycle-time for the required orders. Therefore, they generate proposals that attempt to optimize cycle-time to meet the quota and even surpass it or decrease the duration of work shifts. Depending on the conditions established by the students, the proposed modifications make each station perform its activities faster or slower compared to the initial configuration (Figure 7).

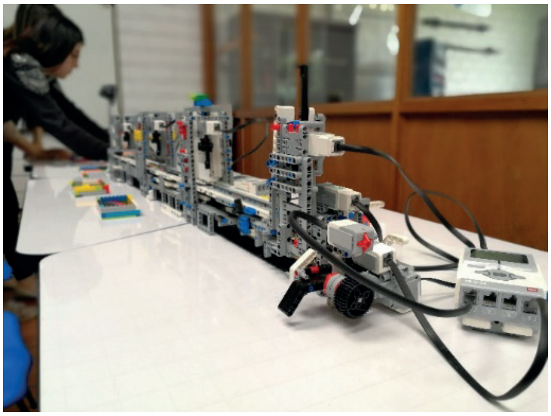

Figure 7. Students implementing modifications. Source: Own creation.

The changes proposed by students because of the experience they have with different simulations prove that there is an improvement in their skills and decision-making development. The proposed strategy is correct because it proposes to decrease operation times when operators are in action, due to, operators' idle times being longer compared with the station's assembly time. Based on their proposal, assembly-line times are improved and cycle-time, efficiency and produced units increase evidently. Furthermore, different proposals to modify the speed of the assembly line appear, since by increasing its movement speed and decreasing dead times, effici°ency varies, raising or lowering the number of units capable of producing.

All of this evidence that performing Step 4 enables students, through a ludic strategy, to analyse in a holistic manner which difficulties are present in a real assembly line and to use their observations to propose solutions to optimize its real efficiency through decision making, thus developing systemic thinking.

Step 5: Performance Analysis

The four (4) criteria described in the methodology were used to analyse the performance of this qualitative research. The table below shows how each criterion was approached in this research.

Table 6. Alternative criteria for judging research. Source: Own Creation

Criteria for judging qualitative research	Description of the application in this research
Credibility	The researchers and participants confirmed the credibility of the contributions made by the activity. The students and leader students expressed that their expectations were met as they put into practice the theoretical concepts and reinforced the aspects that were not clear to them, thus fulfilling the objective of the research. The expert teachers who participated recognized the value and credibility of the research, because they witnessed the knowledge that was acquired after developing the activity.
Transferability	To ensure transferability, the methodology and results describe in detail the context under which the research was performed: the type of Lego used, the role played by the students and teachers who participated, and the content of the tables used for each stage are detailed. The assumptions under which this research was carried out were: 1. Students have prior theoretical knowledge about the development of a production line and the factors that influence it. The proposed gamification activity will allow them to better understand the theory and develop it in a practical way. 2. The teachers who filled out the checklist for the corresponding evaluation had to be experts in the applied subject.

Criteria for judging qualitative research	Description of the application in this research
Dependability	Considering that the same thing cannot really be measured twice, the changes presented in the investigation were detailed to ensure reliability. This investigation presented the following situation that required an unplanned action at the time: In the step 2, students claimed that there were some difficulties in understanding the concepts of cycle-time and takt time, corroborated by a reduced analysis in theory and use of necessary equations to find the solution to the challenge, which were worked out with the support of leader students and expert teachers.
Confirmability	The processes were documented and presented in the methodology and were developed with the objective to make them replicable in a similar context.

CONCLUSIONS

This article shows the results of an ongoing research project sponsored by a higher education institution in Bogotá, Colombia. To strengthen education in the country, this research explores the use of Invention System kits as a strategy to improve teaching practices through practical spaces that complement traditional education. Through a ludic strategy, the interaction of students with a Lego-based airplane assembly line is studied, this lets them reinforce their engineering knowledge and develop systemic thinking for accurate decision making that enhance their social and professional development.

Developing the activities under the proposed methodology motivates and engages students, including leader students, since it is an attractive ludic strategy for the use of Lego sets, generating teamwork, collaboration and participation spaces in the classroom and involving them in their own learning process. This type of methodology poses a challenge for students, which stimulates creative thinking and a sense of achievement when they obtain the expected results. After verifying that the four (4) criteria in the performance analysis applied in qualitative research are met, it can be established that this activity can be replicated in another similar context. Consequently, this project has a long-term expectation due to its potential applicability to keep on improving professional training.

Additionally, by carrying out the proposed methodology, a product is created (in this case the "assembly line"), which helps, through simulations, to develop capabilities and skills for decision making, evidencing the development of systemic thinking of Colombian students. The designed prototype also fosters knowledge appropriation and development of analytic capabilities in engineering students, especially in the fields of programming and facility design.

The participation of undergraduate students in research projects is to be highlighted, especially those projects aimed at strengthening education. Therefore, it is suggested to promote higher participation of engineering students in research activities, since it enhances skills in the research field, development of critical thinking and improvement of their learning through scientific production in engineering. These types of experiences promote articulation between theoretical and practical knowledge, which is the reason for it to be promoted in the engineering training process.

The authors recognize the limited number of students that participate in the project and the development of the ludic strategy. Because this is a new field of research in the sponsoring institution, this study is being developed in a pilot group of students for the ludic strategies to be eventually implemented with larger groups of students. Nevertheless, up to this point, it is possible to identify relevant and solid findings, as described in this article, that highlight the positive impact education has when using innovative tools such as Invention System Kits, especially Lego Mindstorms EV3. Furthermore, current developments in this research are referents for any education institution, especially in the field of engineering, which want to include new teaching strategies in the training they offer.

For further studies, besides increasing the number of participants, it is suggested to include other aspects to recreate new scenarios that usually occur in an industry and that can enhance engineering teaching. For example, for the practical ludic strategy, a system of costs per produced airplane can be added, shortage penalizations, overtime, service times, etc. All of this to keep on fostering integral and systemic decision making in the students by imitating real-life situations of Colombian companies.

Finally, within the context of the Colombian post-conflict that has recently established the desire and goal to offer an education of higher quality and equality, it has become necessary to create conditions and spaces that materialize these results on education without holding it back. Thus, through this project, there is an advancement in developing innovative teaching methods for developing capabilities through analysis and accurate decision making in students, achieving the goal of training competent and integral professionals, much needed for society to last and the country to progress. (Kumar, 2014)

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