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Developing in engineering students a critical analysis about sustainability in productive systems

Empirical evidences from an action research experience

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Abstract

Purpose – The Mechanical Engineering course at the University of Campinas is composed of different disciplines in the areas of materials, mechanical design, manufacturing (production and manufacturing), computational systems, thermal and fluids. In the manufacturing area, in particular, there is a discipline entitled Productive Systems whose main objective is to offer to the student a global vision about operations management. In the field of operations management, sustainability is gaining more and more importance; thus, it is important to develop in the students a critical sense about social and environmental aspects. Thus, this paper aims to present the main initiatives developed in the discipline to promote sustainability in engineering students.

Design/methodology/approach – Since 2015, the professors responsible for the Productive Systems discipline, assisted by post-graduate students and professors from other universities, have begun to redesign the discipline, including debates, lectures, projects and other initiatives to provide a critical view concerning the traditional concepts taught. The discipline has been performed three times with this new conception. The methodology to structure this research was literature review, documental analyses of the discipline records and meetings with professors that participated in the initiatives. An Action Research approach was performed by two professors and a graduate student. The authors of this paper also compared the results with those obtained by initiatives performed at Chalmers University of Technology (Sweden).

Findings – This study allowed to reinforce some results from initiatives performed at Chalmers University of Technology (Sweden); however, some differences were identified. For example, similar to the initiatives mentioned, the professors of University of Campinas had problems with didactic books, as they loosely integrate the basic operations management concepts with sustainable development fundamentals. On the other hand, debates related to social sustainability were considered positive from the point of view of the professors and students, differing from initiatives performed at Chalmers University of Technology.

Research limitations/implications – Results come from one field study (University of Campinas) when professors of the Mechanical Engineering course try to integrate operations management concepts and sustainable development. Different results may be observed by other higher education institutions.

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Practical implications – The authors of this paper believe that the diffusion of these initiatives can stimulate other professors and researchers in the field to broaden the academic debate about the insertion of sustainability into engineering courses.

Originality/value – There are few papers presenting didactic experiences and empirical results about the integration of operations management concepts and sustainable development. Results of this paper reinforce some good practices and they also present other ones, in a way that extend the debate about educational engineering.

Keywords Higher education institutions, Sustainability, Engineering education, Didactic experiences, Production systems

Paper type Research paper

1. Introduction

Corporate competition and stakeholder pressure have increased considerably in recent decades, forcing companies to hire professionals that are more skilled in critical thinking (Leal Filho *et al.*, 2016; Mochizuki and Fadeeva, 2010; Mulder *et al.*, 2012). In addition, the new generation of students also requires innovative forms of education. Faced with these characteristics, higher education institutions need to rethink their approaches (e.g. learning processes and methods, programs organization and course content) to help graduate students adapt better to the new social and economic reality. This reality is present in all professional fields, including engineering (Guersola *et al.*, 2016; Holgaard *et al.*, 2016; Pinto *et al.*, 2015).

In this context, engineering students cannot only have specific technical disciplines, it is essential to develop other skills like critical thinking (Baroutian *et al.*, 2016; Carmo *et al.*, 2010; Gatto *et al.*, 2015; Häfner *et al.*, 2013). The traditional engineering education, aiming only at financial gain, is changing. Taking responsibility for the negative impacts generated (economic, environmental, social and others) has become a growing concern (Guerra, 2017; Palacin-Silva *et al.*, 2017; Staniškis and Katiliūtė, 2016). The future engineer's education must contemplate the principles of sustainable development (SD) in all their aspects (Sharma *et al.*, 2017; Tejedor *et al.*, 2017).

Focusing on operations management (OM) and production systems, Fredriksson and Persson (2011) published a study showing the experiences of Chalmers University of Technology (Sweden), where they worked on the integration of OM concepts with SD principles in two courses. There are only a few studies published in the academic literature that focus on the integration between OM and SD in education of engineers, and the research developed by Fredriksson and Persson (2011) is extremely relevant to this theme. The authors of this article understand that there is still much to be discussed in this area, including the most appropriated didactic practices, how they stimulate critical thinking and so forth, evidencing a research gap to be explored by the academic community. This article contributes to reducing this research gap, proving an empirical contribution to the theme.

Thus, the main purpose of this article is to present the initiatives developed by the Mechanical Engineering Faculty (University of Campinas) to integrate OM concepts and SD during a three-year project, implemented in the course Productive Systems by two professors and a teaching assistant. In addition, the results will be compared with those of Fredriksson and Persson (2011), who also performed a field study but in Sweden. The authors of this article believe the results presented can contribute to the debate about best practices in engineering education.

In addition to this introduction, this article is composed of four more sections. Section 2 is dedicated to the background, which discusses the general aspects related to the insertion of sustainability in higher education, concepts related to sustainable engineering education and presents the main characteristics of the study developed by Fredriksson and Persson (2011). Section 3 presents the methodological procedures, while Section 4 depicts the main results. Finally, Section 5 outlines the final considerations and conclusions.

2. Background

2.1 Sustainability in higher education

According to Gudz (2004), Bilodeau *et al.* (2014) and Howlett *et al.* (2016), higher education institutions need to rethink learning processes and methods to correctly insert sustainability concepts into their courses. The sustainability concept needs to be constantly debated by educators, as it has a dynamic definition, as argued by Leal Filho *et al.* (2015). A good example of this statement can be evidenced in the Burford *et al.*'s (2013) study, which identified three new pillars for sustainability beyond traditional economic, social and environmental. These new pillars are cultural diversity, political pillar and spiritual pillar.

Gudz (2004) and Bilodeau *et al.* (2014) affirm that there is no ready formula to insert sustainability into higher education and each institution must apply the practices that best suit its reality. Mochizuki and Fadeeva (2010) argue that coordinators should study the good practices developed by other institutions and understand how they can contribute to curriculum improvement.

Although there is no ready formula, Moore (2005) presents some interesting principals that can better direct sustainable education projects. These principals are as follows: sustainability must be included in the institution objectives; programs should be flexibilized and disciplines should be redesigned to provide a multicultural vision; communities should be involved in education; all university relations need to be rethought, including relationships with industry, government and community; and critical thinking, experiential learning and community service should be encouraged. Wooltorton *et al.* (2015) emphasize the importance of critical thinking as a fundamental element in granting diplomas, as future engineers can make better decisions regarding aspects of sustainability.

For Ferrer-Balas *et al.* (2008), transformative education is successful when it is able to prepare students for the complex challenges imposed by the future and for this, an inter and transdisciplinary approach is necessary. According to Ashford (2004), Shields *et al.* (2014), Pichi Júnior *et al.* (2015) and Guerra (2017), educators need to better understand these concepts to redesign their disciplines and create effective educational projects. Interdisciplinarity allows the union of a variety of areas of knowledge to be used together in problem-solving and thus to create a new set of knowledge (Clark and Wallace, 2015; Pichi Júnior *et al.*, 2015). Transdisciplinarity, in turn, aggregates concepts from different areas to consider them holistically (Pichi Júnior *et al.*, 2015; Shields *et al.*, 2014). It does not consider the boundaries between the different areas of knowledge and therefore, according to Guerra (2017), it can be characterized as a very interesting approach to insert sustainability concepts and critical thinking into higher education courses. This same view is corroborated by Leal Filho *et al.* (2016). Mochizuki and Fadeeva (2010) recognize, however, the complexity required in terms of the articulation of educational programs and student motivation to achieve transdisciplinarity.

In terms of student motivation to perform sustainable projects, it is important to stress on Mulder *et al.*'s (2015) study. Conducting a literature review about sustainable teaching success stories, they identified that student motivation is potentiated when the following practices are adopted: student autonomy in decision-making, challenging students to think about their roles in the future society, connection with other students' courses, self-realization and individual learning.

For Miller *et al.* (2011), the role of higher education institutions goes far beyond sustainable education. They should become learning and knowledge generation poles, with examples of sustainability practices. The campus should be open to the community to motivate discussions about main local, regional and global problems. Bilodeau *et al.* (2014) agree with the point of view previously presented and stresses that higher education institutions should lead this process, mobilizing all members of society to discuss and find solutions to the main problems.

Despite the existence of good examples of institutions moving in the SD direction, the majority of higher education institutions in the world still do not consider sustainability concepts in their strategic actions, according to Weissman (2012). For Natural Edge Project (TNEP, 2008) and Desha *et al.* (2009), the majority of universities will act strongly in favor of sustainable education only from 2030.

2.2 Sustainable teaching in engineering courses

Engineering is an area linked to problem-solving, and as a result, many experts believe that it should be taught with an applied approach (Aravena-reyes, 2014; Vemury *et al.*, 2018). Martins *et al.* (2013) and Bi and Mueller (2016) argue that to achieve this, courses need to have laboratory disciplines and practical activities to make the course more interesting and attractive.

According to the literature, there are three types of engineering education: academic, market-oriented and integrative (El-Zein and Hedemann, 2016; Jamison *et al.*, 2014). The integrative approach conciliates the ability to solve problems based on technical and scientific knowledge with critical analyses of the problems (Jamison *et al.*, 2014). For Sartori *et al.* (2016), critical thinking is one of the major legacies that a good degree can provide to future engineers. It is necessary that all the problems are evaluated from the perspective of different stakeholders contemplating sustainability concepts and systemic vision. This point of view is aligned with Wooltorton *et al.*'s (2015) ideas. For Karatzoglou (2013) and Lozano and Lozano (2014), engineering is a critical career for SD; therefore, a better connection between traditional disciplines and sustainable objectives is needed. For Vemury *et al.* (2018), engineers provide solutions that contribute to improving the quality of life of society. For Seay (2015), the education of engineers must be based on strong technical concepts immersed in an accurate social and environmental awareness.

In this context, Shields *et al.* (2014) and Guerra (2017) recognize the difficulty of achieving a transdisciplinary approach in engineering courses to adopt new values when compared with other undergraduate courses as cited by Mochizuki and Fadeeva (2010). As an example, Mulder *et al.* (2012) highlight the interdepartmental barriers within institutions. In addition, many engineering educators have difficulty inserting the sustainability concept into their disciplines because the concept encompasses several areas of knowledge. For Segalàs *et al.* (2012), the sustainability technical aspects are even contemplated in some disciplines, but the cultural and social aspects are still poorly debated in the institutions. de Camargo Cortelazzo (2015) argues that many engineering educators still consider only the economic and environmental aspects of sustainability. It is necessary to train teachers for this activity, but as Pérez-Foguet *et al.* (2018) argue, this is still an undeveloped field. Edvardsson Björnberg *et al.* (2015) in their study evidenced that many engineering educators have difficulty even to conceptualize social sustainability.

Mulder *et al.* (2012) provide some guidelines about how engineers should be educated for SD. According to Mulder *et al.* (2012), students need to understand that solutions to the problems associated with sustainability do not fit into a single discipline and "tools and techniques" are not available in ready-to-apply packages; they need to be created and developed. The solution for one problem may not be suitable for another. Active learning, stakeholder analysis, external cooperation and the use of differentiated teaching methodologies contribute to this. Desha *et al.* (2009) corroborate these arguments.

Von Blottnitz *et al.* (2015), Guerra (2017), Holgaard *et al.* (2016) and Leal Filho *et al.* (2016) agree with Mulder *et al.* (2012) in relation to the different engineering teaching methodologies, citing as examples problem-based learning and project-oriented learning. Problem-based learning is a technique that starts by identifying the problem and this will conduct the learning process. This process is self-directed, and students understand how to select and apply theoretical knowledge to solve the problem (Kolmos *et al.*, 2009). Project-oriented learning, in turn, presents similar characteristics to problem-based learning, but the focus is on a project to be developed (Guerra, 2017; Leal Filho *et al.*, 2016).

Focusing on sustainability teaching in engineering courses offered in Brazil, it is possible to observe that two realities coexist: some institutions provide dynamic courses contemplating sustainability in all its aspects, while others only teach sustainability superficially (Loureiro *et al.*, 2016). As examples of institutions that are achieving good results, the following universities can be mentioned: University of Campinas (Unicamp), University of São Paulo (USP), Paulist University (Unesp) and Fluminense Federal University (UFF). In this sense, Layrargues (2012) explains that many Brazilian institutions signed international agreements committing to insert SD into their academic programs; however, many fail to do so. For de Brito (2011) and Loureiro (2015), engineering education in Brazil is still quite focused on technical aspects, but the market demands new and wider professional skills, including critical thinking about social, environmental, political and cultural aspects.

The next section will converge in terms of engineering teaching, presenting the main characteristics of the study developed by Fredriksson and Persson (2011). The mentioned study focused on the Chalmers University of Technology experience to integrate OM and SD. The mentioned study it was useful to define the initiatives present in this article.

2.3 Sustainability in operations management

When focusing on sustainability insertion in OM disciplines, the study performed by Fredriksson and Persson (2011) deserves to be highlighted. There are few studies published in the academic literature that focus on the integration between management operations concepts and SD in education of engineers and the research developed by them is extremely relevant in this theme. The main objective of this study was to present the experiences of Chalmers University of Technology (Sweden) to integrate OM concepts and SD. For Jiménez *et al.* (2001), the OM disciplines have enormous potential to be integrated into sustainable education.

Both sustainability concepts and OM fundamentals require critical thinking and models development to solve complex problems and involve real-world situations where different actors interact. According to Fredriksson and Persson (2011), the differences between the two concepts lie in the scope and actions horizon. While SD focuses on analysis of the society, planet and countries economic development projecting decades, the OM fundamentals analyze markets, relevant regions and company financial development in a horizon of years.

The main activities developed by Fredriksson and Persson (2011) in their courses were two lectures on people development, two lectures on environmental management systems (EMS), reading of four book chapters about EMS, development of environmental plans based on case studies, lecture on OM and green products development, discussions about sustainable business, reading of two journal articles and exams about SD. These activities were divided into two disciplines: OM 1 and OM 2. To prepare these courses, the educators received extra resources and they argued that the main bottlenecks were related to time rather than the financial factor.

Fredriksson and Persson (2011) made some interesting considerations about bibliographies used. For them, there are problems with the majority of books when they try to integrate the basic concepts and SD principles. For example, Fredriksson and Persson (2011) cite Jiménez *et al.* (2001) who argue that the basic objectives of a productive system (quality, flexibility, cost, reliability and speed) should be complemented by environmental aspects. To solve this bibliography, the educators used two books in the disciplines together with journal articles.

In terms of experience acquired, they also consider as interesting learning the need for development and training of teachers in terms of SD, as they had not received this kind of education. To structure an OM course integrated with SD concepts, teachers need to develop the discipline and themselves.

To finish, they conclude that the integration between OM concepts and sustainable principles needs to be carefully studied, in order for students not to see them as "unrelated complements". At Chalmers University of Technology, this did not occur and the students very well assessed the disciplne.

3. Methodological procedures

This is basically a qualitative descriptive and exploratory research. From the point of view of research strategies, this study used literature review, document analysis and group discussion workshops in an Action Research design.

In an Action Research project, researchers and participants are cooperatively involved in the situation to be investigated, with a more participative and objective approach than traditional research (Thiollent, 1992). The authors of this article follow Tripp's (2005) setup, called educational research-action. In this kind of project, researchers and professors work together to develop, implement, monitor, describe and evaluate teaching practice. These kinds of setups are quite dynamic, since researchers can correct small mistakes and better explore positive points to advance teaching in a continuous improvement mindset.

The literature review was used to identify the main concepts associated to the insertion of sustainability in higher education and in engineering education. The document analysis was used to:

- retrieve information about the course, debates and seminars performed in the three times the discipline was offered (2015, 2016 and 2017);
- collect information about the assessment made by students about the course; and
- retrieve debate records held with other educators from other universities and who contributed to structure the initiatives presented here.

In this Action Research project, two professors and a teaching assistant (a PhD candidate) were involved with the discipline.

Regarding methodological procedures, the following steps were performed in three Action Research cycles: literature review, group discussion workshops with professors who participated in the structuring of all initiatives, document analysis of the disciplines records and comparison between the results obtained by us and those obtained by Fredriksson and Persson (2011). A total of three cycles were performed, one per year (from 2015 to 2017).

The literature review was done in scientific databases following search strings combining "engineering education", "sustainability", "production systems", "operations",

"operations management" and "critical thinking". In total, the authors of this article reviewed 41 papers. Because of theme specificity, several articles were published in the*International Journal of Sustainability in Higher Education*.

As for the discussion workshops, ten meetings were held during two months. Professors responsible for the discipline, post-graduate students and professors from other universities who contributed to structure the initiatives (two PhDs with experience in SD and one PhD in education) were present. The participation of the professors from other universities took place via videoconference. Based on the course records, the most important results were indicated to be reported and compared with the results of Fredriksson and Persson (2011).

To better understand the initiatives developed in the course Productive Systems, it is important to explain how it is organized. The discipline is traditionally offered in the sixth semester of the Mechanical Engineering program, in three groups of 60 students each. The main topics include manufacturing conceptualization and production systems classification, historical evolution of production systems, work organization, general concepts about OM, group technology, industrial productivity, production planning and control, theory of constraints, MRP I and II, layout developlemt, Toyota Production System and its evolution to lean manufacturing. During the semester, students need to solve exercises and present seminars about different themes, including corporate social responsibility and SD. The final student evaluation is composed of two tests, together with various activities and a final project to design a factory layout. The professors continuously analyze the students' critical thinking and the concepts learned about sustainability.

4. Results and discussion

4.1 Initiatives developed

The main objective of the Productive Systems course is to provide students with a global vision about OM concepts and, in addition, in the past three years, to show how sustainability fundamentals and critical thinking should be part of the future engineer's life. The professors responsible for the discipline participated in many debates with educators from other universities. In the 60-h workload of the course, they decided to focus on the three classic aspects of sustainability: economic (traditionally already addressed in this type of discipline), environmental and social. It should be noted, however, that one class is devoted to the Burford *et al.*'s (2013) study showing and debating the new sustainability pillars.

Social sustainability is discussed with students through presentation of different points of view. For example, it is possible to cite the topic production systems evolution in which professors initially present the traditional engineering point of view about the theme and, in the sequence, present commentaries made by critical authors. The books used for this activity are *Management and organization in globalized capitalism: history of the psychological manipulation in the world of work* by Heloani (2012) and *The Madness of Work: study of work psychopathology* by Dejours (2003). Heloani (2012) and Dejours (2003) have critical points of view regarding productive systems evolution, always analyzing the employer's point of view. For them, the evolution has always been marked by unilateral objectives. The purpose of this approach is to create a counterpoint of ideas and to stimulate the students' critical thinking. Students are led to rethink the professional role of the engineers during the evolution, understanding that it is necessary to create value for all stakeholders, providing a safe, healthy and quality workplace.

Similarly, the same approach is applied when professors present the theme "lean manufacturing". In addition to the traditional concept, which focuses on considerable costs reduction using technical tools, the presentation also shows the point of view of Heloani (2012), which classifies the technique as "management by stress". From 2017, the professors also included in the discipline a debate about the article "Primary problems associated with the health and welfare of employees observed when implementing lean manufacturing projects" by Rampasso *et al.* (2017). This article helps students understand the consequences of "lean manufacturing" if all aspects are not analyzed in an integrated way. Issues associated with ergonomics, physical and mental fatigue are widely debated.

It is important to emphasize that social sustainability is not debated only from employee's perspectives. In some debates, professors select a productive system real company and encourage students to discuss the possible advantages and disadvantages that the mentioned systems can provide to surrounding communities. Aspects related to communication, environmental impacts and sustainable global gains for all parties are discussed.

Regarding environmental sustainability, the main focus is on the concepts of Cleaner Production and EMS. For the first concept, students analyze manufacturing processes presented by professors and they are prompted to think how it can be optimized in relation to reduction resources consumption, efficiency improvement and materials reutilizations. As the course is offered in a mechanical engineering program, there is a great emphasis on mechanical and metallurgical processes. For example, it is possible to mention the debate about "machining processes". Students should evaluate the consumption of steel to manufacture a mechanical element and analyze if another process could be more sustainable. They also analyze manufacturing parameters to reduce energy consumption and waste. The same analysis is made for processes such as "forming", "casting", "welding" and others. In the case of "casting", students are questioned about the environmental impacts generated by sand used in the molds after the process. Regarding EMS, special focus is given to the ISO 14001 and the definition of environmental performance indicators. Students critically analyze which are the essential indicators that allow an accurate analysis of a productive system.

Economic sustainability is maintained in its traditional vision, as the productive system must provide profitability for its investors in the same time that respects social and environmental requirements. To stress this argumentation, professors use the book *A Theory of the Firm: Governance, Residual Claims and Organizational Forms* by Jensen (2000). According to the author, every company needs to understand the "enlightened stakeholder theory" that defines the maximization of the value company without neglecting the stakeholders.

To conclude the discipline, the students need to develop a final project about factory layout, concerning a manufacturer of automotive parts producing two axles and five gears forming an automotive gearbox. Students have to consider all concepts learned during the semester, including the sustainability and critical vision about industrial processes. As a starting point, professors provide a sequence of processes to manufacture auto parts, containing process description, equipment used, standard time and setup time for each activity. In addition, students also receive monthly demand, work shift, deliveries periodicity (weekly, biweekly or monthly) and unproductive times percentage associated with contingencies and equipment maintenance. It is important to note that this information is a starting point, in which students are encouraged to critically analyze all characteristics and suggest modifications to provide better results in terms of environmental aspects, job creation and quality of life. They are encouraged to seek knowledge through self-learning. A typical example is the replacement of some processes by others because of environmental efficiency or the increase in the number of employees to improve the quality of life because of a less intense work pace. The final project needs to contemplate nine items, as shown in Table I.

Table I. Items of the final project of the discipline "productive systems" (source: authors)

Item	Description of the item
1	Item 1: analysis of the manufacturing process characteristics
2	Item 2: analysis of the advantages and disadvantages related to outsourcing of some activities considering aspects associated with logistics, cost, technology, environment and job creation for the region
3	Item 3: analysis of the equipment characteristics used and of alternative options to minimize environmental impacts
4	Item 4: calculation of the minimum number of machines considering productive, environmental aspects and generation of jobs
5	Item 5: definition of the movement equipment system to transport auto parts inside the factory
6	Item 6: critical analysis of setup
7	Item 7: definition of the workplace areas considering ergonomic aspects, contemplating employee's welfare and quality of life
8	Item 8: design of the layout factory considering all aspects defined in items previous
9	Item 9: critical analysis of the layout and productive system projected considering requirements of ISO 9001, ISO 14001, OHSAS 18001 and SA8000 standards

As for the first topic of the project, students need to describe the manufacturing processes characteristics for each piece, including "facing", "centering", "turning", "milling", "heat treatment" and "grinding" specific processes for each mechanical component. For this, students should use the concepts learned in other disciplines, books and academic papers. Already in this introductory phase of the project, students should check the negative impacts of process that can be transmitted to the environment.

In the second item, students need to discuss the advantages and disadvantages related to the outsourcing of some processes, for example, start the manufacturing with a "forged" element developed inside the factory or buy it and perform the "heat treatment process" inside the factory or buy this service. In this analysis, students should include factors associated with logistics, cost, technology, environment and employment generation for the region.

In the third item of the project, students should perform an analysis of equipment characteristics used in each process. To do this, they need to find information as power, dimensions and operational speeds recommended, giving preference to machines that have better efficiency and minimize environmental impacts. As an example, it is possible to mention some equipment of turning that works with MQL (minimum quantity of cutting fluid). This practice is environmentally more interesting than the traditional one and students can obtain this information in equipment catalogs available on internet or in making contacts with manufacturers.

In the fourth item, students should calculate the minimum number of machines required. To help in this task, they structure spreadsheets that perform all calculations. From the minimum number of machines calculated, each group should define a factory layout that best meets the demand and parameters established. Students are encouraged to work with mixed layouts, considering the cost of equipment. Issues associated with the generation of jobs for local communities and environmental aspects are also discussed, not just economic aspects.

The next three topics are more succinct but not less important. In the fifth item, students choose an equipment system to transport pieces inside the factory (example, forklifts that consume less fuel or electricity). In the sixth item, students do a critical analysis of setup times, considering quick tool change concepts. In the seventh item, in turn, students need to calculate the necessary workplace areas for productive system, such as passageways, areas for the operators' activities, areas for materials to be recycled and areas for workers conviviality.

The eighth topic integrates the information presented in the previous items, since the students need to design the factory layout. They are encouraged to think critically about cleaner production concepts, job creation, ergonomics and the quality of the employees. In this way, the professors hope to graduate an engineer who has a critical vision regarding sustainability and understands that a good productive system must provide profit without neglecting behind environmental and social issues.

Finally, the ninth item requires students to analyze the designed factory layout according to requirements of ISO 9001, ISO 14001, OHSAS 18001 and SA8000 standards. The idea is that students discuss the integration between quality, environment, health and safety at work and social responsibility.

Under this structure, the course has been offered three times (2015, 2016 and 2017) and pleased the students. During these three years, the authors of this article have identified those concepts the students had more difficulty understanding to deepen the debates about them. The evaluation performed by the institution shows an approval of more than 90 per cent in relation to the approach used. It should be emphasized that it has also provided a better integration performance in the next course, such as "Process Project".

To contribute even more to the debates about the insertion of sustainability in OM courses, the authors of this article compare Chalmers University of Technology (Sweden) experiences with the School of Mechanical Engineering - University of Campinas (Brazil) experiences. This comparison allows reinforcing some findings and discussing some evidenced differences. Table II presents this comparison.

5. Conclusions

The market has demanded dynamic professionals that, besides solid knowledge, also have practical skills and abilities in critical thinking. In this context, engineering higher education institutions are trying to improve their courses to integrate different areas of knowledge with sustainability concepts, thus providing students with a closer vision about the complex future (Baroutian *et al.*, 2016; Kellam *et al.*, 2007; Leal Filho *et al.*, 2016; San-Juan *et al.*, 2015).

This article presented the initiatives developed at the University of Campinas in the discipline Productive Systems. These initiatives aim to enhance the integration between OM concepts and SD fundamentals, in addition to stimulating critical thinking by students. A comparison between the results observed by Fredriksson and Persson (2011) at Chalmers University of Technology (Sweden) and by authors of this article in the University of Campinas (Brazil) was made, reinforcing important issues and debating differences.

The main conclusion of this study is that there is great potential regarding the integration between productive systems concepts and SD fundamentals. Good practices and initiatives aiming at critical thinking and sustainable teaching are presented in this article, but the theme has not been exhausted. Academics need to debate the theme to improve engineering education. At the School of Mechanical Engineering, for example, professors will try to expand sustainable teaching to other disciplines, promoting better integration between them. The authors of this article hope that all engineers graduated by the School of Mechanical Engineering will reflect on their role in future society and evaluate their actions.

The results presented in this article can be useful for researchers and educators willing to integrate OM and SD in teaching practice. For educators interested in inserting SD concepts into OM disciplines, the findings presented here (mainly in Table II) can be characterized as initial guidelines. Using the knowledge presented in this article, educators can avoid early mistakes and achieve satisfactory results in a shorter time. In a minor but not less important

Table II. Comparison between the experiences of the chalmers university of technology (Sweden) and the school of mechanical engineering (Brazil)

Chalmers University of Technology, Sweden. (Fredriksson and Persson, 2011)	School of Mechanical Engineering - University of Campinas (Brazil)
Activities developed: lectures, reading of chapters about EMS; case studies about environmental plans; sustainable business discussions; reading of two journal articles and exams about SD issues	Activities developed: lectures, book chapters about social aspects, seminars at the end of each topic, debates about corporate social responsibility, reading of fifteen journal articles; exams contemplating integrated concepts about productive systems and SD
Two disciplines: OM 1 and OM 2	Only one discipline entitled: Productive Systems
According to the professors, the majority of the books have problems in trying to integrate the basic OM concepts with SD fundamentals. To solve this, they used two books in parallel and journal articles	The professors also observed this difficulty. It is not easy to find a good basic textbook that covers the production systems basics concepts and sustainability in an integrated way. It was used five different books and 15 journal articles
Professors responsible for the disciplines did not receive training contemplating SD concepts. They learned by themselves and developed the course	This reality was evidenced. The professors responsible for the course received few sustainable development concepts during their Bachelor's. It was necessary to seek additional capacitation about social and enviromental aspects. In this phase, meetings with other educators were fundamental, highlighting two PhDs with experience in sustainable management issues and a PhD in education
At Chalmers University of Technology, professors received extra resources and argued that the main bottlenecks were related to time rather than to financial factor	In recent years Brazil has experienced a financial crisis and this has impacted the university's finances. As a consequence, resources are scarce. The professors responsible do not receive extra resources for the development of the discipline, creativity and dedication were necessary to structure the activities. The bottleneck was financial
The integration between OM concepts and SD fundamentals needs to be carefully studied, so that students do not see the areas as "unrelated complements". The students evaluated the discipline very well	The professors responsible agree with the point of view of Fredriksson and Persson (2011), students need to understand the integration between areas, contents cannot be seen as "unrelated complements." The students also evaluated the discipline very well

way, educators can also use the script proposed in Table I to develop final projects in their disciplines, improving students' learning. For researchers in the area of engineering education, this article points out many possibilities for debates and future research. As an example, a critical analysis of OM textbooks can be developed to better understand how these textbooks should englobe the SD concepts. The findings of this article showed problems observed by educators in some textbooks. Researchers in this area can also develop innovative teaching practices to facilitate the learning process of sustainable concepts in OM using the knowledge presented here. In addition, it is important to perform an in-depth study comprising surveys and statistical models with the same course to understand how often students incorporate sustainability concepts and what they value the most during the learning process. These are some examples of the implications that the results presented by this article can generate.

Finally, it is also important to highlight some limitations of this research. First, the results presented come from a three-year project when the course was offered and evolved. A longer longitudinal analysis (10 years, for example) may provide more significant results and new insights. The authors of this article intend to continue to investigate this discipline at the University of Campinas in the coming academic years. Another limitation concerns the cultural factor, some characteristics vary from one country to another, which may influence the research results. This factor can be studied in collaboration with other higher education institutions from different countries.

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