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iJEP International Journal of Engineering Pedagogy

iJEP | eISSN: 2192-4880 | Vol. 16 No. 4 (2026) | OPEN ACCESS

https://doi.org/10.3991/ijep.v16i4.53901

PAPER

Does Learning Factory Reveal Creativity? An Exploratory Study in Engineering Education

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ABSTRACT

Recent literature underlines the benefits of learning factories in students' learning regarding a large range of competencies. This paper proposes to explore one of these competences (creativity) within the context of engineering education. Using a case study approach with data triangulation, this paper explores the forms of creativity emerging from a learning factory environment. The research involved engineering students enrolled in an industrial management course and collected diverse data, including surveys (22 responses), observational notes (16 pages), and photographs (47 images). The results demonstrated that the learning factory environment has a positive impact on engineering student creativity, particularly in three categories: collaboration, exploration, and perceived effort-result alignment ("result worth effort"). Additionally, the study identifies the influence of "positive management" practices in fostering creativity in learning factories. These results reinforce the potential of learning factories as dynamic environments for creativity and experiential learning in engineering education.

KEYWORDS

creativity, learning factory, learning environment, industrial management

1 INTRODUCTION

Learning factories are pedagogical and research platforms that enable new approaches to knowledge transfer for both students and professionals [1]. From a collaboration between universities and companies, the first learning factories appeared in Germany in the 1980s and then in the United States in 1994 [2]. In France, the first learning factory appeared in Lyon in 2009. The learning environment was democratized following the government's Dorison report [3]. Learning factory corresponds to a pedagogical learning environment in engineering education that enables new approaches to transfer knowledge based on experiential learning [4]. By using industrial settings as close to the reality of the industry, participants in this training can interact with a product, workstation, and other elements that constitute

Jacob, E., Magnani, F. (2026). Does Learning Factory Reveal Creativity? An Exploratory Study in Engineering Education. *International Journal of Engineering Pedagogy (iJEP)*, 16(4), pp. 57–68. https://doi.org/10.3991/ijep.v16i4.53901

Article submitted 2025-01-30. Revision uploaded 2026-03-18. Final acceptance 2026-03-25.

a factory. Learning factories have emerged in a lot of universities and colleges as a valuable educational environment that recreates an ecologically valid "work" space. As revealed in the literature, learning factories permitted the acquisition of competencies [5]. However, some competencies have to be explored from a deeper perspective. Creativity skills are part of it.

On this topic, creativity has gained a significant place in the engineering field [6] driven by the growing need to develop divergent solutions to real-world problems [7]. Due to the importance of creativity, this skill has to be investigated in multiple aspects of engineering education. From these observations, there is still much to be explored about the learning aspect in a learning factory environment. It is also the case for creativity. In our case, we focused on pedagogical aspects of learning factories, especially in the context of transferring lean management practices [1].

In order to explore this subject, this paper focuses on creativity in a learning factory in engineering education by employing various methods to reveal different aspects of creativity (impact of creativity from students and creativity support from the learning factory). This paper is organized as follows. The methodological aspects are presented in Section 2, the main results are developed in Section 3, and a discussion is provided in Section 4.

2 LITERATURE REVIEW

2.1 Learning environment in engineering education

In the field of engineering education, the most recent research in learning environments has focused on virtual learning conditions and the incorporation of new technologies. Voordijk and Vahdatikhaki [8] based their research on virtual reality (VR) environment; they identified four human-technology relationships: hermeneutic relationships, alterity relationships, background relationships, and embodiment relationships. The authors demonstrated that hermeneutic relationships and alterity relationships were particularly relevant. In addition, Justo et al. [9] posited that virtual conditions promote students' understanding of basic structural engineering concepts. In a literature review, Asiksoy [10] showed that Metaverse tools can be utilized in diverse ways and lead to varied forms of engagement in learning: cognitive, affective, and behavioral. Furthermore, Olorunfemi et al. [11] underlined that the integration of digital equipment within this educational system has improved learning capacity and increased students' motivation, focus, interest, enthusiasm, and drive to study. In addition, the utilization of online/hybrid engineering modules and online tools has been the subject of studies [12], [13], [14]. These studies underlined the improvement of learning outcomes of these learning approaches.

Other studies have questioned the learning environment, focusing on the physical dimension. Literature reviews focusing on challenge-based learning (CBL) [15] and experiential learning [16] have underscored the importance of learning environment in engineering training due to its ability to facilitate learning.

However, this literature review on the concept of learning environment in engineering education revealed some gaps: learning environment in management education within engineering education; learning factory as a learning environment.

2.2 Learning factory in engineering education

Learning factories were contextualized as a pedagogical and research context by highlighting organizational dysfunctions that need to be resolved. Recent researchs about learning factories involved introducing sustainability concerns [17] and digitalization [18]. From the perspective of participants, the literature indicates that learning factories facilitate the acquisition of multiple competencies [5]: professional competencies, and methodological competencies, social competencies. To date, the competencies most commonly evaluated in learning factories are those closely aligned with industrial management, such as technical problem-solving and process optimization [19]. A previous study examined the learning factory as a cooperative learning environment, displaying group dynamics in learning lean principles [20]. While this represents a preliminary step toward assessing more social and interactional competencies, the evaluation of broader outcomes remains largely absent in the literature.

2.3 Creativity

In engineering education, creativity is mainly taught through three aspects [21]: creativity-enhancing tools, problem-based learning (PBL) methods, and the establishment of interdisciplinary environments in education. This literature review doesn't mention the concept of 'learning factory,' despite the evidence suggesting its efficacy in developing students' multiple competencies. In addition, creativity is rarely studied through the aspect of the learning environment [22], even if student creativity can take different forms: the ability to work with other students [23] and the development of personal creativity [24]. Taking a closer look at learning factories, no studies have explicitly examined the impact of learning factories on students' creative capabilities or investigated their potential as environments that actively foster creativity. Indeed, examining the relationship between lean, as part of industrial management, and creativity, existing research has primarily focused on its impact in product development [25], with little attention given to production impact in both individual and collective continuous improvement [26]. So, learning factories appear to provide a hands-on environment where engineering students and professionals can develop proactive and creative problem-solving skills [23], [24] in industrial management. It will contribute to research discussions on the learning environment in engineering education [4], [27] and creative behaviors in the workplace environment [28].

2.4 Research question

As highlighted in the previous sections, there is substantial evidence that learning factories have been under-researched from an educational and learning environment perspective, in contrast to the extensive focus on industrial aspects. Moreover, creativity plays a significant role in engineering practices and engineering education. Yet this competence is not questioned in a learning factory context and in industrial management education. From these aspects, it is necessary to explore the conditions in which a learning factory supports creativity generation in engineering education. This study raised the following original research question: Does the learning factory serve as a support for creativity?

3 MATERIALS AND METHODS

3.1 Context of the study

The study was conducted in a learning factory in a French engineering school. The following section presents the morphology of the learning factory, as outlined by [17]:

- Operating Model: A hybrid approach integrating academic and industry partners, proprietary development, and funding through a mix of public grants and internal revenues, leveraging open collaboration models.
- Purpose and Targets: Dual focus on education/training and research, addressing a combined audience of students and employees in industrial management (lean).
- Process: Physically supported operations encompassing six manual workstations and two automated processes, transitioning from workshop-style production to one-piece flow systems.
- Setting: A fully physical, life-sized factory environment with a flexible, reconfigurable layout.
- Product: Reusable materials for demonstration purposes (e.g., snowshoes), featuring two base products and approximately 10 variants (colors, shapes).

The course consisted of 16-hours of lean management content designed for second-year engineering students. It was divided into four sessions, each lasting four hours. Each session followed a structured cycle all happening in the learning factory: presentation, preparation, production round, debriefing, theory introduction, and appropriation. The pedagogical objectives of the course were threefold: (1) to familiarize students with the theoretical and practical foundations of lean management; (2) to enable them to experience and lead lean practices, fostering the ability to initiate lean transformations; and (3) to assess the outcomes and implications of lean transformations within industrial settings. The theory introduction phase was inductive based on the participants' explanation of the issues arising from the production round.

3.2 Research design

To investigate creativity in a learning factory, we conducted a case study in a French engineering school, employing a data triangulation methodology [18]. In 2022, we made a preliminary study based on an observation of a group of engineering students (24). During May 2024, we conducted a second study including another group of engineering students. This second study was conducted using a survey completed by students (22 answers). In both studies, we also took pictures, which enabled us to collect qualitative data to identify creative thinking in a range of artifacts. These are considered teaching artifacts [19] due to their generation within a training context. They can be used to identify various features of instructional practice. Accordingly, the combination of data from two studies represents an appropriate methodology, given that observation alone is insufficient for identifying creativity [20].

3.3 Data collection

During the first study, we made observations of a group of engineering students (24) without an observation grid. There were three women and 21 men, aged between 21 and 24 years. As a preliminary study, this study did not focus on specific aspects of creativity. We collected observational notes (16 pages) and took pictures of the artifacts they used/constructed (33).

In the second study, the sample consisted of 22 engineering students, comprising eight women and 14 men, aged between 21 and 24 years. All of them had a one-month experience in manufacturing (mandatory internship), and among them, seven students had extensive prior experience in manufacturing, highlighting a mix of participants with varying levels of manufacturing exposure. Most of the data were collected anonymously throughout a survey and an observation grid. Specifically, we focused on six sets of variables related to creativity support [21]: collaboration, enjoyment, exploration, expressiveness, immersion, and results worth effort. It was measured with a 10-point Likert scale before and after the training. We collected 22 answers with the survey. We also participated in the training and took pictures (14) of the artifacts constructed by the students.

3.4 Data analysis

From the first study based on observations, we analyzed the impact of creativity through the four C model of creativity [22], [23]:

- Big-c Creativity: This level of creativity involves groundbreaking innovations that significantly impact society.
- Medium-c Creativity: It entails the generation of new strategies or alternative approaches to problem-solving.
- Little-c Creativity: In this approach, creativity is more focused on everyday activities. They are notable within the individual's immediate context.
- Mini-c Creativity: It involves the novel and personally meaningful interpretation of experiences, actions, and events. It emphasizes the dynamic and interpretive process of constructing personal knowledge and understanding within a specific sociocultural context.

We used NVivo software to classify data per models of creativity. We moved from inductive to deductive analysis to check our results against established theoretical patterns [24]. We used the same analysis for pictures. We also analyzed the 22 answers collected from the survey. The six dimensions of the Creativity Support Survey were analyzed individually, and we compared pre- and post-training data to measure the impact of the learning factories on the six dimensions of creativity support.

3.5 Conceptual framework

The purpose of the study was to explore if learning factories permit improvement in creativity. The conceptual framework for this study is presented in Figure 1.

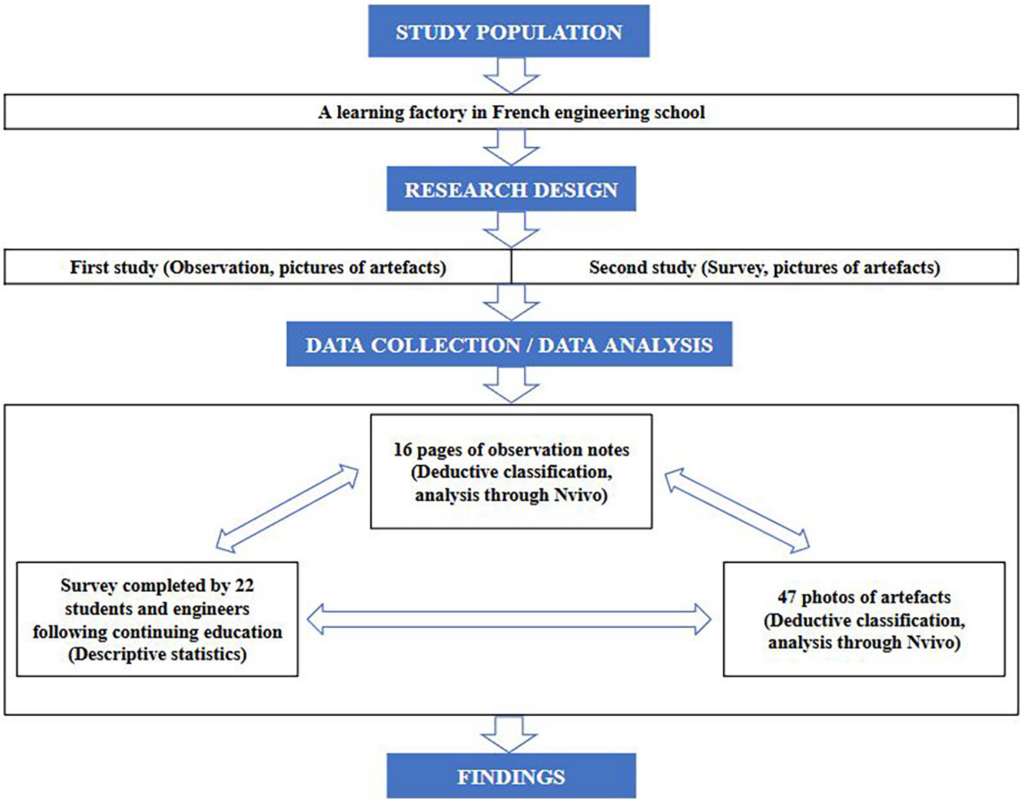

Fig. 1. Conceptual framework

Source: Own elaboration.

4 RESULTS

4.1 The impact of creativity through the four C model of creativity

Results obtained from classification with Nvivo software are presented in Table 1.

Table 1. Most frequent forms of creativity identified in observation data and pictures

Forms of Creativity	References in Observation Data	References in Pictures
Big-c	0	0
Medium-c	4	6
Little-c	0	0
Mini-c	10	8

From observation data, we identify fourteen observation notes associated with forms of creativity. Mini-c creativity is overrepresented, with a predominantly individualistic orientation (7) as opposed to a collective one (3). Forms of mini-c creativity correspond to small actions in order to optimize production (ex: a student puts tape on the simulated drying oven to provide a visual indicator). Forms of medium-c creativity correspond to training or organization mobilized to solve problems of optimization.

From pictures, the analysis indicates that mini-c creativity is overrepresented (8) in comparison to medium-c creativity (4). The majority of mini-c creativity (7) is associated with the utilization of "smiley", "emoji" and jokes in whiteboard/ paperboard during planning preparation ("see Figure 2"). About medium-c creativity, they are linked to different plans constructed by students, such as pie charts or tables. They serve as an alternative means of problem-solving, specifically in the context of chain optimization.

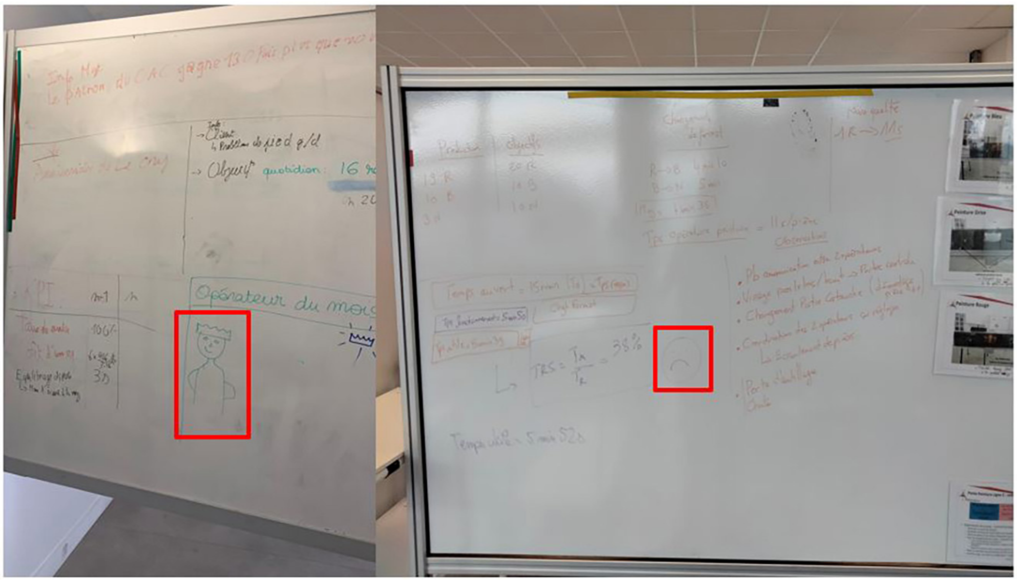

Fig. 2. Example of "smiley" and "emoji" used by students

4.2 Creativity support of learning factory

Results obtained from the creativity support survey are presented in Figure 3.

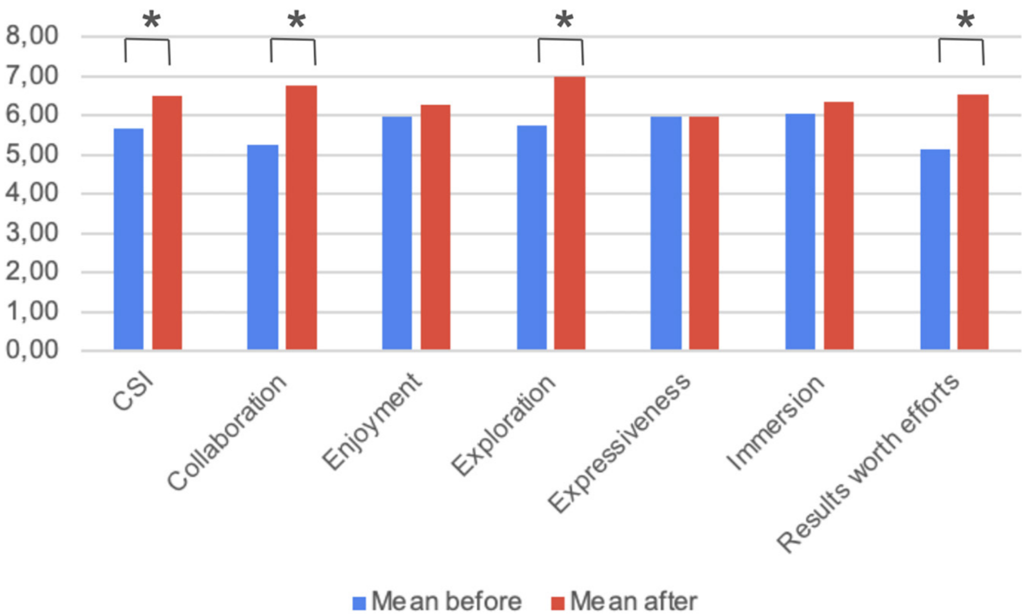

Fig. 3. Data related to creativity support

The analysis of creativity supports pre- and post-training and revealed significant improvements in key dimensions (* in Figure 3): collaboration, exploration, and results worth the effort. These dimensions showed statistically significant gains ($p < 0.05$), underscoring the training's positive impact on creativity. The homogeneous background of students and predefined collaboration time may enhance collaboration. Freedom to choose roles and tools in the learning factory fostered exploration, while the training content and context drove efficiency and satisfaction, reinforcing results worth the effort.

Other dimensions—expressiveness, enjoyment, and immersion—showed slight, non-significant improvements. Limited time and dominant leadership roles likely constrained expressiveness. Structured training and survey phrasing may have influenced enjoyment, while immersion declined as students adapted to the learning factory environment.

From a pragmatic standpoint, students used whiteboards and paperboards available in the learning factory (see Figure 4). They used it to depict the layout/organization of the learning factory, planning preparation, and activity monitoring. There is some variability in the information displayed and common ground too (organization representation, quality and service, main concerns, and problem-solving). Some groups of three or four students (2 out of 6) decided to use digital tools on their own, especially for planning and monitoring activity.

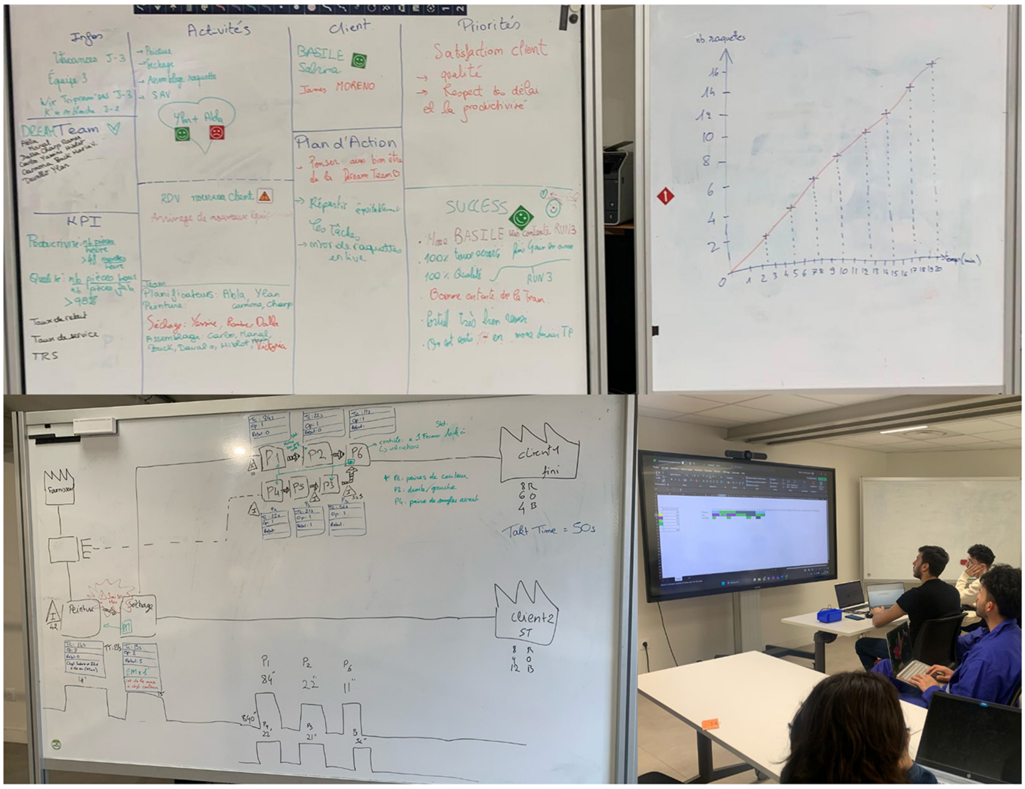

Fig. 4. Data related to creativity support

5 DISCUSSION

The results reveal limited insights from picture and observation analyses, in contrast to survey data, which highlighted notable improvements. By triangulating our findings, elements emerge for discussion, particularly within creativity categories.

About the "collaboration" category from the survey, we can explain the results with several factors. Firstly, students were all engineering graduate students of a similar age and gender, which lends a degree of homogeneity to the population. Secondly, the time allocated for interaction and collaboration in order to solve industrial problems was pre-defined (30 to 60 min). A collaborative [25], [26] and experiential context [2], [4], [16] allow collective creativity through group activities. However, personal creativity is overrepresented in observation data, which is linked to personal creativity development [26]. This may be attributable to the type of data.

The "exploration" score can be explained by the autonomy afforded to solve problems arising in the learning factory. During the training, students had the opportunity to select their role and their collective organization to achieve the objectives given by the trainers. From pictures and observations, students employed plans as pie charts, tables, root-cause trees, and planning or had short action plans in order to explore solutions to production problems. In this context, creativity serves as a driver to explore new knowledge through practice [26].

Additionally, the results from the survey show a positive impact in the "results worth effort" category. This can be attributed to the educational context and the content itself. In fact, students are required to be efficient rapidly and achieve outcomes in order to enhance the production line. Therefore, when they achieve expected results, they experience a sense of satisfaction that makes their efforts worthwhile. This part of the survey allows us to underline this aspect in the physical learning environment, which must be more defined in engineering education [14]. Moreover, as previously stated, learning factory context is to foster collaborative interaction within teams. However, pictures and observations evidence can't be triangulated with this category survey results due to the type of data. Alternative forms of data must be employed to develop "results worth effort" results.

About the "enjoyment" category as identified in the survey, there is a slight improvement. However, observations and pictures show forms of "positive management" practices, which fosters a positive atmosphere and encourages students to collaborate [25]. The "enjoyment" aspect in creativity could be attributed to the novelty of the pedagogical approach (vs. classroom teaching), the autonomy and absence of pressure on students. Furthermore, no notable advancement is observed in "immersion" category. However, several artifacts (objects, pie charts, tables, planning, root-cause trees …) constructed by students are identified in pictures. These artifacts can represent forms of immersion exhibited by the students.

To link the analysis of results with previous research, learning factories as learning environments support competencies [5], [27] and development related to problem solving [4]. Specifically on the environmental context of creativity [28], the quantitative findings validate the learning factory as an environment shaped by collective design, lived experiences, and its role as an enabler for students. In addition, the integration of digital tools within the learning environment, particularly with the objective of enhancing learning, underscores the need to think about digital tools [29] in relation to creative practices. This integration has the potential to enhance students' flexibility in their collaborative work practices [11]. Furthermore, it has the potential to engender heightened student engagement [10], which is congruent with the "enjoyment" category of creativity [11], [21].

However, further exploration is needed to examine the specific elements within the environment, the social dynamics that emerge, and the interplay between the environment and students' engagement or behaviors.

6 CONCLUSION

This study raised the following research question: Does learning factory serve as a support for creativity? We saw that is the case. We shed light on the forms of creativity fostered in the learning factory environment. In the context of industrial management learning exemplified by lean, we showed that a learning factory environment has a positive impact on engineering student creativity, particularly in the categories of collaboration, exploration, and results worth the effort. This reinforces previous findings about PBL linked to creativity and demonstrates that learning factories have the potential to be a creativity support environment. In addition, "positive management" practices in the learning factory emerged as forms of creativity. As a conclusion, we suggested that academic research and educators in engineering education consider creativity skills in the context of a learning factory due to the experiential learning context and the potential of creativity practices that students could develop. Furthermore, this integration may facilitate the development of interdisciplinary competencies among students.

Despite these results, we identify several limits, such as survey phrasing [21]. The employment of specific terms, such as 'system' and 'tool,' was ambiguous. Indeed, the term 'system' was not changed in the questionnaire for the study. Consequently, it can lead students to misunderstandings (ex: "what was the system?") Also, the small sample size of the survey study can bias the study. More answers could undermine our exploratory results, while this enables the formulation of hypotheses that can be substantiated or refuted in future studies. Finally, our study doesn't take into account student's background. They probably have the habit to learn in experiential learning (e. g., PBL). As a consequence, they know how to work together.

However, these findings invite further exploration of the learning factory as a pedagogical learning environment for developing skills considering individual and collective aspects, such as creativity, and for integrating concepts from the social sciences. Based on our study, "positive management" practices have to be investigated in further studies in learning factories. As well as the integration of digital technology and engagement in learning context, which are developed in the literature review dealing with the learning environment.

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