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INTEGRATING SENSORS IN PRODUCTS: A NEW TOOL FOR DESIGN EDUCATION

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ABSTRACT

This paper present a pedagogical tool to address a lack of creative approach in traditional education on embedded sensors. The tool is built in a systematic way from the data sheet information of a large number of different sensors. The tool presents the main monitoring capabilities of embedded sensors on cards to assist students in the creative stages of product design. An experiment was conducted to test its educational potential with 30 Masters students in product design. The statistical analysis on the experiment data indicate that the tool enables the improvement of knowledge on embedded sensors, with a more significant gain in advanced thinking skills. Finally, the tool is easy to implement in product design education and accessible to a wide range of students.

Keywords: Design education, Creativity, Early design phases, Design learning, Big data

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1 INTRODUCTION

Data has grown phenomenally over the last decade. It has become essential in a wide range of areas, services and products (Porter and Heppelmann, 2014). With the rapid development of electronic technologies, complex solutions have become more accessible. This trend has enabled the evolution of physical products by making them more connected (Zheng et al., 2019). The Design Society report by Isaksson and Eckert (2020) forecasts the future of products and development processes in 2040. The products of the future will involve even greater connectivity between the user, the product and the manufacturer. Data is indeed a solid means throughout the life of products to monitor their behaviour, their usages and related processes for optimisation purposes (Li et al., 2015). Data monitored through sensors can inform key phases of the product lifecycle as defined by Terzi et al. (2010). In the use phase, sensors data can inform the product about its environment to adapt its operation (Zhang et al., 2017). For the maintenance phase, the sensors data can be exploited to provide information on the functional status in real time and can be analysed to anticipate failures (Dalzochio et al., 2020). The integration of data in the end-of-life phase can support intelligent recycling and refurbishment of products based on the assessment of the components' condition through the sensors data (Joshi and Gupta, 2019). As for the product design phase, sensors data informs designers about the actual usage context, resulting in better designed, more robust and durable products (Klein et al., 2019). The design phase of the product is particularly important in its life cycle. The choices made during the design phase have an impact on the whole life cycle. Indeed, it is according to the choices made in this phase that a large part of the financial costs (Ullman, 2009) as well as the environmental impact of the product (Diaz et al., 2021) are determined. Sensors data as an insightful decision-making tool becomes very important because, if well integrated, it can lead to significant reductions in these costs. Moreover, designers can anticipate, at the design stage, the data that could be interesting to collect in order to integrate the appropriate sensors, thus anticipating future remote modifications of the product (Abramovici et al., 2017) or the design of future product generations (van der Vegte et al., 2019).

In this context of data-informed design, it has become essential to teach future design students about the possibilities offered by sensing technologies. Embedded sensors belong to the “sensing” layer, one of the 4 essential layers of the Internet of Things (IoT) architecture (Chen and Jin, 2012). Thus, frameworks for teaching the IoT require course on embedded sensors (Raikar et al., 2018). A review of the literature on IoT teaching (Abichandani et al., 2022) highlights that for the embedded sensors part, the pedagogical approach rely mostly on low cost IoT prototyping solutions such as Arduino or Raspberry Pi (El-Abd, 2017). These are simple and accessible technical means to teach the students the live feedback of embedded sensors data informing about the product, its environment and its user (Teikari et al., 2012). Common pedagogical approaches to sensors teach students the technical and functional aspects of sensors but do not invite them to experiment with creative uses of these technologies. Yet creativity is an essential aspect in product design and at the origin of innovations (Geschka, 1983). It seems necessary to teach product design students a creative point of view on these technologies too. The aim of this paper is therefore to propose a novel pedagogical approach based on a tool to complement the traditional teaching of embedded sensors. The tool should therefore assist students in the creative phase of product design to propose innovative embedded sensor solutions. It should require means simple enough to be accessible to the largest number of students. In addition, it should be effective enough to allow the learning of new knowledge about embedded sensors.

Section 2 present the research approach for the construction of the novel pedagogical tool capturing the possibilities of embedded sensors. Section 3 describes a use case for testing the developed tool involving 30 students preparing a Master's degree in product design. Section 4 provides the results of the experiments and their analyses. Section 5 discuss the results and outlines the limitations of this paper. Finally, section 6 concludes the paper and presents future works on the pedagogical tool.

2 RESEARCH APPROACH

2.1 Requirements

The objective of the paper is to develop a new pedagogical approach to embedded sensors based on a tool. To be relevant, it must address several key aspects: to propose a creative approach to embedded sensors, to be accessible to the widest possible range of students, to be engaging and effective for education.

The authors have therefore chosen to develop a tool capable of transcribing the capabilities of embedded sensors to designers. The idea is to propose to students a panel of what sensors are capable of measuring and to integrate it as a support to the creative phases of product design. Designers will be able to draw on these sensing capabilities to imagine scenarios that integrate them into their products. Thus, the tool makes it possible to link a product to monitored data and therefore to embedded sensors. In this manner, the tool intends to address the lack of a creative pedagogical approach to embedded sensors.

Moreover, by considering the possibilities of data acquisition rather than the sensors themselves, the tool makes it possible to leave out the technical details related to embedded sensors. It leaves this aspect to the more traditional pedagogical approaches to sensors. Thus, it allows all students to actively participate in the design process regardless of their technical level and field of expertise. In addition, considering the possibilities of sensing also allows for a holistic tool that is not dependent on the product or its domain, thus reaching a larger range of students.

In order to be effective and engaging for the students, the pedagogical approach also draws on the educational standards prescribed by the CDIO framework (Conceive Design Implement Operate) (Malmqvist et al., 2020a). Thus, small groups of students will use the tool in a simulation of the design process creative phase. This is an active learning approach that is more engaging and that allows the acquisition of knowledge through the simulation of professional design practice. In addition, it also allows students to develop personal and interpersonal skills through working together in a group. Finally, the student will address a real case study as prescribed by Tovey (2015) to develop relevant and advanced professional skills.

2.2 Design of the tool

To build the tool, the authors first had to identify the most widespread embedded sensors and their various associated applications. Therefore, the authors selected 5 major companies in the global embedded sensor market. They are intended to cover the majority of sensors applications. Next, the authors examined the available data sheets of all the different models and types of sensors produced by these companies. Data sheets were analysed to extract the content of the "Applications" section in which the sensing capabilities offered are listed. Thus, each type of sensor had in the end an associated raw list of applications, independent of its field of use, in a spreadsheet. To remove duplicates in the lists, an automatic detection of exact duplicates was first performed, followed by a manual detection removing the analogous duplicates. These filtered lists of the different applications for each type of sensor were then processed. Among the different application, the similar usage of the sensors were clustered manually and independently of the fields of application. This allowed the authors to assign a common capabilities label to each group of applications. For example, "vehicle tilt measurement" in the mobility domain, "platform stabilisation" in the industrial domain, "screen rotation" for smart devices, "tilt compensation" for drones, "angular position detection" for robots, "static orientation detection" for holistic applications, etc., were all considered as concerning the same sensor capability and were therefore all grouped together under the "tilt" measurement label. Another example could be the "vibration" measurement label that has been assigned to the following applications: "suspension vibration monitoring", "vibration sensing", "shock and vibration monitoring", "white goods shake detection", "equipment monitoring: vibration analysis", etc. In an effort to keep the tool focused on the major capabilities of the embedded sensors, solitary or overly specific applications have been discarded.

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In this way, the authors have established a list of 14 measurement labels highlighting the sensing capabilities of sensors: proximity, force, position, gas, elevation, humidity, brightness, orientation, temperature, contact, image, sound, vibration and speed. It is important to note that this list of measurement capabilities cannot be considered exhaustive. However, given the way it has been constructed, it can be expected to represent the majority of applications and therefore to cover the majority of use cases.

2.3 Tool manufacture

In order to make the previously identified sensing capabilities a tangible tool for the students and to integrate them into the ideation phases of the product design process, a card form was chosen. This form helps to enhance student engagement in learning through an interactive and serious game approach (Zhonggen, 2019). Moreover, it also enhances the creativity and ideation of the design process of the creative phases (Roy and Warren, 2019). For easier differentiation of the cards, each card includes the name of a sensing capability, an associated logo and a different neutral background colour. To exemplify the accessible means required for the implementation tool, the cards were made from a simple colour print on thick paper. The prints were then cut to a square size of 60mm. Figure 1 illustrates the 14 sensing capabilities in the form of cards.

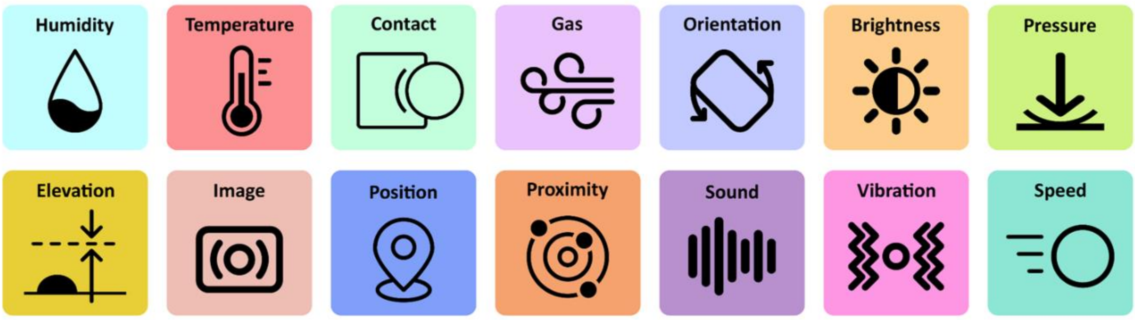

Figure 1. The 14 sensing capabilities cards

The way the cards may be used depend on the time allocated to the pedagogical approach. Indeed, depending on the case study, the sensing capabilities explored could be in different numbers and combined differently. Thus, if students have little time, a more random approach with the cards might be more beneficial. Alternatively, if students have more time, a structured and systematic approach to the cards could be considered.

3 USE CASE

3.1 Design of the experience

The main objective of the pedagogical tool is to enable an increase of knowledge on embedded sensors among students. Thus, to assess the knowledge gained by using the developed tool, a survey based on Bloom's taxonomy of knowledge revisions was developed (Krathwohl, 2002). This taxonomy ranks knowledge in a domain on a scale of thinking skills. The 6 levels of thinking skills are, from lowest to highest: remember, understand, apply, analyse, evaluate and create. The higher the thinking skills mastered is, the stronger the knowledge. The survey created took these 6 thinking skills as the basis for assessing knowledge about embedded sensors in product design. Thus, each survey entry is a self-assessment of a category of thinking skills. The assessment is based on a Likert scale from 1 to 7, where 1 means that the thinking skill is not at all mastered, 4 that the skill is partially mastered and 7 that the thinking skill is highly mastered. Thus, assessing the 6 entries of the survey enables self-evaluation of one's knowledge in product design with embedded sensors. Figure 2 presents the entries for knowledge self-assessment illustrated with Bloom's taxonomy of knowledge.

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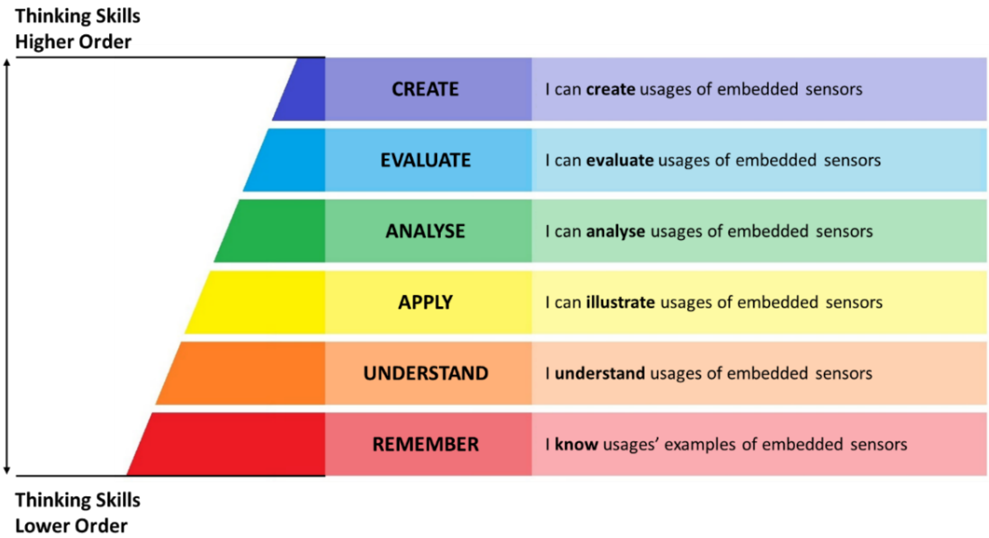

Figure 2. Entries of knowledge self-assessment adapted from Bloom's taxonomy of knowledge revisions (Krathwohl, 2002)

As the educational tool is integrated into the creative phases of product design, the experiment naturally took the form of a creativity session. All the groups of student went under the same process structured as follow:

Step 1: Each student in the group individually completed the survey for knowledge assessment.

Step 2: The students started the creativity session by performing a brain purge (Van Gundy, 2005) related to the subject. The brain purge approach consists of writing down all the ideas they had about the topic on post it notes independently and silently within a short time limit. When the time limit is reached, students are invited to share their ideas. This approach serves as a warm-up for creativity and as a way to get rid of all immediate conventional ideas.

Step 3: The pedagogical tool was then introduced to the students. It was presented as an illustration of the main capabilities of current sensors. Using the cards as a support for brainstorming, the students were invited to collectively generate concepts integrating sensor capabilities. They were free to use the tool as they wished during the allotted time.

Step 4: The students were asked to synthesise their most interesting concepts from the previous steps into idea sheets. It is a blank sheet of paper with several boxes of different sizes to be filled in: one box for the name of the solution, one for a sketch and/or written explanation of the solution and finally an advantage and a drawback boxes.

Step 5: Each student in the group individually completed the survey for knowledge assessment again.

Figure 3 illustrates all the steps of the experiment.

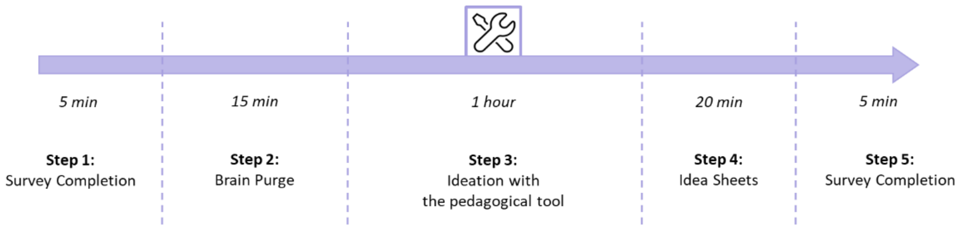

Figure 3. Proposed pedagogical approach

3.2 Conduct of the experience

To ensure the relevance of the pedagogical tool, it was necessary to test it with students in design. The authors therefore carried out an experiment with students following a master degree in product design in a major engineering school.

A total of 30 participants took part in the experiment, 10 women and 20 men, among them, 23 had an engineer background, 5 had a designer background and 2 had an ergonomist background. For the

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experiment, the students were divided into groups of 4 or 5 with one designer or ergonomist in each group to introduce multidisciplinarity among the students group.
The case study of the creativity session was a shared and connected city bikes system. The objective was to generate ideas for sensors embedded in the bikes to improve the users' experience of this system. The venue for the experiment was a classroom, an environment familiar to the students and associated with learning. As for the materials, the students were provided with pens, markers, post-it notes, large white paper boards and blank idea sheets.

The students, due to their specialisation in product design, are familiar with creativity sessions, their process and modalities. The role of the authors was to observe the course of the workshop and to ensure that the timing allowed for each step was respected. The authors only intervened when the developed tool was presented to the students at the beginning of step 3. Two different sessions took place with respectively twenty-one students (5 separate groups) in the first and nine students (2 separate groups) in the second. Both sessions lasted 1 hour and 45 minutes, with 20 minutes allocated to both steps 1 and 2, 1 hour to step 3 and 25 minutes for steps 4 and 5.

Students were free to use the pedagogical tool as they wished. They all naturally deployed a systematic approach. After jointly discovering the sensing capabilities, they decided to address each one individually to generate solutions. Thus, they conducted a series of short brainstorming sessions for each capability. It is interesting to note that a few groups broke down the case study, the shared city bike, into sub-systems before confronting them with the different capabilities in order to generate more concepts. Figure 4 shows one group's approach to the sensors capabilities cards.

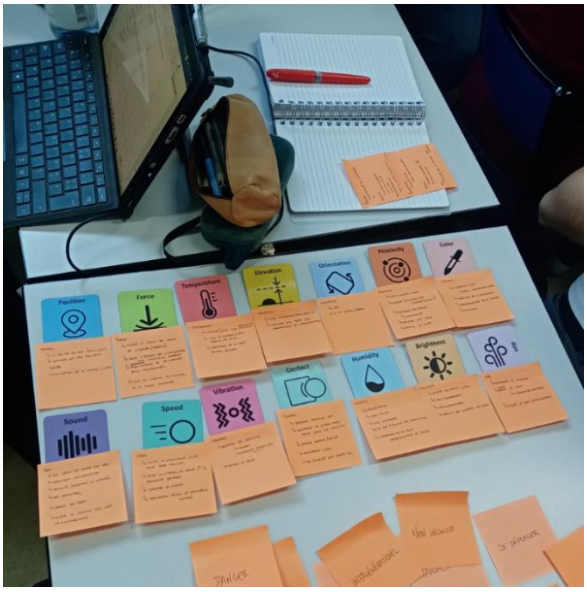

Figure 4. Working board of a students' group during the experiment

4 RESULTS

This section details the numerical results of the surveys' analysis. The statistical analyses of the data were carried out using Penguin (Vallat, 2018), an open source statistical analysis software in the Python programming language.

The data is based on a qualitative self-assessment on Likert scales by 30 different students. They answered the same 6-entries survey twice, before and after the use of the educational tool. An Anderson-Darling distribution test (Anderson and Darling, 1952) confirmed that the data followed a normal distribution for each entry, before and after the tool. Therefore, the reliability of the assessments was assessed through Cronbach's alpha (Cronbach, 1951). Its value is 0.84 which corresponds to a good consistency as it is higher than 0.8 (Nunnally, 1994). In this context, the statistical tests performed are paired sample t-tests, it enables the assessment of the following null hypothesis: no difference in knowledge after the tool usage (Hsu and Lachenbruch, 2015). The results

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are presented in Table 1. Figure 5 show the data from the experiment in a box and whisker plot using Matploblib graphics for Pyhton (Hunter, 2007).

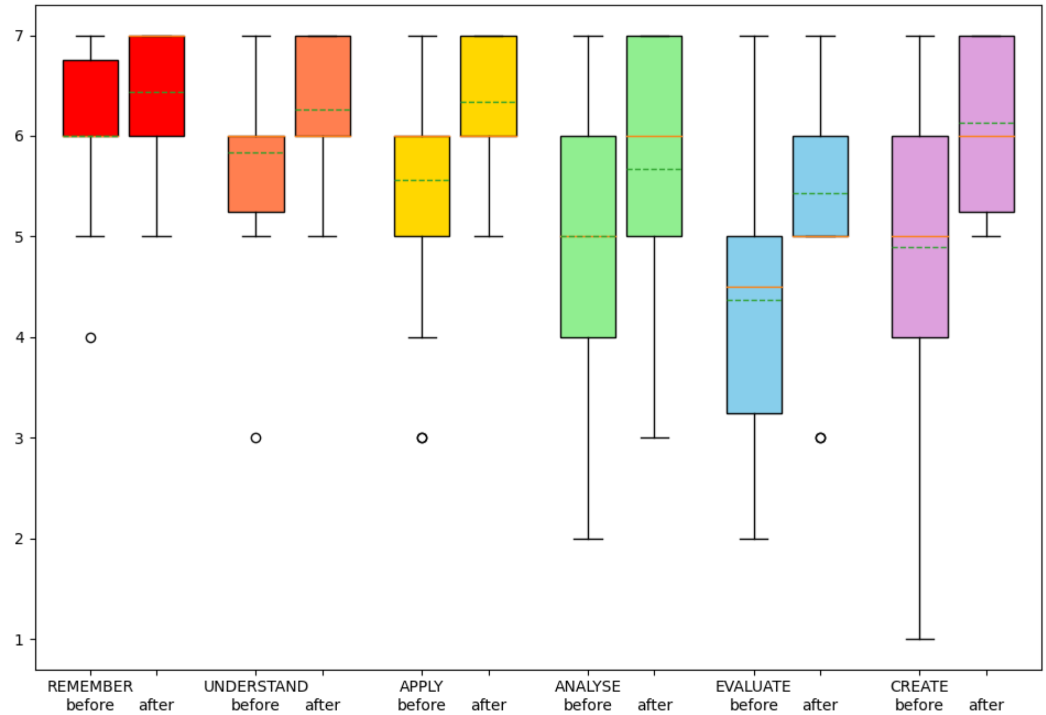

Figure 5. Box-and-whiskers plot of surveys responses

Table 1. Results of the surveys data analysis

Thinking Skills		Means	Means Difference	t	p
REMEMBER	*Before*	6	0,43	-3,791099	(0,0007)*
	After tool	6,43			
UNDERSTAND	*Before*	5,83	0,44	-2,904386	(0,0070)*
	After tool	6,27			
APPLY	*Before*	5,57	0,76	-4,322702	(0,0002)*
	After tool	6,33			
ANALYSE	*Before*	5	0,67	-2,818724	(0,0086)*
	After tool	5,67			
EVALUATE	*Before*	4,37	1,06	-6,186117	(0,0000)*
	After tool	5,43			
CREATE	*Before*	4,9	1,23	-4,083392	(0,0003)*
	After tool	6,13			

* p < 0,05

The p value for each entry is inferior to 0.05 therefore the null hypothesis can be rejected and the observed groups before and after can be considered as significantly different. For every thinking skill as defined by Bloom, a higher means is observed in the survey answers after the use of the pedagogical tool. Moreover, the increase between the averages before and after the use of the tool is substantial for the higher thinking skills. These results support the hypothesis that the usage of the pedagogical tool enabled the learning of embedded sensors for product design knowledge among students.

5 DISCUSSION

This section presents a discussion of the results from the authors' perspective and highlights the limitations of this paper.

Several observations can be drawn from the results of the case study depending on the thinking skills considered. First, concerning the three lower order skills: “knowing”, “understanding” and "apply". The means before the use of the tool were already high, which shows that the students were already familiar with the embedded sensors. The vast majority are indeed engineering students with a very

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similar background as they came from the same engineering school. This may also explain the lower increase in means before and after for the first three thinking skills. It is likely that they have encountered sensors through their school or personal experience.

As expected, there is naturally a greater dispersion and lower means for the three most advanced order thinking skills before the experiment: "analyse", "evaluate" and "create". The considerable increase in means before and after the use of the teaching tool for "evaluate" and "create" is an indication of its success, as it contributes to the mastery of higher order thinking skills. The increase in the thinking skill "create" can be explained by the creative approach adopted by the pedagogy. The students indeed proposed many solutions by creating their own design scenarios with embedded sensors. As for the increase in the thinking skills "analyse" and "evaluate", this can be explained through the collaborative approach of the pedagogy. The students actively interacted in groups around their ideas, thus analysing and evaluating them naturally.

The aim of this paper was to provide a new framework for teaching design with embedded sensors by offering students a more creative approach than those traditionally offered in their curriculum. This objective seems to have been achieved, as the students have increased their thinking skills and thus their knowledge in this field. The pedagogical tool is the basis for this novel approach to embedded sensors. It presents embedded sensors through the measurement capabilities. The knowledge is thus naturally transmitted to the students via the use of cards illustrating these sensing capabilities. Hopefully, the students will keep these capabilities in mind and consider them in their next design projects to integrate sensors if necessary. Knowledge is also conveyed through the collaborative ideation approach. It indeed allows students to acquire knowledge actively and independently. The students imagine design scenarios in which sensors provide relevant information. Although the ideas generated may not always be realistic or feasible, they can explore the design space opened up by the sensing capabilities of the embedded sensors. The students in their systematic way of using the tool tried to generate as many scenarios as possible for each sensing capabilities. During this process, they exchanged and worked together on potential scenarios developing their ability to integrate sensors into product design.

The limitation of the paper lies in the qualitative factors of the experiment and its results. Firstly, the population of participants in the experimentation was mostly engineering students in a master's degree of product design. They are potentially more familiar with embedded sensors because of their background. An experiment with another student population, for example with a majority of designer students or students with a different university degree, might provide different results. Secondly, the choices of the design case study, the way of assessing knowledge or the experimentation method could also influence results. A different scientific framework for testing the might provide different results. Finally, the results presented are subject to the authors' interpretations. They may be different if discussed by another group of researchers. To overcome these limitations on qualitative factors, the authors recommend that the tool be subjected to other evaluation processes and conditions in order to validate its educational value in a robust way.

The tool is also subject to some limitations. They can naturally be related to the challenges faced by embedded sensors in actual product design. Firstly, some challenges concern the technical complexity of embedded sensor solutions and their integration into products (Hou and Jiao, 2020). This tool deliberately leaves out these technical factors as they can be overwhelming for novice designers and generally hinders creativity sessions. Nevertheless, the students were still able to generate feasible solutions. Thus, this tool-based approach should be integrated into a more comprehensive course on IoT product design. It could be complemented by a practical course presenting the technical aspects of embedded sensors using hardware sensors for example. Further challenges to the integration of embedded sensors into product design concern their environmental impacts (Briard et al., 2023) as well as the ethical issues related to their uses (Briard et al., 2021; Gorkovenko et al., 2020). The tool does not address these aspects and should also be complemented by an approach that introduces these nuances to the use of embedded sensors. The sustainable dimension is indeed among the first optional aspects recommended for design education by the CDIO (Malmqvist et al., 2020b). This knowledge could, for example, be provided in the framework of a lecture afterwards.

6 FUTURE WORKS

In this article, the authors proposed a pedagogical tool to complement the classical education on embedded sensors. Indeed, these teachings are often focused on the explanation and experimentation of the related technologies but do not seem to include a creative approach to the students. The tool addresses this lack by supporting students in the creative phases of designing products with embedded sensors. The tool is built in a systematic way based on the data sheets of a large number of different sensors. The proposed applications were extracted from these data sheets and aggregated into groups under common labels. A non-exhaustive list summarising the main monitoring opportunities of which the sensors are capable was thus structured to form the tool. An experiment was then built and conducted to test its educational potential with a total of 30 students from an engineering school preparing a master's degree in product design. The experimentation consisted of a creativity session during which the students deployed the tool to support idea generation. The results of the statistical analysis on the experiment data indicate that the tool enables the improvement of knowledge on embedded sensors. There is even a significant gain for the highest thinking skills. These findings confirm the hypothesis of the paper that the tool-based pedagogical approach developed is of educational interest. Furthermore, the tool is easy to implement and to use, and therefore accessible to the widest possible range of students.

A short-term action to be implemented following this paper would be to verify the acquisition of lasting knowledge among the students who participated in the experiment by having them take the survey again months later. Another action, but of a continuous nature, would be to monitor new technologies to integrate potential novel developments in the field of embedded sensors into the pedagogical tool.

In this paper, the students worked on user-centred scenarios. They improved the user experience in the use phase of the product by integrating sensors. The tool is not exclusively reserved for learning in a user-centric design curriculum. The tool is, by its construction, inherently holistic and should be suitable for all domains where the data collected is of interest. Thus, it could be used in courses related to other phases of the product life cycle: distribution, maintenance, end of life, etc. Likewise, the tool should provide an accessible illustration of the main sensing capabilities available. Moreover, it could allow to envision scenarios in which the sensors can provide useful information. In the medium term, it could be interesting to implement the tool in different educational courses.

Finally, a perspective of future work would also be to pedagogically test other more complex forms for the tool. The form of analogue cards was chosen because it is accessible, simple to produce and to implement. However, at the cost of accessibility, it could be interesting to develop the tool further in order to have a more complete pedagogical approach on embedded sensors. The tool could then, for example, take the form of a board game or a mobile game application to create a playful and engaging learning experience for the students.

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