Digital synesthesia in product design. Building a vocabulary of physical interactions for a sensible quantified self

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Abstract
The paper explores the possibilities of presenting quantitative information in qualitative, expressive, engaging, and entertaining ways. To do so, experiments focus on a range of sporting activities, where numeric performance data tends to be prevalent, but there is also an aspect of self-awareness and community that can benefit from a connection enriched by carefully expressed data. In this context, through three design workshops, we examine the sensory and semiotic quality of the interactions, leveraging outputs in the form of haptic actuators, as well as subtle uses of lighting and kinematics. The exercises challenged participants to transform raw data into novel sensorial experiences through commonly available hardware (sensors and actuators) and software, constituting a meta-medium to be valorized with the same agility as conventional materials, albeit with an obviously shifting set of skills. Based on the scientific literature and experimental results, this contribution offers a mapping of possible values between individual and shared experiences, working towards a new vocabulary of tactile and kinetic experiences that may be useful for the creative industries.

Author keywords
sensorial quality; haptics; kinematic objects; experimentations.

Introduction
The boundaries between digital and physical reality are becoming increasingly blurred, paving the way for new forms of hybrid interactions and opening up new meanings in perception. While eXtended Reality strives for a socially interconnected "metaverse" via VR and MR visors, this contribution tackles with interactions that often bypass the visual channel in order to connect people to (or through) data in more sensory ways, considering also haptic actuators (a growing communication channel, Zannoni et al., 2021).

In many fields of application, including those outside of sports, tracking and monitoring technologies have entered the daily lives of people through various wearable devices for observing the physical, mental, and emotional states of individuals (Mukhopadhyay, 2015). This phenomenon of self-tracking via technological devices relates to the concept of the Quantified Self (QS) (Wolf et al., 2010), and can be considered a cultural movement dedicated to the collection of body data with the goal of assessing and improving one's own physical, mental, and emotional performance. But going beyond the technical possibilities, the QS phenomenon has generated debate around its sociological and ethical implications in terms of privacy (Thuraisingham et al., 2018) and equality (Lupton, 2015). In fact, while measuring specific body parameters offers objective data for evaluation and personal improvement, it also implies the continuous confrontation of a user's health and performance indicators with extraneous standards that may be above (or below) their realistic possibilities, leading to a potentially conflictual relationship between the QS and the sensitivity (Qualified Self?) of the users.

In contrast to human behaviour, which is based on perceptions and sensations, the data-driven approach to the self is capable of reconfiguring actions and responses that rely on objective measurements of data from devices, enacting a manipulation that "could result in loss of human free agency and autonomy and even deceptions of humans" (Stephanidis et al., 2019). As stated by Wiener (1950), technology has the power of influencing and changing human key values and behaviours, which is becoming increasingly evident in this era of rapid technological advancement and permeation in human society. This leads the research towards a more symbiotic relationship (Licklider, 1960) between devices and people, close to the concept of Human-Computer Confluence (Ferscha, 2016) and Human-Computer Integration (HCInt) (Farooq & Grudin, 2016; Mueller et al., 2020), leading to data-based communication through new forms of sensing, blurring the barriers between the physical body and the digital self.

Computational Thinking and sensorial interactions
This work is based on the assumption that Computational Thinking (the ability to define a step-by-step solution to complex problems; Wing, 2006) acquired through the practice of Learning by Doing (Bruce & Bloch, 2012) should be a part of every student's curriculum in order to better understand technology and develop a proactive approach to using technology for improving everyday life. The relevance of Computational Thinking (CT) is widely recognised and it is taught at various levels of general education or STEM-focused, from el-

ementary schools to universities (Sabitzer et al., 2014; Mannila, 2014; García-Peñalvo & Cruz-Benito, 2016).
At the elementary school level, for example, an innovative education approach grounded in project-based teaching is proposed by Lyu (2021),tackling the children's problem solving skills while assisted by the teachers. Another didactic approach by Rossano (2020), consists of teaching middle school students the basics of Arduino and coding through simple exercises and applying the newly acquired knowledge to real-life situations, like the management of a wooden rail crossing model. At the high school level, Yin (2022) uses a didactic process with four steps to show how using Arduino-based activities can improve CT and engineering learning.

On the level of higher education for the Design Profession, the ambitions of a CT-focused course can be more advanced, not only teaching but also inquiring about the possibility of turning digital, quantitative data into qualitative, sensorial feedback, and evaluating whether these can become an actual framework. Beyond innovative functionalities, Design has a particular responsibility for finding appropriate semantic associations. New sensory qualities and gestures may follow analogue metaphors or pure abstraction, based on the intrinsic nature of the information being communicated or controlled. This paper presents the findings of a series of workshops, carried out with students of (industrial/product) design, with the goal of experimenting with such new sensory qualities.

In particular, the general theme of sports has been chosen, as this provides wide opportunities for experimentation. Physical activity is already one of the main targets of self-tracking, and sports are mostly quantitative, measurable, while also including various layers of social interactions between players, trainers, and fans. Indeed, past research works have shown interesting experimental augmentations of sporting activities, both within the boundaries of existing sports and reinventing them altogether. An interesting example by Hribernik (2022) developed a haptic feedback interface specifically for water sports, which pose obvious challenges, in order to effectively communicate data during a physical activity session. Another take on the haptic approach is tackled in the creation of a superhuman sport, "DubHap," with the intention to redesign existing sports and adapt them to the new era (Chernyshov et al., 2018). With a design-driven approach, technology can also help to invent completely new "superhuman sports" for the AR/VR and sensing gloves, engaging citizens through a series of "ideathons" (participative design workshops) in order to pull in ideas, such as interacting with a virtual energy projectile that can only be sensed and not seen (Orikasa et al., 2017).
Taking inspiration from the above mentioned research, our workshops' participants started experimenting with isolated sensorial aspects of various sports, then proposed smart objects that highlight a range of possibilities, analysed in the last section of the paper.

Workshop structure

The workshop format, called "Smart Design Pills", has been developed for design students in the third BSc year, therefore with a solid background of creative exercises, modelling and presentation skills, but without any knowledge of interactive hardware & software prototyping or coding. The programme comprises three workshops that cover the fundamentals of prototyping, beginning with the simplest actuator and gradually increasing difficulty: LEDs and light signals are the theme for the first workshop, "Shiny Rhythms"; vibrating signals and tactile perceptions are studied during the second workshop, "Touching Signals"; while movement and kinetics are explored through the third workshop, "and Yet it Moves."

Each workshop is three weeks long and begins with an introductory exercise focused on computational thinking skills without digital hardware and software, by substituting and simulating the sensors/actuators with readily available tools and materials: the phone's flash and vibration motor are used for role playing, cardboard and clay for stop motion animation. Later during the first week, students learn about the sensors, actuators, and code necessary for the workshop, as well as studying relevant case studies of smart objects. The second step concentrates on defining a concept and developing a rough prototype of the group's interactive product in view of the third and final step, which is committed to creating a final prototype while also taking aesthetic factors into account.

For the purposes of this course, students were divided into 17 groups of two or three, and each was assigned a random sport. Numerous factors were considered in order to create a collection as diverse as possible, including the potential need for equipment, the degree of interaction (individual or team-based), and the settings in which the sports could be practised (gyms, particular outdoor settings, settings irrelevant to the practice). Based on their technical characteristics, the sports were divided into six macro-groups (water sports, balance sports, ball sports, racket sports, urban sports, and martial arts) to facilitate planning and review processes and the sharing of useful information between groups within the same macro-group.

Workshop 1 - "Shiny Rhythms," was based on the use of light signals via white LEDs. A couple of evocative images were selected for each sport, specifically drawing from visual, kinetic, and acoustic aspects, as inspiration or reference. The students were required to recreate each of these concepts using an animated light signal that included timing, rhythm, and intensity as variables, with the aid of particular apps that allowed them to control and modify the values. Sketches, notes, and illustrative graphs showing the intensity of the signal over time were required to document the brainstorming and design phases. Afterward, a brief video showcasing the three final performances had to be created.

Students were then asked to apply the knowledge they had acquired to a product that would incorporate the use of LEDs into their assigned sports activities as the actual exercise for the first workshop, proceeding in the three weeks process as described above. The final goal was to elaborate digital signals into a light performance that could visually express the qualities of the sport.

Workshop 2 - "Touching Signals", focused on experimenting with the perception of haptic signals using vibrating actuators. The materials provided for the introductive exercise were an illustration of the emotion spectrum (Plutchik, Robert, 1980) as well as a map of emotions perceived by the human body (Nummenmaa et al., 2013) that helped them identify the areas of the body where sensors and actuators should be placed. The introductory activity focused on the representation of a designated emotion through vibrating sequences. The purpose of the activity was to find haptic feedback for conveying information that is typically processed through visual or auditory channels during the training processes, athletic performance, and communication with other participants (fans, teammates, coach). The actual three weeks long activity of this workshop requested the students to design a product that incorporated haptic actuators in sports activities.

Workshop 3 - "And Yet it Moves", requested to design a kinetic smart object capable of interacting with the athletes, the audience, or the sporting environment. To familiarise students with the concept of movement, they were asked to identify some key aspects of sport (e.g., strength, coordination, acceleration) and represent them through a stop-motion video, using clay. Subsequently, they were asked to focus on three categories (objects for training, for sport execution, and for communication), elaborating a concept for each situation, rough prototyping and physically simulating the interaction of their products. Based on the findings from this exercise, students designed the project for the third workshop.

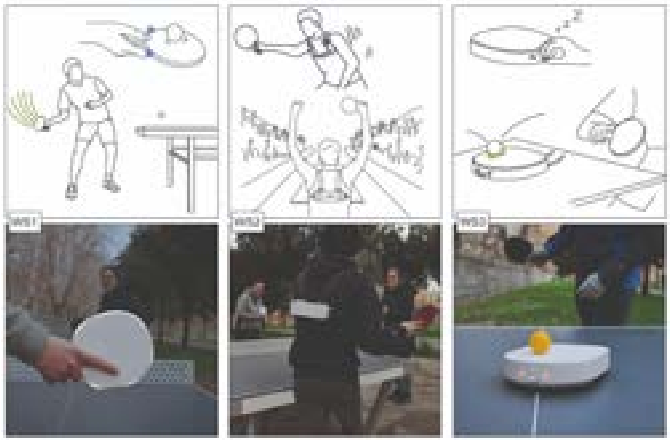

Figure 1. Top row: a storyboard for each project; bottom row: the prototypes resulted from the workshops. Designed by: Barberis Lorenzo, Ciubotaru Gabriel Cosmin, Guarnieri Elena.

Results can be illustrated through the projects of the table tennis group (FIgure 1). The interactive table tennis racket designed for the first workshop features built-in LED lights that react to the ball's stroke through a shock sensor and the racket's movement through an accelerometer, providing a visually appealing indicator for the most spectacular (quickest, strongest) moves during the game. The product from the second workshop is a wearable harness for the player, equipped with vibration actuators on each shoulder. Each vibrating actuator responds to the audience's cheers on its respective side, giving the player haptic feedback on their surroundings without distraction from the game. Training the player with a small wheeled robot is the aim of the final movement-themed project. The robot is designed to run in random directions and it must be hit with the ball to raise the speed and therefore difficulty.

Interactive approaches

The 51 interactive projects developed across the three workshops lend themselves to a categorisation that can identify various aspects along which the projects are diversified. Prior to analysing our case studies, it's worth noting that past research has examined and theorised on qualitative design values in a variety of ways. Some of the methodologies that emerged from the research have been applied to the projects as a first step to approaching a more fitting system of values for this subject. Among the pioneers of Design for IoT, Rose (2014) categorised projects according to 7 possible characteristics: Glanceability (43% of the 51 projects fall under this characteristic), Gestureability (41%), Affordability (59%), Wearability (47%), Indestructibility (43%), Usability (56%), Loveability (33%). According to Rose, designing a product that exhibits all seven characteristics is quite difficult. In fact, only 10% of the 51 projects displayed one or two of the traits; around 30% displayed three or four; barely 15% displayed five out of seven; and only 4.5% presented six out of the seven characteristics. On the other hand, a more generic categorization such as the well-known "three levels of design" (Norman, 2004) - Reflective, Behavioural and Visceral - may be (even more) useful to better understand the product.

Beyond pre-existing categories, the traits of each student project were analysed separately, thus identifying a set of connotation parameters that were common to all of the projects. Each parameter presents two dualistic and mutually exclusive values: one that leans on a "personal" and "closed" aspect and one on a "shared" and "open" side. The parameters that have been identified are as follows, naming the "personal" value first and the "shared" value second:

P.1 - Instinctive / New language: Products marked "instinctive" appeal to the immediacy of human instincts and common knowledge, whereas products marked "new language" present a new vocabulary of symbols that the user must learn in order to interact with the device. An example of an instinctive project is a parkour-specific leg band that vibrates in the event of a violent landing, simulating the wave of impact from the ground upwards. A rotating and portable basketball hoop that can be attached to any vertical pole is a project that introduces a new language, revolutionising the traditional game of basketball.

P.2 - Individual / Collective: Products marked "Individual" are defined by a single user, whereas "collective" projects rely on the participation of multiple users who contribute to the device's functioning. The climbing belt is an example of an individual product that, through vibration, "pushes" and accompanies the climber towards the wall, correcting the position without the help of instructors. The floats that confine the water polo field demonstrate the collective aspect. These light up to show the intensity of the fans' cheers for the players in the water.

P.3 - Performance / Entertainment: The projects that present the value of "performance" are those focused on pure sports execution (competitive or training). Instead, "entertainment" indicates the projects that highlight the visual or spectacular aspect for those who are watching. The fencing target that moves to dodge the shots of the fencer is an example of a product for sports performance and training. The kinetic sculpture in the centre of the skateboard arena, which reacts to the noise of the fans, effectively expresses the concept of entertainment.

P.4 - Human-driven/ Device-driven: Products marked "Human-driven" react to user input, detecting human interaction and then providing feedback. On the other hand, the "device-driven" products are the first to provide an indication to the users to guide them through the practice. A bracelet designed for boxing fans is a "human-driven" product that provides vibrant feedback to the wearer based on the power of the boxer's blows. Whereas, a small wheeled robot equipped with a chalk that traces a random path on the floor for the skater to follow is an example of a "device-driven" approach.

P.5 - Wearable/ Tangible: These two values indicate the product's location in relation to the user: "Wearable" projects are products that are actually worn by the user and remain in direct contact with the body; "tangible" products are physical devices that can be either individual objects or applied to sports equipment. An example of a "wearable" device is composed of two leg bands designed for paddle tennis that vibrate alternately to indicate to the player the correct rebound to keep during the game. A "tangible" device applied to the hockey stick warns the player by vibrating when the disc moves too far, allowing them to maintain control.

The visualisation of the data (Figure 2) has made it evident that the majority of the products that resulted from the course tend to place in the "personal" sphere (65%) rather than the "shared" sphere (35%). In fact, the majority of the projects displayed characteristics that were considered personal (instinctive, individual, performative, human-driven, wearable). The third workshop marked a high point for wearable product design, which is one of the main causes of this result. This outcome demonstrates that the interaction between humans and devices is mostly viewed as a private experience, but on the other hand, the tendency to involve the collectivity is relevant. Perhaps as human-machine contact advances, it will become more diverse and inclusive to the point where it serves as a tool for strengthening human unity.

Figure 2. Result of the systematisation of projects through the "personal" and "shared" parameters.

Conclusions

The research conducted to date has made it possible to test the "Smart Design Pills" didactic format with the goal of refining and verifying it in the future also in other fields. The programme includes the formulation of three workshops that focus on the human-device symbiosis, in this specific case in the field of sports, with the aim of transforming quantitative digital signals into sensory and qualitative interactions. Each workshop focuses on a fundamental concept and is approached through introductory activities giving the participants an alternative perspective before tackling the actual project. The products obtained from the workshops confirmed the ability of the participants to start from a basic level of interactive prototyping, but still achieve meaningful results, developing significantly their skill of computational thinking in the meantime. Five versatile parameters with polarised values that lean either to a "personal" sphere or to a "social" sphere have been developed based on the evaluation of the projects that resulted from the course. The outcome of this distinction shows a propensity to view human-machine connection as an individual experience, however the encouraging quantity of collective interactions may provide an opening to a more expansive definition of "human-device" interaction.

From the perspective of the Cumulus community, it would be interesting to see whether and how such principles can be applied by students (and professionals) of different cultural backgrounds (compared to Rome, Italy) and in different fields of activity. Finally, the research confirms the value of Quantified Self as a tool to "reflect, learn, remember and improve" (Wolf, 2010) on the individual's performance, but also confirms a possible "qualified self" approach by treating raw numerical data as a design material, that can lead to engaging experiences and ultimately a more a symbiotic experience between people and data.

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