Experiencing the flow: design issues in human-robot interaction

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Abstract

The experience of "emotional tuning" with artefacts that are not merely static (a teapot), nor merely reactive (a VCR), but that are autonomous, physical objects with decision-making abilities, pro-active, dynamic and designed with the general purpose of engaging users in social interaction, is an intriguing issue for interaction design.

This paper is a reflection about the compelling yet difficult nature of interaction dynamics among humans and robots, and a special category among them: robots capable of mediating social interaction.

Supporting such experiences means providing intensive embedding in the situation, motivating the users through a sense of engagement, similarly to what Csikszentmihalyi (1990) defines "optimal flow", the absolute absorption in the activity where the experience is guided by the personal feeling of the external worlds. The objective of our investigation is to analyze and try to understand if and when robotic devices can engage humans in activities likely to result in "being in the flow". We will try to analyze the different dimensions of flow in relation to different kinds of robotic devices: the seal robot Paro, used both for company and for therapeutic activities, the Intelligent Building Blocks, a robotic construction kit often used in educational activities, LEGO Mindstorms, the popular construction kit developed by LEGO.

The perspective that will be presented is connected to the quality of interaction and to the personal significance that every human being creates by getting involved and involving its own life experience in the interaction with the robot.

1. Introduction

The experience of "emotional tuning" with artifacts that are not merely static (a teapot), nor merely reactive (a VCR), but that are autonomous, physical objects, pro-active, dynamic and designed with the general purpose of engaging users in social interaction, is an intriguing issue for interaction design.

This paper is a reflection about the compelling yet difficult nature of interaction dynamics among humans and robots, and a special category among them: robots capable of mediating social interaction. Such systems are not designed to help the human being performing work tasks or saving time in routine activities, but to engage them in personal experiences stimulated by the emotional/intellectual affordances supported by the robot.

We refer to robots able of taking initiatives and having certain autonomous decision-making abilities, able of negotiating their presence with the environment in which they operate and that are mediators of communication in social contexts. The concept of sociality in robots has taken on a wide variety of nuances and meanings that basically depend on two elements: the ability these machines have to support the social model they refer to, and the complexity of the interaction scenarios they are capable of facing [1].In line with these two elements there are various kinds of social robots, from those which *evoke* sociality *(socially evocative robot)* by placing the accent on anthropomorphic or zoomorphic characteristics; to those known as *social interface robots*, which adopt social and behavioral rules to provide their human interlocutors with a "natural interface"; from *socially receptive robots* with learning abilities by means of imitation; to *sociable robots* capable of pro-actively engage in interaction with human beings in order to satisfy an internal need (desires, emotions).

In this paper, we concentrate on the interaction dynamics that hold between humans and different categories of robotic devices. The objective of our investigation is to analyze and try to understand if and when robotic devices can engage humans in activities likely to result in "being in the flow" [2]. We will try to investigate if "optimal experiences" can be established and endured with robots and under which conditions.

Supporting such experiences means providing intensive embedding in the situation, motivating the users through a sense of engagement and absolute absorption in the activity. The experience of flow is a sense of full engagement in and control of an activity, the perception that time passes more quickly and we feel immersed in that activity to the exclusion of all else: all experiences that people refer as extremely pleasurable and outstanding.

Whilst the concept of "optimal flow" has been widely analyzed by Csikszentmihalyi who presented many characteristics of human optimal experience, this has only recently been applied to the field of Human-Computer Interaction and in particular to Web Design [3], but it is still unexplored in Human Robot Interaction.

This paper attempts to bridge the gap and to provide insights for the interaction design with robots.

In particular, we will discuss some of the characteristics of flow that Csikszentmihalyi observed, discussing them along with examples of robotic devices that exemplify those characteristics at different scales.

Csikszentmihalyi proposes that there are four dimensions comprising the flow construct: control, attention focus, curiosity and intrinsic interest. These dimensions are linked and interdependent. He further describes nine main elements of characteristic dimensions of the flow experience as:

1. Clear goals;
2. Immediate feedback;
3. Personal skills are well suited to given challenges;
4. Action and awareness merge;
5. Concentration on the task at hand; irrelevant stimuli disappear;
6. A sense of potential control;
7. Loss of self-consciousness;
8. Altered sense of time;
9. Experience becomes autotelic and intrinsically rewarding;

In order to reach the flow state, a balance is required between the challenges perceived in a given situation (opportunities or obstacles for an activity) and the skills a person brings to it (the potential abilities an individual possesses to face the challenges). If the challenges in an activity are too high and beyond an individual's skill level, they may simply produce anxiety rather than flow. Conversely, if an activity is not challenging enough it may result in boredom. The same stands for challenges and skills that are balanced but do not exceed a certain level of complexity and difficulty. These may produce apathy rather than flow. Only when challenges and skills reach a balance and exceed the level that is typical for the day-to-day experiences of the individual, the state of flow is likely to emerge.

But do these characteristics and dimensions of flow play a similar role when the activity is supported or mediated by robotic devices?

The concept of optimal experiences applied to human-robot interaction refers to the overall subjective feelings of high involvement, concentration, enjoyment and intrinsic interest in interacting with robots.

In this paper we analyze the different dimensions of flow in relation to different kinds of robotic devices: the seal robot Paro [4], used both for company and for therapeutic activities, the Intelligent Building Blocks [5], a robotic construction kit often used in educational activities, LEGO Mindstorms, the popular construction kit developed by LEGO.

The reason for considering such a different robotic devices is to investigate the different dimensions of the "flow" at different scales. Indeed these three applications present different features in relation to physical appearance, functioning and the activities they support. The analysis we propose stems from the trials we carried out with groups of university students.
One of the purposes of this study is to encourage the discipline of Human Robot Interaction to consider the interaction not only from a functional point of view but more broadly. By focusing too closely on narrow quantitative measures of what makes an interaction with robots effective, the field may risk missing out on other important characteristics of what makes an interaction experience engaging and stimulating.

In order to pursue this objective we carried out an ethnographic study of students interacting with robots or robotic devices in everyday life contexts. The analysis was done using video recordings, augmented by more conventional fieldwork (observation and interviews), to explore the dimensions of flow and investigating the ways in which participants accomplish practical activities in interaction with robots. Such naturalistic approach allows to look "beyond the cognitive" and to understand new aspects of human behavior related to engagement as an aspect of action and practice.

Figure 1: The seal robot Paro

2. The seal robot Paro

Paro is a seal robot developed to engage in interaction with human beings. Robot's appearance is from a baby of harp seal covered with pure white and soft fur. It is equipped with the four primary senses: sight (light sensor), audition (determination of sound source direction and speech recognition), balance and the above-stated tactile sense. Its moving parts include vertical and horizontal neck movements, front and rear paddle movements and independent movement of each eyelid, which is important for creating facial expressions.

The robot is able to exhibit three kinds of behaviors: proactive, reactive, and physiological. Pro-active behaviors are generated considering internal states, stimuli, desires, and a rhythm of the day. The basic behavioral patterns include some poses and some motions. The seal robot reacts to sudden stimulation like turning the head towards a source of sound and behaves following the rhythm of a day with some spontaneous desires such as sleep and tiredness. Indeed, Paro has its own "physiological life". Paro generates its behavior depending on its internal states, rhythm of a day and stimulations. There are several candidates of behaviors in a situation and each behavior has a weight that is used as probability of behavior selection. When Paro is stroked gently, it feels good, and adds some weight on a candidate of its behavior that was chosen in the situation. Therefore, Paro responds to pats and to external stimuli by moving the body and the head in a coordinated way, by fluttering the eyelids, making sounds, purring if cuddled.
People who interact with this robot mostly report a sense of pleasure, enjoyment and involvement. They spend time stroking the robot, exploring its behaviour, stimulating the emission of sounds and the movements. Some kiss it and smile even if they are perfectly aware that it is not a living being.
This effect was observed many times and in very different contexts: with adults, elderly and children, in informal situations or professional contexts like meetings at the university or at the hospital (Paro has been used in educational as well as in rehabilitation contexts). People like engaging in interaction with Paro and keep on repeating the same actions waiting for the reactions and the initiatives of the robot.
If we interpret this as a manifestation of flow, the following dimensions are the most relevant:

Control: Interacting with Paro does not require any specific skill but the robot's behaviour seems to be sufficiently articulated to maintain attention and interest in the interlocutor. Since it is an autonomous agent people do not need to be completely in control of the interaction. Indeed the robot is considered as an intentional agent thanks to its self-initiated movement that people see as intentional and goal-directed. Other agency characteristics contribute to strengthen the impression of zoomorphism: the morphology of its body is efficiently harmonized with the tactile experience that one can have through direct contact, the movements of its head and eyes are coordinated, and it can behave in a reactive or proactive way to stimuli whose proximity is either immediate or not.

Feedback: Paro is an example of "autotelic" experience, in which the activity is done simply because it is pleasurable and rewarding regardless. The individual engages in the activity for the sake of the activity, and perceptual features of the robot play a key role in engendering such an effect.
Stroking the robot is a pleasurable experience by itself and the articulated feedback that the robot produces strengthens the

general effect. Even in presence of not completely clear goals and ambiguous feedback the experience is still rewarding and worthwhile.
Paro provides a quite sophisticated response to the external stimuli. The robot's reactions are not completely predictable since its behaviour critically depends on the history of previous interactions and it's not directly controllable by the user. Furthermore, its responses are quite ambiguous, since they are the result of the combination of different factors. Indeed Paro has internal states that can be named with words indicating emotions. Each state has a numerical level that is changed by stimulation. The state also decays in time. The interaction changes the internal states and creates the character of Paro.
This generates a high level of unpredictability in the interaction, since the user has continuously to codify and interpret a kind of feedback that is very articulated. For example, when its batteries are fully charged, it acts in a livelier manner, but if it "works" for a long time it looks tired and its movements slow down.
This aspect of the robot is quite interesting and the emotional impression this makes on human interlocutors is very strong. They normally sense the robot's "tiredness" immediately and tend to pet it and keep it quiet to help regain energy.
The fact to be exposed to such an articulated feedback generates a continuous process of interpretation along the interaction with the robot absorbing user attention and producing engagement.

Time: By observing and interviewing people interacting with Paro, we tried to understand if the perception of time changes as a consequence of being involved in the interaction with the robot. We proposed to two groups of university students a task of reverse engineering in which they had to analyze the behaviour and the technical features of the robot by direct exploration. The whole activity took 53 minutes, but when the subjects were asked to estimate the duration of the activity their answer was 30 minutes. The same situation occurred in similar experiments where, at the end of the activity, people were not able to estimate, even approximately, the time spent with Paro.

3. I-BLOCKS

I-BLOCKS technology is an innovative concept of building blocks, which allows users to manipulate conceptual structures, compose atomic actions and emerging behaviors, while building physical constructions [6]. The tool consists of a number of 'intelligent' building blocks (I-BLOCKS) that can be manipulated to create both physical functional and conceptual structures [5], [7]. The focus on building both physical and functional structures with the I-BLOCKS also lead to the possibility of investigating the concept of 'programming by building' [7], in which programming of a specific behaviour simply consists of building physical structures known to express that specific behaviour. This technology was developed to allow everyday users to develop functionality of artefacts, avoiding to split the process of artefact development into two processes of physical creation (e.g. physical construction of a robot) and functional creation (e.g. programming of the robot). Furthermore, this technology avoids the users to learn syntax and semantics of a programming language necessary to program the pre-built physical structures of the robot. This may results in a long and tedious process. Hence, such an approach will exclude most everyday users from becoming creative with the new technology. The housing of the I-BLOCKS takes the form of LEGO DUPLO bricks, each one containing electronics, and including the microprocessor [5] (the PIC16F876 40-pin 8 bit CMOS Flash microcontroller).

Each I-BLOCK has four communication channels, two on the bottom and two on top of each brick. So, when attached together, I-BLOCKS communicate with each other over the two-way serial communication channels. The physical processing structures can therefore be built in two and three dimensions. Energy power from a 9V battery building block is transported through the construction of I-BLOCKS.

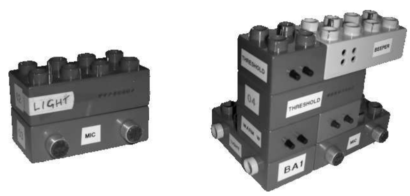

Figure 2: Intelligent Building Blocks

By attaching a number of basic building blocks together, the user may construct an artifact that can both perceive input, process, and produce output. The behavior of an I-BLOCKS structure depends on the physical shape, the processing in the I-BLOCKS and the interaction between the structure and the sensory inputs coming from the surrounding environment.

The different role played by these three elements generates diverse outcome in relation to the following flow dimensions:

Action and awareness of the system merge and Concentration on the task at hand. The novelty of I-Blocks relies on the concurrent manipulation of two compositional levels of the robots: physical and behavioural. The conceptual model of the system behaviour stems from the knowledge acquired during the construction of building blocks. For example, the combination of two building blocks determines a specific behaviour resulting from the combination of an input and an output device plus the sensory stimuli coming from the external environment. In doing this, the users construct, negotiate, and update the system representation in relation to the actual and the expected system behaviour. This implies a deep understanding of the role of each block in defining the overall functionality.
When this occurs *action and awareness of the system merge* and users are able to be *concentrated and focused on the construction task.* The maintenance of this condition is subordinated to the matching between the user conceptual model of the physical and the behavioural construction.

Control: Whenever the physical appearance of the device is not oriented to reproduce life-likeliness, like in the case of I-BLOCKS and LEGO Mindstorms, than the characteristic of *control* assumes a fundamental significance. If we should redesign the I-BLOCKS technology in order to improve *control*, than the different building blocks should be developed in a way to make their functionality completely transparent to the user. Indeed if at a first glance one could figure out the functionality of each brick, and how connections are propagated through an assembled I-BLOCKS structure, than people would be encouraged to explore the different combinations, and easily debug errors avoiding anxiety and boredom.
Indeed, observing the students at work with I-BLOCKS, we found that when the expected behavioural model of the robot did not correspond to the physical one, the users got bored of the construction task. They could not understand the resulting

behaviours and how to modify them, by changing the configuration of I-Blocks. This provoked the *interruption* of the task and a sense of loss of the system *control*. Such a phenomenon is strongly related to the complexity of the proposed task.
The cognitive complexity of the task is given by the computation of a complex web of cause-effect interactions between assembled modules, the understanding of those invisible dynamics [8] and the matching process between the physical conceptual model and the conceptual model of the system behaviour.
In order to reduce this cognitive complexity and minimize the risk of loss of control, the system behaviours might be made more transparent. This means making visible: 1. the passing of information between blocks which contribute to determine the structure behaviour; 2. the behaviour of each block; 3. the role of each block in affecting the whole function.
On the other side, the system itself enables strategies for reducing the intrinsic complexity of the task [9].

Feedback: In our observations we found that users adopted an "expansion strategy" for building up the targeted structure. For example, they started to assemble the light sensor with a sound actuator building a very simple artefact which emitted sounds when the sensor had been stimulated. Then they proceeded to expand this structure adding new blocks between the sensor and the actuator in order to observe how the behaviour changed. They continued to build intermediate artefacts of increasing complexity until they completed the construction. This strategy allowed subjects to reduce the cognitive complexity of the task, since they could progressively observe the emerging behaviour in the intermediate structures and reduce the mental elaboration and inference process necessary to understand all the invisible interactions among the blocks. Thus, tasks were accomplished by means of the interlink between internal (cognitive) and external (physical) transformations supported by the specific system of *feedback*. We recently made a trial experiment where groups of users were asked to build artefacts of increasing complexity. A group of subjects had to accomplish the task working under the 'action concurrent feedback' condition (subjects received feedback from the system every time they added a new block to the structure); while another group worked under the 'final feedback' condition (they received feedback from the structure when they declared the task accomplished). The result of this experiment was that non-expert subjects (people who had never seen the system before the test) could succeed in the tasks only in the concurrent feedback condition.

Skills and sense of challenge: The concurrent feedback enables the users to observe the resulting behaviour of the assembled intermediate structures and to adopt the "expansion strategy" in order to support a learning process within the activity itself. As evidence of this, in our experiment we found that non-expert subjects reached the same system representation of experts at the end of a proposed task [10]. This means that they undertook a learning process and they acquired the necessary *skills* to accomplish the task during the activity itself. When the increase of the task complexity is grounded on the progressive acquisition of the skills, users experience a sense of *challenge* and engagement, staying in the flow of the activity.

Time: When experiencing such a condition, the perception of time significantly changes. Users operating in concurrent feedback condition worked on the construction of complex artefacts for a considerable amount of time; on the average, they were involved in the activity for about 20 minute, trying about 20 different structures; while subjects working under the final feedback condition interrupted the activity without accomplishing the task after 10 minutes of work, and attempting only 4 different structures on average.

4. LEGO Mindstorms

LEGO Mindstorms is the popular robotic construction kit to teach children and adults the basics of robotics using familiar Lego bricks. With LEGO Mindstorms it is possible to build robots that move and react to inputs from the environment, e. g. touch and light. The robots' programs are written on a host computer, downloaded to the robot via an infrared connection, and then executed autonomously. The latter is probably the most fascinating about LEGO Mindstorms – no cables or any other connection to a stationary computer is required for the robots to move around.
From a technical point of view, the kit is featured with sensory, actuator, and control capabilities. The system consists of a main LEGO brick functioning as a control unit (RCX), sensors (e.g. light sensors and switch sensors) and motors. Using these components it is possible to build LEGO constructions and associate behaviours which are programmed on the host computer and downloaded to the RCX. This control unit has three input channels – which can be connected to sensors - and three output channels for the motors. The connectors follow the traditional LEGO design easing the user to build robots with the desired shape and the appropriate programming. Robots' behavior is defined using the graphical programming environment ROBOLAB.
Differently from the I-BLOCKS, LEGO Mindstorms maintains the divide between the physical and the digital. The physical constructions are built separately from the programming environment, and the user is required to master and continuously coordinate the different representations of the problem space: morphology, mechanics, balance, aesthetics of the physical construction with the programming aspects.
Observing students at work with LEGO Mindstorms the following dimensions of flow emerged.

Skills: LEGO Mindstorms requires the acquisition of different skills from mechanics to programming. It can support complex tasks requiring a quite advanced knowledge and skills usually acquired with the support of expert users (collaborative learning) or following the tutorial to get instructed on how to use the system at different levels of complexity.

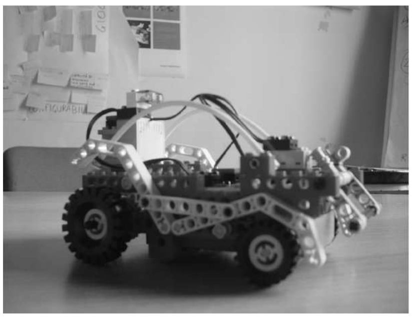

Figure 3: LEGO Mindstorms

The main challenge of LEGO Mindstorms is to master the ability of building a physical construction of the robot and to define a consistent software program for it. This implies that

the user has to walkthrough two different representations of the problem space for accomplishing the task.
Personal skills are necessary to create a coherent conceptual model of the whole system and meaningfully integrate the physical and digital dimensions.

Control: The cognitive and attentive load necessary to accomplish the activity and maintain the coherence between the different representations of the problem space often cause *interruptions* to the development of the optimal flow. Concentration and interruptions define the border between *loss of control* and an outstanding experience of flow. If the user perceives the divide between the physical and the digital dimensions as too difficult to manage, than the flow experience is damaged. The same stands when the trade-off between the challenge of the task and the acquired skills is not well balanced. This often places LEGO Mindstorms to a critical borderline between the *flow condition and the anxiety condition*.
An additional reason for a problematic flow experience is the lack of *immediate feedback* in the programming environment. The user does not know if the program is correct until the code is downloaded to the RCX and the robot tried out. Furthermore, the physical structure of the robot is often constructed without a proper consideration of the programmed behaviour. Frequently a correct software program is impossible to be run out because of an incoherent mechanics of the structure (e.g. wheels that are too big for being moved by motors with an insufficient associated speed).

Time: As soon as the user is able to manage the different representations of the problem space, than the activity becomes engaging and challenging. In these cases, observing students at work with LEGO Mindstorms we witnessed a *change in the perception of time*. We made a simple experiment with university students who were asked to build and program a robot. At the end of the activity we asked them to estimate the time spent in accomplishing the task: their answer was 1 hour, while they actually worked for two hours and five minutes.

5. Discussion

From the overview of three profoundly different robotic technologies, this paper offered a reflection on the concept of optimal flow trying to understand on which extent it may be applied to human-robot interaction and which lessons can be derived for the interaction design.

While the three robotic applications exhibit different dimensions of flow, in particular high involvement, curiosity, enjoyment and intrinsic interest, none of them should be considered as a discrete unit or a design guideline *per se*.
First of all, we believe that optimal flow is not something that can be embedded in the system formalizing discrete dimensions like time, control, personal skill etc.

Involvement, curiosity, enjoyment and interest can be supplied by the users and the systems work only by bootstrapping the flow based on existing, rich contexts of activity. Therefore measures of success for such systems are not whether the systems induce a specific dimension of flow but whether they are flexible and rich enough to support flow experiences in the context of stimulating and rich activities that engage users individually and collectively. Flow is not part of system design but is an emerging property of the activity that the system supports.

In this respect, we believe that flow is more likely experienced when the system allows interpretive flexibility of the activity. In the applications we considered, the 'meaning' of the system is not the one supplied by the designer but rather the situated understanding of users that turned out to be very effective in producing an experience of flow. When interviewing the participants in our trials, they reported good experiences of flow each time the system could support their imagination and meaning construction that emerged in a situated way over the course of interaction.

In this respect the *quality of interaction* (that includes not only functional but also perceptual and emotional components) and the *personal significance* that the individuals create by getting involved in the interaction with the robot assume a fundamental role. In this sense the space of design is similar to a learning space: human-robot interaction is the element that mediates in the building of knowledge, a creation of significance that does not depend on the physical and functional characteristics of the machine only, but also and mostly on the specific context of interaction, and on the perception of mutual affordances, some of which come from the stimuli given by touching, hearing, seeing, moving, some others from psychological processes that mediate the empathic response. This process of knowledge construction leads also to consider another component of flow that is usually underestimated: collaboration in team activities.

When working with LEGO Mindstorms, teams experience both sub-tasks division and sharing of clear goals. We observed that when the goal of the activity is well shared and agreed and the problem space equally comprehended, people enjoy coordinating the execution of sub-tasks using different media (the bricks and the programming environment in the case of LEGO Mindstorms). The fact that the device supports a clear distribution of roles (building and programming in our example) among groups of users may sensibly reduce the anxiety of passing from the physical to the digital dimension perceived when working individually.

The study presented in this paper is purposely qualitative and explorative. It shows that if we want to adopt a wide view on human-robot interaction that goes beyond a functional perspective to include also the analysis of flow dynamics, it is desirable to avoid trying to formalize something that is unformalizable. Often flow experiences cannot be easily observed and users cannot articulate in straightforward ways, what they exactly experienced. As a consequence, the designer can unintentionally attempt to force users into a straightjacket of formalized expressions.

If we eschew the notion of flow as formal properties or information bits in interactive system design, then we focus on assessing things such as awareness, expression, and engagement – aspects for which human-robot interaction as yet has developed few strategies.

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