



Article

Use of Haptics to Promote Learning Outcomes in Serious Games

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Abstract: Integration of haptics in Serious Games (SGs) remains limited compared to vision and audio. Many works seem to limit haptic interactions to the mimicking of real life feelings. Here, we address this by investigating the use of haptics to promote learning outcomes in serious games. By analyzing how we learn, we proposed a model that identifies three learning outcomes: (1) engage the user with the content of the game, (2) develop technical skills, and (3) develop cognitive skills. For each learning skill, we show how haptic interactions may be exploited. We also show that the proposed model may be used to describe and to evaluate existing methods. It may also help in the designing of new methods that take advantage of haptics to promote learning outcomes.

Keywords: haptics; interaction; serious game; virtual reality; learning

1. Introduction

The origins of the expression Serious Games (SG) can be traced back to the fifteenth century when a serious topic (politics, business or even private life) was treated with an amusing approach [1]. Today, Serious Games are mainly computer-based games. Games mechanics (rules that define what is achievable or not at a specific moment) attempt to mimic real life scenarios [2,3]. They exploit the game context in order to affect the real life of players [4,5]. In terms of content, SG may invoke any aspects of real life. As a result, SG has been used in multiple domains ranging from advertisements to military training exercises. In such games, the primary goal is not only the entertainment of the player, but, rather, the serious purpose of the targeted domain [6]. We share the point of view of many researchers who see in SG *an active and situated problem-solving with probably some social interactions* [7]. Researchers have investigated aspects related to the potential of SG for the transfer of knowledge. One of the first observations started with Norman who underlined that players tend to learn more in the artificial context of a video game when compared to the traditional context of school [8]. Later, Stapleton et al. noticed that these types of games present a learner approach while creating a meaningful environment for learning [9]. For Oneil et al., the potential of these types of games is even bigger because they can address both cognitive and affective dimensions of learning [10–12]. Nevertheless, the characteristics of SG that would be a predictor of success in learning remain an active problem in the domain [7]. These authors have observed that engagement with the content is probably a key requirement for achieving cognitive learning gains [7]. The present research targets this point with the presentation of a model that identifies three learning outcomes associated with SG. *Learning outcomes are statements of what a learner is expected to know, understand and be able to demonstrate at the end of a learning experience* [13].

Moreover, several studies focused on visual and audio interactions as key elements to maintain the motivation and engagement of the player [14–17]. It seems to us that such an approach does not exploit the full capabilities of the human being.

We, as human beings, experiment with our own environment as well as with our own body only through our sensory organs [18]. Although a large part of our brain is involved in the processing of visual information [19–22] compared to other channels, it has been shown that vision should not be considered as the predominant human sense. Instead, each modality is particularly efficient for specific tasks [23]. Vision is perfect for the comparison of the spatial arrangement of objects, whereas haptics are at least as good as sight for the discrimination of textures [24]. It thus appears that solutions based only on one of the visual channels do not take advantage of the multi-sensory capabilities of humans [25,26].

Furthermore, when compared to other modalities [27–29], the potential of the haptic modality remains under exploited. There are explanations for this:

1. It appears that the haptic modality has been exploited mainly in order to reproduce real-life sensations.

For example, Rodrigues et al. suggest that the incorporation of haptic systems in Serious Games allows one to augment the level of realism and to achieve a more efficient level of involvement [30]. Deng et al. concluded that haptics introduce one more dimension of sensory modality for a more immersive game experience [27]. In the same way, Hou et al. highlighted that haptics may be used to simulate an immersive and realistic virtual environment [29]. Beyond the incontestable advantages mentioned, noting that one of the main advantages of a SG is in its ability to exceed the limits of the real world, we argue that haptics can be relevant for the rendering of information that is not represented (or is under represented) in the real world. For example, in a Serious Game dedicated to the analysis of data resulting from Computational Fluid Dynamics (CFD) simulations, the haptic feedback may be useful to help the user to track a streamline [25].

2. Haptics are not included at the core of the game design process; one talks about integrating the haptic into the game.

In this view, the haptic interaction is seen as being a third party that would be added afterwards into the game. For example, Rodrigues et al. noticed that there is an important question about to how "to integrate haptic devices", to conform their limitations to a specific problem addressed in a Serious Game [30]. They also point out that the integration of the device should be realized without compromising the content of the SG [30]. However, considering the singularity of the haptic modality (being bidirectional), one cannot separate haptics from the content nor from the interaction with the game. On the contrary, we argue that haptic interactions have to be central to the design process.

Considering such observations, it appears that while many can see haptics as being useful to promote the immersion and the realism of a game, it is not obvious that many think that haptics may promote learning outcomes in serious games. With this work, we want to promote a new vision of the use of haptics in serious games. Since we intend to study how haptics may be exploited to favor learning outcomes, we start this research by analyzing how we learn. To do so, we will analyze the behavioral and the constructivism theories. This will let us identify three learning skills that may be associated with SG. For each identified learning skills, we will describe how haptics may be exploited.

The remainder of this paper is organized as follows: Section 2 briefly describes the haptic modality. Particular attention is paid to visio-haptic association and to the psychophysical characteristics of haptics. In Section 3, we propose a model to support learning outcomes in SG. In Section 4, we describe how haptics may be exploited for identified learning outcomes. Section 5 concludes the paper.

2. Haptics

Haptics refer to the sense of touch and associated sensory feedbacks. Haptics encompass tactile and thermal modalities (associated to skin receptors), force feedback (associated to muscles), as well as proprioception and kinesthesia. Proprioception refers to the perception of the body part whereas

kinesthesia allows for perceiving motion. Both proprioception and kinesthesia are associated with muscles, joints and tendons and inner ears. In everyday life, when interacting with objects, all these data are combined into what is called haptic perception. This is the haptic perception that informs us about the texture, the hardness, the temperature as well as the weight. This perception may also provide information about the shape and the volume of objects.

This section includes some characteristics of the haptic modality. We first present the added value of visio-haptic rendering; thereafter, we recall some psychophysical characteristics of the haptic modality.

2.1. Added Value of a Visio-Haptic Interaction

The visio-haptic association offers three main advantages [31]. They are:

- **The haptic channel may be helpful to unload the visual channel.**

In contrast to a situation having a pure visual interaction, the haptic feedback offers an additional channel for the rendering of information. For example, the haptic feedback is used to convey physico-chemical forces of intermolecular bonds [32]. In this situation, the haptic interaction may be exploited to extend the communication bandwidth between the user and the virtual environment.

- **The haptic rendering of information allows for strengthening information already presented in the visual channel.**

As in the case of a pleonasm, to reinforce information, although already visually rendered, it can also be presented via the haptic channel. In [33], the haptic feedback allows for reinforcing the rendering of various internal organs perceived throughout different hardness.

- **The haptic rendering of information may be exploited to supplement the visual feedback.**

In this case, the haptic modality gives access to information that is hardly or not perceptible visually. For example, Menelas et al. have exploited *tactons* to convey a risk of fall while walking [34].

2.2. Psychophysical Characteristics of the Haptic Perception

When compared to other modalities, it appears that haptics has a set of unique characteristics that may be useful in SG applications. Here, we present some of these characteristics:

- **Haptics provide a bi-directional communication channel.**

The characteristic that is unique to the haptic modality is its bi-directionality. The perception of visual information is not much influenced by the action of the person. Furthermore, a scene presented visually is perceived as a coherent whole. In the haptic case, the process of integration is quite different because the haptic perception of information requires a specific type of movement named Exploration Procedure (EP) [35,36]. Therefore, the perception of any particular haptic information (weight, texture, hardness) requires for each one a specific movement. A weight requires different vertical movements, while lateral ones are better suited for the perception of a texture. Doing so, the haptic perception of information implies a two-way communication with the entity of interest.

- **Haptics are very intimate and provide a strong connection.**

However, humans can express emotions through speech or writing as one says in intense emotional moments: *there is no word to express the feelings*. For such moments, only a touch, the physical contact, allows to convey what one feels as trusting someone [37,38]. This explains why touch is more intimate and creates a direct link between a person and the environment (ecological, digital). In the same way, a mother hugging her child will transmit the love and the feeling of security that the child needs for his well-being and for building his self-esteem [39]. Furthermore, the fact of feeling material properties such as temperature and texture strengthens

the emotional dimension of other modalities [40]. For instance, touching a rough texture can lead to feeling more empathy [41], just as a temperature can affect people's generosity or even influence their judgment [42]. That being said, touching may also become inappropriate and too invasive in some cases [43]. In some societies, touching someone can be seen as being a very impolite act, or even rude. McLean argues that some people are *haptically challenged* and do not generally find touching natural, informative or pleasant [44,45].

- **Haptics allow high differentiation but are not adapted to memorization [44].**

By touching, one can differentiate several levels of texture or detect a damaged surface or a scratch. However, it is almost impossible to recall these levels. Unlike in the visual modality where any color gamut is associated with a shade; for the haptic case, it is completely different. One can identify only a few textures described with adjectives such as: sticky, rough, smooth. In fact, all the physical properties that define the microstructure of a surface (roughness, hardness and elasticity) are encompassed in the term "texture".

- **Haptics can be influenced by the visual.**

Welch noticed that vision dominates the other channels in spatial perception [46]. Therefore, visual information has a direct impact on the haptic perception as well as on limb position (hand) [47] and object size [48,49]. Koseleff has pointed out that subjects perceived differently the weight of an object through a lens [50]. The perceived weight increases whenever the size increases.

3. A new model to support learning outcomes in SGs

With the work of Iten et al., it appears that the characteristics of SGs that would be a predictor of success in learning remain an active problem in the domain [7]. In this research, we want to promote a new vision of the use of haptics in Serious Games, namely, we intend to show that haptics may be used to promote learning outcomes. Rather than focusing on the precise role of the haptic modality, we adopt a more global approach where we analyze the learning process. To do this, we will refer to different learning theories. We will show that these theories, although having different approaches, are adapted to different learning situations. On the basis of this observation, we will propose a new model to support learning outcomes in Serious Games.

Gross defines learning as the act of acquiring new knowledge, or modifying and reinforcing existing knowledge, behaviors, skills, values, or preferences that may lead to a potential change in synthesizing information, depth of the knowledge, and attitude or behavior relative to the type and range of experiences [51]. Over the years, several learning theories have emerged. Among the well-known theories, two are of particular relevance: the behaviorism and the constructivism theories. For more information on learning theories, one can refer to [52]. Although often reduced to the respondent conditioning [53], the behavioral theory also encompasses the operant conditioning [54]. We will thus analyze these three learning theories in the following sections.

Here, we briefly summarize the behaviorism and constructivism theories. In doing so, we will identify learning outcomes associated with these three learning theories.

3.1. Respondent Conditioning: A Means for the Development of Technical or Motor Skills

This is the first behavioral approach. In the respondent conditioning, attention is given to the subject's reaction following the reception of a stimulus. In such a case, the input dictates the reaction [53], as we experience it for several reflex actions. For some specific inputs, we have a certain involuntary and nearly instantaneous reaction independent of anything else. For example, a person will instantaneously withdraw their hand from a burning surface. Respondent conditioning can thus be suitable if we want to promote the development or the acquisition of reflex movements.

At birth, babies resort to several reflexes that allow them to evolve in their new environment. Subsequently, with the development of the nervous system, a significant number of these reflexes are inhibited. Other reflexes, such as those related to the control of equilibrium, remain throughout life.

The most interesting fact regarding reflexes is their speed of execution. Since they are processed in the spinal cord, reflex movements [55] are faster than voluntary movements. Hence, when it is desired to develop very rapid reactions (as in technical gestures), reflex movements are more suited for the task than voluntary movements. Reflex motions are, indeed, of paramount importance in the completion of technical gestures [56–58]. As a result, we can deduce that a situation of applicability of this learning approach is in Serious Games aiming at the development of technical gestures. Technical gestures are found in multiple fields such as medicine, sports, the assembly industry and more. In medicine, palpation is one of the most common technical gestures. Palpation involves touch and small pressure exerted with the fingers [59]. Palpation is exploited by health professional to assess the state of a body part [60]. In sports, technical gestures are legion because the practice relies essentially on the realization of technical gestures. As an example, Lavoie and Menelas have identified a set of 19 gestures associated with soccer practice [61].

Technical gestures concern a set of movements of a body part (mainly limbs or head) aiming at the completion of a particular task linked to a professional field. They often require a high level of dexterity [62]. Because of their high level of technicality, beyond biomechanical aspects (related to the motion), technical gestures require a cognitive and psychic dimension [63–65]. In terms of learning outcomes, Kraiger et al. associated them with motor or technical skills [66]. Hence, it appears that the respondent conditioning approach may be appropriate for the development of technical or motor skills. In Section 4.2, we will describe **the use of the haptic modality in the development of technical or motor skills**.

3.2. Operant Conditioning: A Way to Engage the Player with the Content of the Game

In operant conditioning, the behavior is more influenced by associated consequences (reward or punishment) than by a stimulus that precedes it [54]. This explains why we prefer to achieve rewarding actions. More generally, one talks about positive reinforcement. When used effectively, positive reinforcements allow one to maintain or to increase a behavior. In the context of a game, positive reinforcements may be the reason why the player continues to play. It allows one to improve the motivation and/or the engagement of the player. According to Csikszentmihalyi et al., because of their motivation, the player may be fully engaged in the game [67]. Without a profound analysis of motivation theories, we assume that the motivation to keep playing a game may be linked to two main aspects: the enjoyment and the serious content of the game. The enjoyment can increase the engagement in the game. However, it will not necessarily improve the engagement with the learning content. In fact, one can be distracted by the game mechanics and its environment [68]. Of course, these two aspects may not be mutually exclusive. As discussed in [7], we think that the engagement with the content of the game is probably a better way for achieving learning gains. Given this, it appears that the operant conditioning approach may be appropriate for the engagement of the player with the content of the game. One may note that not all the content of the game plays the same role in terms of the learning objective. Indeed, for a specific learning task, some contents may be useful while others may be trivial. We then may have two types of content: RC (Relevant Contents) and TC (Trivial Contents). RC are contents that are linked to the learning objectives. In a driving simulator, for example, all contents that relate to operation of the car are relevant contents, whereas the decor defines a trivial content. In Section 4.1, we will describe **the use of the haptic modality in order to engage the player with both relevant and trivial contents of the game**.

3.3. Constructivism Approach: A Means to Support Cognitive Skills

Although some human behaviors may be dictated or influenced by stimuli, it is clear that we may not be able explain all our behaviors based only on behavioral theory. In fact, these theories do not take into account the role of our cognition and beliefs in our behaviors. In various situations, morality leads us to do what is right at the expense of a personal reward. The constructivism theory addresses such an aspect. This theory hypothesizes that an individual acquires their knowledge through a mental

activity aiming to construct a representation of reality. This suggests that the individual continually constructs a representation of the reality by exploiting past representations [69,70]. In this process, a new representation can cling to, or even be opposed to, old ones. Based on this approach, once a child knows how to add, subtraction may be taught as being the opposite operation. Hence the operation $A - B = C$ may be seen as $A = C + B$. In this context, to favor the self-acquisition of knowledge, this approach places the learner at the center of the learning process. Furthermore, it aims to develop activities that allow the learner to manipulate ideas, knowledge and associated processes. Therefore, to support the development of cognitive skills, the learner has to be in an active learning experience. Kraiger et al. associated the process of an active learning experience to cognitive learning outcomes [66].

A learner is in an active learning experience when he is able to transform the situation he is facing. Following the various changes that he will initiate, a new image will have to be built, leading to a new understanding of the initial situation. For the applicability of this method, we will be interested in the various means (possibilities of actions) that may allow the learner to transform the presented situation. Furthermore, some recent theories support the idea that the acquisition of knowledge requires an active experience [71]. Talking about the user's possibilities for action is part of the much broader field of Human Computer Interaction (HCI). Although there is not any precise theory to capture all the implications of human and computer interactions, several taxonomies have been developed. Here, we briefly relate some of them. Since the work of Shneiderman [72], which highlighted seven types of data and seven tasks, several data characteristics (continuity, dimensionality and others) have been used to develop categorizations [73]. Other taxonomies are oriented toward interaction techniques. In this group figure taxonomies based on a low level of interaction [74] and those based on intentions of users [75]. While these taxonomies provide a useful understanding of visualization technologies, they do not take into account the sensory-motor channels that may be involved in the interaction process. Only two taxonomies [31,76] have considered how the haptic modality intervenes in interaction processes, and these will be presented in Section 4.3. We will describe **the use of the haptic modality to support cognitive skills**.

3.4. Schematization of This Model

From the analysis of learning theories, we identified three learning outcomes that may be supported in SG: (i) development of technical or motor skills, (ii) connection with both relevant and trivial contents of the game, and (iii) development of cognitive skills. Here, we schematize the model that we propose for these three learning outcomes. For any learning SG, one must be able to identify the associated learning outcomes. The proposed model allows for situating these learning outcomes. Indeed, for a given learning objective, some contents are relevant while others are not. Knowing that acquired skills can be both physical and cognitive, we schematize the model in Figure 1. This figure defines six areas that relate to the identified learning outcomes (Cognitive Skills, Technical Skills) and their interrelation with the content of the game (Relevant and Trivial Contents). It is important to observe that these three learning outcomes are interdependent. In this section, we describe each area.

- In area 1, technical skills associated with trivial contents are considered. In a driving simulator, the auditory rendering of the engine of other cars is located in this area.
- In area 2, cognitive skills associated with trivial contents are considered. In a driving simulator, if the goal is to learn to maintain the steering wheel in a particular direction, interactions with the dashboard are situated in this area.
- In area 3, the technical skills associated with valuable content are represented. In the case of a simulation about the landing performance of an aircraft in turbulent conditions [77], the rendering of the turbulence is a relevant content that is associated with technical skills.
- In area 4, the cognitive skills associated with valuable content are represented. In a tornado analysis simulator [78], tools that allow one to draw or to follow elements of interest as "flowlines" are valuable contents associated with cognitive skills.

- In area 5, physico-cognitive activities with trivial information are considered. Let us consider a driving simulation where the objective is to avoid technical mistakes. Having a map that allows the user to search for the quickest route is a trivial content that requires physico-cognitive skills.
- In area 6, motor and cognitive skills are solicited with a relevant content. In the case of a surgical simulator, a scenario that would take us to this area would be the following: the practitioner has to make several realistic maneuvers to try to stabilize a patient. Every element of the simulator that informs about the state of the patient is relevant content.

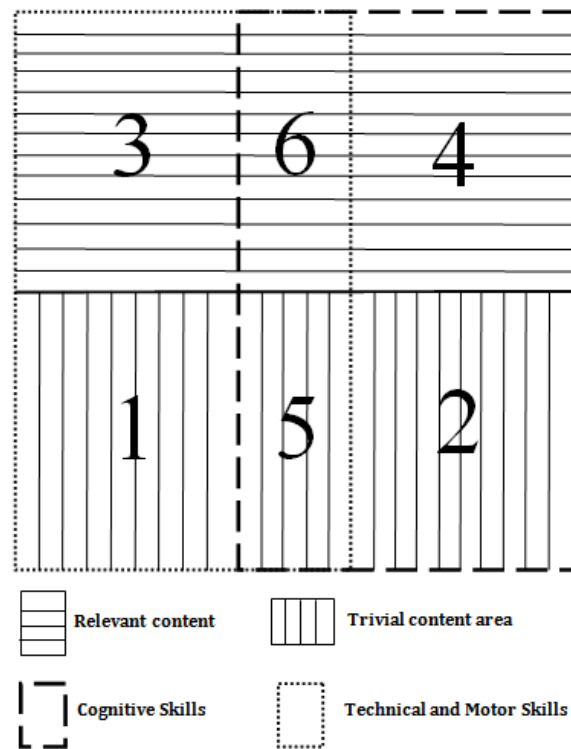


Figure 1. The model proposed for the identified learning outcome.

Throughout these examples, we observe that the most relevant areas are #3, #4 and #6. When using this approach, one has to ensure that selected haptics interactions are located in those areas.

4. Use of the Haptic Modality to Support Learning Outcomes

In previous sections, we have identified three learning outcomes associated with the main learning theories. Since we are interested in exploiting the haptic modality to promote learning outcomes, here we will analyze how haptic interactions intervene. We begin with the use of the haptic modality to engage the user with the content (both trivial and relevant) of the game. Thereafter, we describe its usage for the development of motor or technical skills. Finally, we consider the use of haptics for the development of cognitive skills.

4.1. Haptics to Engage the Player with the Content of the Game

To engage players with contents of a game requires eliciting of emotional reactions of users with regard to that content. We observed that most researchers have mainly focused on visual and auditory based interactions [14,15] to elicit emotional reactions from users. Being strongly related to feelings, the haptic channel seems to be much more appropriate, compared to visual and auditory channels, to elicit emotional reactions of users (see Section 2.2). To achieve this, haptic tactile interfaces

should be exploited since very little work has been done on the use of force feedback for affective communications [79].

Regarding the use of tactile feedbacks, Bailenson et al. demonstrated that it is possible to translate seven types of emotions such as: anger, fear, disgust, sadness, joy, interest and surprise through virtual interpersonal touch. They utilized a haptic interface as a mediator between users to convey emotions through gestures. A feasibility study using human haptic emotion as a feature to enhance interactivity and immersiveness in a Virtual Reality (VR) game was established by Basori et al. in [80]. A two-degrees of freedom force-feedback interface allows the delivery of emotions from virtual character interactions to the player by the means of different vibrations. Other studies suggest that it would be interesting to use material properties such as textures and temperatures to introduce emotional factors [41,42]. A sticky texture usually creates unpleasant feelings like repulsion. Recently, Brewster et al. have evaluated subjective interpretations of thermal feedbacks [81]. Furthermore, by connecting people, haptics motivate a person by fulfilling their need for affiliation. For a more detailed view regarding the use of haptics as an affective mechanism, one can refer to [79].

4.2. Use of Haptics for the Development of Technical or Motor Skills

Being bi-directional (see Section 2.2), haptics are particularly appropriate for the learning of technical gestures, as they may be exploited for both motor skills (input) and sensory feedbacks (output) associated with the completion of the task. Regarding the development of technical or motor skills, we suggest that force feedback should be exploited. The movement of the haptic probe can be subjected to certain constraints to assist the user in the action he wants to carry out. As an example, if we are dealing with novice users, areas of interest may attract the haptic probe. In the case of virtual mammography, attractive areas may be those likely to have abnormalities in a guided exploration [82]. Regarding sensory feedbacks, various properties of entities of interest may be rendered throughout the haptic feedback. In terms of haptic rendering, such feedbacks may be conveyed thanks to the hardness or the texture of these entities. In the same way, Marti et al. have shown that using haptic rendering to provide real-time assistance to medical gestures combined with visualization may be useful for skills acquisition [83]. They reported that, with visio-haptic interactions in biopsy trainings, one can improve skills and knowledge, as well as feelings of competence during the task completion. Esen et al. reported that audio-haptic augmented interactions increased performance of trainees and accelerated the skill training process in bone drilling [84]. Thus, the inclusion of haptic interactions improves the usefulness of simulated surgical procedures [85,86]. For gestures associated with sports, the entity of interest may be the correctness of the gesture [87].

4.3. Use of Haptics for the Development of Cognitive Skills

Promotion of the development of cognitive skills allows the user to be active in the learning process. To use haptics for this task, we suggest the exploitation of the work described in [31]. Yi et al. have shown that low-level tasks play a central role in allowing users to be active in the discovery of knowledge [88], Menelas has proposed a taxonomy based on haptic-enhanced low-level tasks and this work is based on interaction tasks where haptics seem to have some advantages over the other channels. The proposed taxonomy is divided into four categories: *Select, Locate, Connect, and Arrange*. We propose these tasks as a means to promote the development of cognitive skills via the haptic modality. In what follows, we briefly describe these tasks. For a detailed presentation, one may refer to [31].

- **Select:** to choose or mark an entity of interest.

In a selection, the haptic feedback is employed in order to assist users in picking up a point of interest. In haptic augmented selection, a pseudo-attractive force is usually simulated at the position of the entities of interest (also named target). In situations where a single target is rendered, such haptic feedback allows one to improve the completion velocity as well as the

accuracy of the task [89]. When there are multiple targets, for each target, an area of influence has to be defined in order to obtain the advantage of the haptic interaction [90,91].

- **Locate:** to spatially and temporally situate an entity of interest in the dataset.

One of the first methods that has been proposed concerns the identification of regions containing high values with velocity mapping [92]. The field value is mapped to the velocity of the haptic device. This method slows down the hand of the user in regions having values of interest. In the analysis of an unsteady flow, critical points located in the immediate environment of the users are rendered visually by colored spheres and haptically through a sinusoidal vibration. Realized experiments show that vibration feedback reinforces the visual feedback and facilitate the construction of a mental map of the analyzed Computational Fluid Dynamics simulation.

- **Connect:** to join elements with common properties.

This approach allows one to haptically track structures of interests. In doing so, local properties of this structure can be studied adequately. This also allows one to take advantage of multimodal analysis. With this approach, some methods relate to the haptic rendering of lines, others relate to the haptic rendering of iso-surfaces. For haptic rendering of lines, most of the methods have been proposed by Pao et al. in [92] and van Reimersdahl et al. in [93]. Haptic rendering of isosurfaces have been introduced by Mark et al. and Avila et al., respectively, in [94,95]. Subsequently, several researchers have proposed significant improvements [33,96–98].

- **Arrange:** to assist users in the spatial arrangement of analyzed elements.

Here, some constraint rules may be employed in order to guide the gestures of the user based on some information contained within the dataset. Such methods have been successfully employed to overcome limitations of traditional docking algorithms. The haptic feedback allows one to translate physical and chemical properties of elements to the user involved into the docking process. By means of the haptic modality, a greater amount of information is transmitted to the user without risking the overload of the visual channel.

4.4. Discussion and Evaluation

As shown in Figure 2, the proposed model has two types of objects: cylinder and disk. The inside of the cylinder is described by “Engage user to the content”, where the solid part is the Relevant Content (RC), and the hollow part is the Trivial Content (TC). Moreover, the right end of the cylinder is closed by “Technical or Motor Skills” and the left end by “Cognitive Skills”. In fact, one can see that these two learning outcomes are strongly connected to the content of the game, and it is also in line with the model proposed in Section 3.4, as illustrated by Figure 1.

In addition, the three parallel disks show how to exploit the haptic modality in each identified learning outcome. We recommend the use of tactile feedback in order to engage the user with the content of the game. For the development of technical or motor skills, force feedback has to be exploited. With regard to the development of cognitive skills, four low-level haptic-enhanced tasks are suggested.

Considering that SG usually exploit more than one modality, since the proposed model is dedicated to the haptic modality, it has a limitation in the sense that it does not consider other modalities. In fact, as mentioned previously, haptics may be influenced by other modalities (visual or auditory). Moreover, some tasks require the coordination of two or more modalities. These aspects will be addressed in a future research. In what follows, we discuss the evaluation of this model.

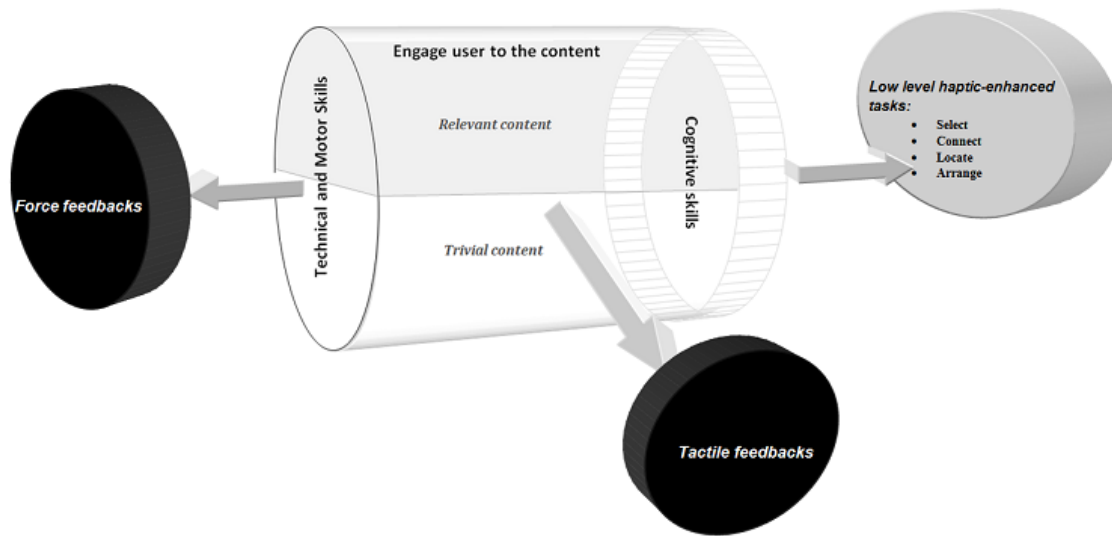


Figure 2. The model proposed to use the haptic modality to support learning outcomes in Serious Games (SGs).

To evaluate this work, we refer to the approach proposed by Beaudoin-Lafond in [99] while adapting it to our situation. Three evaluation criteria are selected:

1. The descriptive power: the ability to describe a significant range of existing methods,
2. The evaluative power: the ability to help assess multiple existing methods,
3. The generative power: the ability to help in the design of new methods.

4.4.1. Descriptive power

When we consider the three disks of this model, one observes that they have two types of classifications. They are the two main categories of haptic interaction (tactile and force-based) represented by black disks and four low-level tasks represented by the gray disk. With this type of classification, it is clear that most methods in the literature should fit in the proposed model. Hence, it appears to us that the descriptive power of the model is quite high. However, as in the case of the cylinder, since the disks are tightly linked to this one (the cylinder), some methods in the literature may fall into two different categories. The reader may refer to the discussion in the previous Section 3.4 for some examples.

4.4.2. Evaluative power

Evaluation refers to the worth and significance of something using criteria against a set of standards. Speaking about evaluation is equivalent to asking the question about the existence of criteria that define whether a method is more or less suitable to promote learning outcomes. One may note that this aspect is one of the facts that motivated our work because we estimated that most use of the haptics have been aimed at the mimicking of realistic feelings or the enhancement of the immersion of the player. The cylinder in this model addressed this point since it identifies learning outcomes that have to be targeted. In fact, as discussed in Section 3.4, Figure 1 constitutes a meaningful tool to evaluate existing approaches.

4.4.3. Generative power

To evaluate the ability of the proposed method to help in the design of new methods, we report here how one may use it in the design of a haptic-enhanced soccer game. This design includes two main steps. They correspond to the two objects of the proposed model.

In the first step, one has to identify learning skills that one expects to promote with the haptic interaction. For a soccer game, one may be interested in :

1. Engaging the player with the content of the game,
2. The development of technical skills.

For each type of learning outcome, one has to identify all associated elements. Table 1 details some of the relevant content required for learning technical skills in a soccer game. It is clear that, in this case, the relevant content is the haptic rendering of the ball and the technical gestures. Regarding the development of the technical skills, one has to list all technical gestures that may be relevant to learn. One may refer to [61] for such a list. Afterwards, one has to analyze the identified elements (contents and technical gestures) using Figure 1. Only interactions situated in area #3 should be retained for the development. After all these steps, tactile feedback may be exploited for the rendering of selected contents, whereas force feedback will help to guide the user in the completion of gestures.

Table 1. The relevant game contents.

The Soccer Ball	Technical Gestures
wet	kick
hard	juggle
rough	feint
smooth	back heel

5. Conclusions

While several games do exploit haptic interactions, we observed that the goal of this has been focused on a pure replication of real life scenarios. In this research, we outlined that the haptic modality should be exploited to promote learning outcomes. For this, we proposed a model where learning outcomes are divided into three categories. For each category, we showed how haptic interactions may be exploited. We discussed the limits of the proposed approach and showed that the proposed model may be used to describe and to evaluate existing methods. In the same way, it may also help in the designing of serious games that want to take advantage of haptics to promote learning outcomes. We believe that these models may guide designers towards a better integration of haptics.

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