On the use of metaphors in designing educational interfaces

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Abstract—**Metaphors are present in a wide range of everyday activities. They usually work by understanding or explaining complex subjects by terms from more familiar domains. Metaphors in everyday context are often used unconsciously, as their sources are basic entities and perceptual experiences. They can, however, be used deliberately in educational discourse to explain difficult concepts and introduce new ideas in an intelligible manner. This approach falls under constructivism, which claims that an effective learning strategy is to scaffold on the previous knowledge and conceptual representations. However, there are some limitations of introducing a new concept indirectly via a metaphor. We consider these issues here in the domains of physics education, human-computer interfaces and human-robot interactions. We argue that metaphors are most effective for novices, when one needs to grasp a general idea about a concept and understand its functions without a detailed analysis. In this respect, metaphor can be a powerful tool for bridging gaps in understanding between familiar terms and abstract ideas that are yet to be learned.**

Keywords—metaphor; human-computer interfaces; physics education; human-robot interfaces

I. Introduction

The role of metaphor as a tool in understanding and cognition [1] can be considered from a pedagogical perspective for introducing a new concept to the students. In this pedagogical approach, known as constructivism, the new abstract concept is introduced in terms of a more familiar one. It exploits previous knowledge and conceptual representations as bases for further learning. However, there are some drawbacks of introducing a new concept through a metaphor (as opposed to introducing it directly). For example, it may lead to erroneous inferences, or suboptimal ways of processing information. We examine here this issue by considering the role of metaphor in three different domains: physics education, design of human-computer interfaces, and design of human-robot interfaces.

II. Metaphors in physics education

Physics has a special place in the field of education, as it contains abstract concepts and operations that have to be kept in mind simultaneously to understand the whole phenomenon: the learners need to refer to elementary aspects of a concept in order to understand the higher-order relations and abstract notions. There is much research to show that metaphors are effective in this process of learning physics. The use of metaphors, however, is also associated with possibilities of misconceptions and incorrect representations. For instance, Ugur et al. [2] designed lessons using metaphorical or analogical models, and compared them with the lessons based on standard didactic methods. The group of students taught using metaphors yielded better results (70.8% to 31.75% in pretest) than the group taught with the standard teaching method (51.75% to 30.1%, respectively). In this design, an extensive evaluation of the impact of metaphors was carried out, including evaluation of the learned knowledge, confidentiality measures and opportunities for correcting invalid inferences drawn from the relationship between the source and the target domains. There are several other studies investigating the impact of a metaphor or an analogy on the effectiveness of learning that emphasize the need of proper explanations of given domains and their relationship for understanding abstract physics concepts ([3-6]). These studies also show that an insufficient understanding of these cross-domain mappings may result in acquiring incorrect models of a given concept. This follows from the fact that a metaphor does not objectively represent an abstract concept, but is rather a construct that facilitates learning. Problems of misconceptions and a proper articulation of the source domain are major difficulties that threaten the role of metaphor as a mechanism to clarify unfamiliar concepts. Additionally, learners often carry certain preconceptions related to the nature of the intended target concepts. For example, they tend to understand abstract physics concepts as substances [7], even though such a view is incorrect; which may be explained by the fact that metaphors are embedded in perceptual experiences. Identification of these preconceptions can lead, however, to a better design of physics lessons and more accurate explanations.

Another important aspect concerning the role of metaphor in physics education is that any metaphor is essentially incomplete. As one metaphor cannot fully explain any given physics concept, introducing more than one metaphor may be helpful in highlighting different aspects of that concept, thereby providing a deeper understanding of it [8]. It is important to acknowledge here that the full explanation of the target concept cannot be provided by any single metaphor, and so one should clearly articulate which metaphor is suitable for which aspect of the concept [9]. Moreover, metaphors seem to be just a starting point in the process of acquiring a certain concept. A metaphor can be useful at the beginning when one encounters an unfamiliar concept because of the similarities with the familiar source concept. However, it can be distracting as one gets more familiar with the target concept because one has to carry much more cognitive load: in metaphorical reasoning one has to pay

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attention to the source and the target domains, and also to the relational mappings between them.

Introducing metaphors in educational discourse can facilitate understanding of abstract concepts, but what matters is also the way in which metaphors are introduced. Improper use of metaphors can result in several difficulties related to conceptual knowledge that are not easy to change and that can lead to erroneous reasoning in the domain.

These results from the research on the role of metaphors in physics education can be used to design more effective physics lessons. Use of metaphors during lessons requires not only explaining what are the similarities between the given domains, but also when they break and why. Furthermore, one must adapt the way in which new knowledge is presented in the context of the existing conceptual structures that the students already possess. For example, the structure of the universe cannot be explained by linking it to the structure of an atom, if the latter concept is unfamiliar itself. One more difficulty of incorporating metaphors in the design of effective physics lesson may be that it assumes that every learner in the class shares the same, or at least comparable, common knowledge. Some of these issues have been addressed in the use of metaphors in the design of human-computer interfaces, as we will discuss in the next section.

III. Metaphors in Human-Computer Interfaces

Metaphor provides a powerful mechanism for designing effective human-computer interfaces. Perhaps the most prominent example of this is Apple's desktop metaphor in the early 1980s. Since then, interface designers have considered the role of metaphors in human-computer interactions, and there have been many studies to explore the advantages and disadvantages of metaphor-based interfaces [10-14]. For example, Erickson [11] noted, "to the extent that an interface metaphor provides users with realistic expectations about what will happen, it enhances the utility of the system." With this goal in mind, Szabo [13] has identified four steps in designing metaphor-based interfaces:

1. Search for possible metaphors: source domains that are familiar to the users but also connect with the target in an effective, meaningful way.

2. Elaborate the details of the mapping between the source and the target.

3. Identify mismatches: figure out where the similarities fail.

4. Design mechanisms to handle mismatches: how to prevent the user from making mistakes due to mismatches.

Nonetheless, there are a number of examples that illustrate the inadequacy of metaphor-based interfaces:

1. When the word processors began to be commonplace in offices, many times their functionality was explained with the analogy of a typewriter. But this prevented the users from realizing the more powerful functions of word processors [15].
2. The trashcan icon of the desktop metaphor caused some confusion among the users, especially as in the early days, when floppy disks were in use, one could eject a floppy by dragging it to the trashcan [16].
3. Until recently, almost all the word processors and multimedia editors used a buffer-file metaphor, which is based on the designer's model. In this metaphor, one makes a distinction between the buffer, which is where editing takes place, which is visible on the screen but is temporary; and the file, which is permanent but the contents of which are generally not visible. This causes some confusion among the novice users [17, 18].

The current approach is to study the conceptual model of the user, and design the interface so as to conform to this model [12]. It is important to pay attention to the user expectations in designing interface metaphors – in a poorly designed interface these expectations are contrary to the system response. Furthermore, metaphors are most efficient for novices, when they have to grasp the general idea of a concept without getting into the details.

Notice that there is a parallel here with physics education. In physics, the domain being studied has its own rules and laws, and as an educator our goal is to facilitate understanding these laws by presenting them through familiar analogs. In the user interface design, the designed object has its own functionalities, and our goal is to make those functionalities intuitively obvious through the interface. An important difference, however, is that the functionalities of the designed object can be changed somewhat, whereas the laws of physics cannot be tinkered with.

IV. Metaphors in Human-Robot Interfaces

As social robots are rapidly pervading our society, it is important to design interfaces that are intuitive and do not require a special training by the users. Indeed, some research in this direction has already started [19-22]. Researchers are finding that tangible interfaces that are physical objects, and are operated by sensorimotor gestures of the users are more effective than the keyboard or mouse operated ones.

Metaphors applied to human-robot interfaces can be approached from two different perspectives. One is to use metaphors in a human-robot interface to control the actions of a robot. Indeed, much research has been done to investigate conceptual models people have of robots, and how to design effective interfaces based on these models. For example, a study by Beran et al. [23] found that many children attribute cognitive, behavioral, and affective characteristics to robots. In another study, Guneysu et al. [24] found that children instinctively imitate robots. Mi et al. [21] designed a tabletop interface to allow users to interact intuitively with a mobile robot. Metaphor-based interfaces to interact with robots can be useful for understanding their complex operations, but also their usage can encourage children to interact with robots and gain interest in the field of robotics.

The other approach to incorporate metaphor in robotics is to design the robot in such a way that it interacts with the user evoking metaphors. As far as we know, there are not many studies in this area yet. However, as social robots seem set to invade our everyday lives, perhaps not unlike smart phones, it is only a matter of time before there will be a need to incorporate a metaphorical module in their design. Researchers have already discovered that robots can be very helpful in helping children with autism learn about social interactions[25, 26]. The results from these studies are being extended to larger population groups (see, for example, [27]). Using robots to engage in metaphor-based interactions may be effective from the user's point of view, but it can also lead to various problems mentioned above. For a dynamic and contextual communication with the user, the robot would have to have some representation of the user's background knowledge and goal behavior of the user. Besides, the robot should be able to perform case-based reasoning, and create cross-domain mappings as needed.

V. Conclusions

Introducing metaphors in educational discourse, as well as in interface design, can be effective but only if it is done after a thorough consideration of the student's (or the user's) background, similarities between the source and target, and also potential misconceptions and erroneous inferences that may result from the metaphor. Metaphors and analogies often assume a shared experience, which is acquired not only linguistically, but also perceptually. Much of the perceptual knowledge may be unconscious and implicit, and so when metaphors based on such knowledge are deployed, they create an intuitive understanding and can be very effective.

We argued that the experience of using metaphor in physics education, which had exposed the advantages and limitations of using metaphor in introducing a new concept via another familiar one, could be applied to design effective human-computer interfaces and human-robot interaction systems. We need to study the background knowledge of the user, and design interface that take advantage of this knowledge to introduce the functionalities of the system or the robot in an intuitive way, while taking care to minimize the misunderstandings that might result from transferring unintended parts of the metaphor.

This pattern of interaction can be generalized to almost any type of education in which artificial agents are used. Learning with metaphors can be helpful for the users, but it is important to realize that finding a relevant metaphor is itself a difficult task. Explanatory metaphors need to meet various conditions in order to be considered as helpful. For instance, an explanatory metaphor should enhance understanding, provide a starting point for further discussions and react to possible errors by self-correction [28, p. 10]. These requirements constrain the direction of research on metaphors in human-computer interfaces.

Results of this research also contribute to the discussion in the wider field of cognitive infocommunications [29, 30], which investigates how humans can interact with artificial agents. Various examples presented in this paper demonstrate that using metaphors can be efficient for humans in terms of intra-cognitive communication: that is, when there are two cognitive agents sharing information. However, this approach can also be applied for inter-cognitive communication, where there are two systems with different cognitive abilities. In such cases, we start with the assumption that although the abilities of the two cognitive systems differ, they can still share knowledge about the environment and abstract relations between objects or concepts with humans. This is, however, difficult to achieve as one of the requirements of explanatory metaphors is their ability for self-correction depending on the situation in a dynamically changing environment. As deploying an explanatory metaphor is preceded by empirical research that takes under consideration cultural models [28], it seems that an artificial system would need a special support system that incorporates at least some language processing ability to consider incoming information and dynamically generate an appropriate metaphor as output. Metaphor-based interfaces can also be considered as examples of representation-sharing communication [30]. In this approach, both the agents use metaphorical representation for certain concept, but only one agent (human) is aware of its meaning. Evolution of such representation-bridging communication would require implementation of a module that can process language and is able to understand and create metaphors. Such a system could be more interactive and adaptive to the user's preferences and experiences.

Overall, metaphor can be very useful, yet dangerous. It should always be remembered that a metaphor is rather a heuristic for understanding, than the actual formal description. While in most of the cases it fits the situation and extends one's knowledge, sometimes it fails. Studying the limits of metaphors, and when and why they fail, can help us design more effective and intuitive educational interfaces.

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