Title: A pedagogical model for e-learning tools design: a semiotic engineering approach

Miguel Murguía\textsuperscript{a} and Salvador Rodríguez-Zaragoza\textsuperscript{b}

\textit{Author for all correspondence: a} Miguel Murguía, UBIMED, FES Iztacala. UNAM. Av. de los Barrios No. 1, Los Reyes Iztacala. Tlalnepantla, Estado de México, México 54090. E-mail: miguelmurguia@gmail.com. Fax: 52(55)-56231333 ext: , phone # 52(55)-56231239

\textit{b} Salvador Rodríguez-Zaragoza, Laboratorio de Microbiología, UBIPRO, FES Iztacala, UNAM. Av. de los Barrios No. 1, Los Reyes Iztacala. Tlalnepantla, Estado de México, México 54090. E-mail: srodrige@campus.iztacala.unam.mx.
A pedagogical model for e-learning tools design: a semiotic engineering approach

Abstract
E-learning tools design is intended to mediate communication between the student (user) and the software involving teacher intervention. The design process could be taken as a dialogue between teacher and student. Thus, the main actors in the teaching/learning process are involved during the software-design process in this semiotic perspective. We aim to introduce a model for designing e-learning tools that allows communication of the intentions that both the student and the teacher specified during the design process. This model is based on the semiotic engineering approach, which incorporates the communicability concept as a property of software to convey efficiently and effectively its underlying intent design and interactivity principles to users. We integrated the ‘semiosis’ and ‘enunciation’ concepts arising from the semiotic discipline into this model. The ‘pedagogical enunciation model’ consists of four elements: teacher model, student model, learning principles, and system design. The first three elements need to be defined, and the system design is built based on the enunciation concept. An example in the life science domain is shown, developing an enunciation about how to transform the items of the three model elements into a system design as a fourth model element.

Keywords: Enunciation concept, learning principle, teacher model, semiotic engineering, student model.

Introduction
The cognitive approach for system design [1] [2] has been the main paradigm for building computer programs and user interfaces; the design of human–computer interaction (HCI) has followed a user-centered model based on a cognitive perspective [3] [4]. Instructional design has also been focused on a cognitive framework [5]. Cognitive theories such as the cognitive load theory [6] and situativity theory have concentrated on how individuals organize information in memory, on how this affects learning, problem-solving, and decision-making, and on the roles that self-regulatory activities and socio-cultural environment play in understanding and reasoning [7].

The semiotic engineering approach has been proposed for designing user interfaces [8] [9] [3]. This strategy is based on a combination of communicational and informatics approaches and considers that designers are present during the interaction time. Then, interaction is conceived as taking place among three actors: the system, the user, and the designer [3]. There are several apparently elusive qualities of interactive system interfaces (like usability, consistency, or intuitiveness) resulting from these deliberated choices, and they are not inherent to the choices of interface signs, like widgets, images, layout, or dialogue structure [3]. For example, attributes such as ‘intuitiveness’, ‘fully graphical interfaces’, or ‘easy-to-use’ that Rangel et al., [10] give as included in the SAM software (Spatial Analysis in Marcoecology and Biogeography) they describe, resulted from deliberate
decisions of its designers about what to communicate to the final user, that is, the semiotic engineering approach. From the user-centered model perspective, the process of system design involves deliberate communication based on the designers’ choices [3]. The semiotic design process must guide designers in how to make the appropriate communicative choices to facilitate the user’s understanding of their intentions.

Semiotic engineering is particularly focused on efforts to achieve a high level of communicability in interactive systems. Communicability can be defined as the property of software to convey efficiently and effectively its underlying design intent and interactivity principles to users [11].

Semiotic engineering has also been used to propose methods to evaluate the communicability of user interfaces [11] [12]. The aim is to determine how well users understand the designer’s intended messages at the interface and to identify communication breaking points during user’s interaction with the interface.

Our approach to semiotic engineering is based on the following characteristics as a method for software design:
- Semiotic engineering approaches design as a process of communication.
- The interaction is conceived as occurring among the following elements: the teacher, the student, the system, and the student’s sessions.
- According to the semiosis action, the user interface can be seen as a collection of signs interpreted by the user.
- The process of system design involves a deliberate communication of the designers’ intentions.

The semiotic design process is compatible with new pedagogical approaches like the knowledge building [13][14] that conceptualizes the educational process as a knowledge-creating culture, more than just a culture of transmission. From this educational perspective, the Internet becomes more than a desktop library and a rapid mail-delivery system. It becomes the first realistic means to connect students with the world of knowledge building and make their classroom part of it [14]. The semiotic design software approach, viewed as a communication process among designer, system, and user, is analogous to knowledge building because both approaches conceive students as learners and inquirers, and in doing so, as members of the knowledge-building community [14].

Based on these characteristics of semiotic engineering, we attempt to achieve a better level of communicability using the semiotic approach at the design stage. The objective is to build a pedagogical model based on semiotic engineering that allows (a) the establishment of the teacher–student interaction at the time of design development, and (b) achievement of a high level of communicability between teacher and student, through the designed system.

We explain our approach of semiotic design based on the semiosis concept followed by an exposition on the enunciation concept as semiotic; next, we propose a pedagogical model based on such an enunciation concept; and finally, we demonstrate an Internet e-learning tool design, resulting from application of the model to support
teaching of a specific biological science domain.

1. **Semiosis of the e-learning tools**

A basic concept in the semiotic discipline is the *semiosis* action. According to Peirce (cited in [15]), *semiosis* is an action that involves a relationship among three elements: a *sign*, its *object*, and its *interpretant*. In semiosis, the sign represents or refers to something [15]. Thus, the sign is used instead of the object and is interpreted by the interpretant (upper left part of Figure 1).

*Figure 1: Three-way relation of Peirce’s semiosis concept and the analogy in the pedagogical enunciation model*

We propose to view the e-learning tool design process as a semiotic action; thus, three elements could be identified: object, sign, and interpretant. These three semiotic elements could be identified within the three systems in the pedagogical context (lower right of Figure 1), as follows: physical system, communication system, and model system.

Each system is an alternative scope of the interrelations among four basic elements interacting in the pedagogical process (Figure 2). A pedagogical model (consisting of a student model, teacher model, learning principles, and system design; Figure 2.c) could be seen as a sign of the physical system (consisting of the student, the teacher, the student’s sessions with the system, and the computer system; Figure 2.a). The communication flow (Figure 2.b) could be taken as the semiotic interpretant of the physical system.

*Figure 2: Three levels of the ‘pedagogical enunciation model’*

2. **The enunciation process**

We use the *statement* and *enunciation* concepts to guide the design process as understood by Benveniste [16] and Mondoñedo [17], putting them into the context of the semiotic theory. A *statement* is a *sentence* located in a particular discourse; depending on the context, it could imply an action. This process is called *enunciation* and refers to the description of the relation between the statement and its contexts; the meaning of a particular statement depends on the communicative situation.

2.1 *Enunciation in linguistic and computer systems design*

Certain elements of the language acquire significance only after a speaker has spoken them, an illustration of the ‘situation of the enunciation’. Thus, enunciation in a linguistic context, *sensu stricto*, refers to recapturing the moment (time, space, and subject) at which the statement was enunciated [16]. Here, we focus on the enunciation concept as a reference to the moment at which the software designer wants to express something to the user. In the specific case of the educational software context, the relationship is between the teacher and the student. Therefore, the moment could be a teaching strategy.

The enunciation is conceived as an act, and not only as a linguistic object like a
sentence or text [16]. The enunciation also supposes a *speaker* and an *addressee*, because all speech involves another person to which it is addressed.

From a semiotic linguistic perspective, enunciation takes into account that both the statements and the author that built such statements (and inherently the circumstances of their building) appear in the same text [18]. Somehow, therefore, the author is present in the text. Analogously, semiotic engineering proposes that the designer is present in the user interface.

### 3.2 User interface as a discourse

Computer user interfaces are another mode of discourse, produced just as the oral or written modes are. The relationship between the statements and enunciation is important because it points out effects on the addressee. The enunciation process supposes an intention of the speaker to have an influence on the listener. From a semiotic engineering perspective, *enunciation* can be considered analogous to the designs of an interface that have the aim of modifying the user’s behavior.

Design is a discourse [19] [20] with its own language and processes, and its main role is to communicate and mediate between the user and the artifact, involving all stakeholders in the product-development process [19]. According to Gagliardi’s concept of design, the main role of e-learning tools design is to communicate and mediate between the student (user) and the software, involving the teacher (and other stakeholders in the product-development process).

For Winograd [21], software design involves object construction with an intention. He conceptualizes software design as: “the study of the intersection of human, machine, and the various interfaces—physical, sensory, psychological—that connect them. When people create software—or any other product—decisions are made and objects are constructed that carry with them an intention of what those objects will do and how they will be perceived and used” [21].

### 3.3. Communication uncertainty

We assume that, in most cases, communication between teacher and student is not so good that it allows a full understanding of all items the teacher wants to communicate. However, it is not as bad as it would be if none of the items were understood. In our approach, communication contains uncertainty about the understanding of the topic under review, and the use of the pedagogical model helps reduce such uncertainty. Communication is non-monolithic; in other words, a concept that is being communicated is formed by several pieces or bits of information, and it is impossible to communicate the concept by means of such pieces of information separately. So, the lines in Figure 2 (section b) represent the connection lines between those bits of information that help us make sense of what the concept means.

### 3.4 Enunciation and hermeneutics
As mentioned before, enunciation can be considered as the design process that the designer of user interfaces employs with specific intentions for the user’s learning. This definition implies that the user can capture such intentions but takes into account the communication uncertainty supposition (explained above), in which it is expected that the student will not understand all of the intentions adequately. This process of communication between the teacher’s intentions and interaction with uncertainty on the part of the student can be identified as hermeneutic.

In general, the hermeneutic process refers to the understanding and interpretation of texts in a linguistic context. Hermeneutics is related to the investigation of the moment of application or appropriation in the act of understanding (Gadamer in [22]) and works to clarify the conditions in which understanding takes place [23]. According to Fallman’s [24] design of ‘pragmatic account’, the design concept takes the form of a hermeneutic process of interpretation and creation of a meaning.

In a system design context, we designate as a hermeneutic process the user’s understanding of the designer’s intentions through interpretation of the elements of the interface. The student performs the interpretation of the signs at the user interface depending on both the intentions of the teacher at the time of the design (ie, enunciation) and the interpretative principles of the student (ie, the student hermeneutic approach). We refer to this here as the ‘communication integration capacity’.

3. A pedagogical enunciation model

A pedagogical enunciation model is built to represent the interaction between the system and the student. The model we propose seeks to achieve a high level of communication of designer intentions at user sessions. Because the designer from a semiotic perspective is somehow present at the user interface, the model is about the interaction (or communication) between the teacher (if s/he shares the model premises) and the student.

The approach of the ‘pedagogical enunciation model’ differs from the student models conceived in the area of intelligent tutor systems; these latter are based mainly on a cognitive perspective (focused on internal knowledge representations), while our approach is centered in the communication process established by semiotic engineering. Because enunciation relates the statement with the moment at which it was enunciated, a pedagogical model to build e-learning tools will focus particular attention on what the teacher wants to communicate to the student through the system if the analogies language statement–interface element, author–designer, and reader–user are accepted.

The terms ‘teacher’ and ‘designer’ are used indistinctly because the model implies the knowledge and acceptance of the model principles by the teacher, regardless of whether or not s/he designed the system.

4.1 Specification of the model elements

We propose to manipulate the model view (Figure 2.c) to determine the
communication flow, which facilitates achieving the pedagogical goals. By ‘manipulating the model view’, we mean to define and operate a set of controls, restrictions, or specifications related to each element of the model (teacher model, student model, learning principles, and system design enunciation).

4.1.1 The teacher model

By teacher model, we mean to specify the basic premises that a teacher needs to meet to use the system as a pedagogical tool. The teacher model is used in two ways as a part of the whole pedagogical model: (a) to clarify the characteristics teachers have to acquire to be able to use the tool, and (b) to apply these restrictions at the time of system design.

Epistemic principles.- The teacher needs to make explicit his or her point of view about how knowledge is conceived and related to theory, method, and technique, including philosophical aspects. For example, the teacher should agree on the perspective that a concept could be approximated by several working definitions, without each definition necessarily corresponding to a separate concept.

Institutional principles.- The teacher should agree with objectives at several levels, from the objectives at the subject program level up to the university mission level.

Social-disciplinary principles.- The teacher agrees and knows the uses and customs of the discipline being taught. For example, if the tools are about a science subject, the teacher should recognize the value of a scientific publication and distinguish between those that are scientific and those that are not.

Knowledge to teach.- It is important to make explicit which knowledge bases underlie the system being designed for the student to learn.

Teaching strategies.- These are the specific ways of introducing the concepts, process, sequences, or exercises to the student with the intention of student learning. These strategies need to take into account the learning principles to ensure compatibility between the teacher and the student.

4.1.2 The student model

The student model is basically about the knowledge that the student can integrate. Issues concerning epistemology, such as how the student structures the knowledge and how s/he adjusts to its acquisition, are considered in the learning principles element. Knowledge in the student model is classified into three categories: what the student actually knows, what the student does not yet know, and the erroneous knowledge or misunderstandings the student has. An example of each kind of knowledge could be, respectively: ‘The Earth is approximately spherical’, ‘The Earth completes a translation cycle in a year’, and ‘Spring takes place at the same time in both hemispheres’.

Missing knowledge.- This refers to the knowledge to teach in the teacher model characteristics, and it is a precondition that the student does not know them yet.
If the student already knows the subject to learn, most probably s/he will be bored if the work is not presented as strengthening exercises.

**Prior knowledge.**- Prior knowledge the student must have to be able to use the tool.

**Possible misconceptions.**- Ideas that the student most probably has erroneously integrated or misinterpreted. Experienced teachers frequently identify common misconceptions of students in a specific context.

### 4.1.3 Learning principles

This element of the model is related to the student learning process from two points of view, that of the student, ie, hermeneutic (interpretation rules) and that of the teacher, ie, pedagogical (pedagogical model).

**Interpretation rules.**- Teachers can identify some basic interpretation rules that the student uses in some context or moments during the pedagogical process. These interpretation rules could be used in two ways: (a) to guide the enunciation process and (b) to induce changes in such student interpretation rules (student hermeneutics). Educational processes involve not only the transfer of knowledge or communication of concepts or facts, but also changes in the ways that students adjust to the knowledge and the educational process itself. We propose interpretation rules as a kind of pedagogical meta-rules, not included in the pedagogical principles. An example of such a principle is the way students interpret the teacher’s statement, ‘it could be in the application’; another example is that students perceive (or interpret) a learning object involving a list of multiple choices in very different ways depending on whether the answers count for a grade or the exercise is only exploratory or non-supervised.

**Pedagogical principles.**- The teacher needs to select the basic principles pertinent to the particular domain to teach according to the educational situation. Here the decision is made about which pedagogical paradigm will be used to approach the learning process; for example, among behavioral, cognitive, Piagetian-constructivist, humanistic-gestaltical, or Vigotskian-sociological paradigms.

### 4.1.4 System design by enunciation

Based on the previous three elements (teacher model, student model, and learning principles), a set of communication items are built. This element of the model is a set of statements with a translation to arrays of signs in terms of the possibilities of the interface (like buttons, lists, images, positions, or colors, among others). The output of the system design enunciation element is a design specification. To perform this enunciation process, we propose the following steps:

**Step 1. Model items.**- For the ‘teacher model’, the ‘student model’, and ‘learning principles’ model, define a set of items that properly define them.

**Step 2. Statements.**- Taking into account the items defined in the ‘teacher model’, the ‘student model’, and the ‘learning principles’, define a set of statements
that the designer wants (as a teacher) to communicate to the student.

Step 3. Sign arrays.- Translate each statement as part of the user interface, i.e., in terms of buttons, lists, or images, among others.

Step 4. Array integration.- Integrate the arrays of signs into a user interface design.

As an aid to performing step 3, these could be defined as correspondence or a semantic map between the kind of signs in the design representation and a concrete widget in the user interface, as proposed by Leite [25].

4. An application example

5.1 The domain: learning tool to understand similarity indexes in life sciences

Study of methodological problems inherent to similarity indexes is valid and needed for proper application in several branches of life sciences. Clarity about the concepts behind the decision of choosing one similarity index over another is the main problem undergraduate students face whenever they need to compare natural communities, biological characteristics, or key steps in a classification process. Classical examples of such problems include: Which index should be chosen for a specific biogeographic or taxonomic study? Which biological aspects are worth to taking into account? In what proportion should these aspects be taken into account? How does each index use these inputs to measure resemblance?

Based on these rationales, as teachers of undergraduate students in the life sciences, we propose that a better understanding of the behavior of similarity indexes will help students understand the way each index is measuring resemblance between two biological units (such as species, communities, or biogeographic units) and choose a tool that fits their needs.

The objective is to design an Internet tool that helps students understand the resemblance concept from the point of view of the overall similarity. Several formulae need to be considered in the tool because of their common use, such as: Fager [26], Jaccard, Simpson [27], and Baroni-Urbani-Buser [28], among others. The Simpson similarity index was used as an example to measure the resemblance between two biological communities in two sampled sites in the field, as follows: Suppose that site A has 32 plant species and site B has 22 species, and the number \( C = A \cap B \) of plants that shares both sites, A and B, is 11, then the Simpson index is calculated as:

\[
\frac{|A \cap B|}{\min(|A|, |B|)} = \frac{11}{22} = 0.5
\]

Thus, the similarity between sites A and B (using the Simpson index) is 50%, and this approach could be used in further comparisons with other sites, for example, in the context of an ecological study.

5.2 Applying the model

Figure 3 shows the resulting enunciation of the system design, including the model items, the statements, and the
corresponding arrays of signs. Design by enunciation process is the strategy to generate the system design that is based on the teacher model, the student model, and learning principles elements. The first part of the process is to select the model items corresponding to the teacher model, the student model, and learning principles. These model items are then taken as a guide to obtain the fourth model element, the system design.

**Figure 3: Design by enunciation process**

Based on the checklist of the model items (Table 1), the basic statements about what we want to communicate to the final users were defined. Each statement is based on a combination of items from teacher model, student model, and learning principles. Then, for each statement, we define an array of signs, taking into account the context of the available elements (Java applets) to build Internet interfaces. For example, the statement S3 ‘results of comparisons’ establishes that each similarity index could produce different output resemblance measures that are not necessarily equals, and this statement is based on three model items:

- Knowledge to teach: formulae of some similarity index
- Teaching strategy: comparing two formulae results
- Learning principle: contiguity learning principle

The arrows in Figure 3 point to the S3 statement that arises from the model item on which the statement is based. Then, supported by statement S3, we defined the array of signs as indicated by the two vertical bars grayed at the level proportional to the numerical results (Figure 3).

**Table 1. Model items checklist for statements**

(We included the ‘complexity reduction’ statement as an item of the learning principles model element (Table 1). Complexity reduction refers to the transformation of one problem into a simpler problem. From an educational perspective, complexity suggests that the way to achieve predictability is through complexity reduction, that is, through limiting the number of possible variables [29]. By reducing complexity in a system, the user–system interaction could be more predictable than it would be in a more complex system. Complexity systems concepts have already been used to guide the design of e-learning environments [30]. Based on ‘complexity reduction’ as an item of the learning principles model element, we defined the statement S2 Three parameters (Figure 3). The enunciation process for this statement involves three items:

- Knowledge to teach: similarity indices tools
- Teaching strategy: changing the parameters
- Learning principle: complexity reduction principle

To simplify and allow the user to concentrate on a general and brief set of parameters, we restricted the number of parameters to be included in the similarity indexes to three, namely:

A: The number of elements in the first set
B: The number of elements in the second set
C: The number of elements common to both sets (INTERSECTION)
These parameters were defined as inputs that the user can vary through the interface. For example, consider the formulae for the Jaccard and Simpson similarity indexes:

\[ \text{Jaccard} = \frac{C}{\text{UNION}(A, B)} \]
\[ \text{Simpson} = \frac{C}{\text{MIN}(A, B)} \]

where UNION is a function that obtains the total number of common elements between sets A and B, and MIN is the minimum number of elements in A or B.

The tool allows modifying values of A, B, and Intersection (C) parameters (Figure 4) to obtain a response about the result of each formula. Several formulae of similarity indexes require other parameters besides A, B, and C, but the model restricted the input to only three parameters to enunciate the learning principle of ‘simplifying reality’. The e-learning Internet tool design presented was implemented in an applet program that is available at http://campus.iztacala.unam.mx/mmrg/similis.

Figure 4: Output from the Similator module of the Similis Internet tool

Advantages

5. Conclusions

The design of learning tools needs to be accompanied by an explicit design process that exposes the communication intentions from designer to user (or teacher to student). If the design process of learning tools is based on an explicit pedagogical model, then communication increases in quality because it takes into account the enunciation–hermeneutic process between the teacher and student. Our model helps aid understanding of how the interactions among the four basic elements—the designer, the system, the user, and sessions—were planned from a semiotic perspective.

The design process of pedagogical computer systems, like e-learning tools, needs to incorporate the learning component explicitly. A student using educational software is more than a user (sensu the user-centered model) because supposedly s/he wants to learn. Moreover, the student who uses an e-learning tool is expected to have the support of a teacher, and the teacher has a direct influence on the student with a theoretical basis in some pedagogical principles.

Acknowledgements

Part of this work was supported by the PAPCA 2007-2008 program (project #70) of the Facultad de Estudios Superiores Iztacala, UNAM.

References


Figure 1. Three-way relation of Peirce’s semiosis concept and the analogy in the pedagogical enunciation model

Figure 2. Three levels of the ‘pedagogical enunciation model’

Figure 3. Design by enunciation process

Figure 4. Output from the Similator module of the Similis Internet tool

Table 1. Model items checklist for statements
### The teacher model

#### Knowledge to teach

<table>
<thead>
<tr>
<th>Similarity indices tools</th>
<th>Similarity indices are tools to measure resemblance between two ecological communities based on the number of common species.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formulae of some similarity indices</td>
<td>There have been several similarity indices; each one has its own way of calculating the similarity expressed in a specific formula.</td>
</tr>
</tbody>
</table>

#### Teaching strategies

| Similarity indices name list | Present to the student the short names of a variety of similarity indices and the corresponding formulae. |
| Change the parameters | Allow the student to change the parameters of a similarity index and show the results of such changes. |
| Compare two formulae results | Compare the results of two formulae. |

### The student model

#### Prior knowledge

| Set theory | Student already knows about the theory: union, intersection, and its representation on Venn diagrams |

#### Learning principles

#### Pedagogical principles

| Contiguity learning principle | Objects experienced together tend to become associated; then, when any one of them is recalled, the others are likely to be recalled, also [31][32]. |
| Complexity reduction principle | The way to achieve predictability is through complexity reduction, that is, through limiting the number of possible variables and reducing the ‘recursivity’ of the system: trying to push the system from an open to a closed state and trying to reduce the impact of ‘feedback loops’ [33]. |
Figure 1. Three-way relation of Peirce’s semiosis concept and the analogy in the pedagogical enunciation model
Figure 2. Three levels of the ‘pedagogical enunciation model’
Figure 3. Design by enunciation process
Figure 4. Output from the Similator module of the Similis Internet tool

\[
\text{Jaccard} = \frac{|A \cap B|}{|A \cup B|}
\]

\[
\text{Simpson} = \frac{|A \cap B|}{\min(|A|,|B|)}
\]