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DESIGN OF A WEBSITE TO SUPPORT THE TEACHING-LEARNING PROCESS OF GENETICS

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Abstract

Genetics is a science whose teaching-learning process is complex, mainly because it involves abstract concepts about objects invisible to human eyes, such as cells, genes, molecules. The aim of this work was the design of a website for the teaching-learning of genetics by undergraduate \ two aspects: content and user interface. The contents were defined based on an analysis of the skills and knowledge necessary for life sciences professionals. The user interface was designed based on the concept of usability, taking "simplicity" as a guiding criterion. The Genetics website (genetica.abaco2.org) contains resources and tools: infographics, short tests on specific topics, and a simple simulator of the Hardy-Weinberg Law, among others. In addition, short educational texts were designed whereby the student can be introduced to specific topics. The efficiency in learning to read two texts was evaluated in ten groups of undergraduate students (5 of them experimental) by applying a ten-question questionnaire. The experimental groups, which previously read the two educational texts, had 19.8% and 32.2 % more correct answers than the control groups (P<0.01). The Genética *website designed is a resource that supports the teaching-learning of specific topics in Genetics that has proven to be useful to undergraduate students and their professors.*

Keywords:

Knowledge Building Theory, Genetics, User Interface Design, Usability

1. Introduction

Genetics is the science that studies the transmission and variation of the hereditary information of organisms stored in DNA and is a keystone of biology that encompasses a strategic

set of knowledge and skills that biology professionals must have. In such a way that those who do not have this knowledge, techniques and theories, are less likely to obtain a job position. That is why it is increasingly important for biology students to have a firm understanding of the fundamentals of this science.

1.1 Factors that hinder the teaching-learning of Genetics

Knowledge of Genetics is of great importance for the study of areas such as Biology, Medicine, and Biochemistry, however its teaching and learning has a high degree of difficulty (Méndez-Méndez & Arteaga-Quevedo, 2016), due to different factors, among which it stands out that science courses involve the understanding of abstract concepts, complex language, and mathematical knowledge (Chu, 2008):

- Abstract nature of scientific concepts. For example, DNA replication is a complex process to understand at the first time.
- Complexity of the language. There are different and new terms and words that students have to review, investigate, and discuss to understand genetic topics; examples of such kind of words are: polymerase, RNA primer, helicase, among others.
- Misconceptions. A common statement is that mutations in DNA are bad or harmful, however, it is known that there are mutations that can be beneficial, and others can be silent and do not affect the phenotype. During the COVID pandemic, many people did not want to be vaccinated with the RNA vaccine, because they believed that the RNA would enter the nucleus and we would be left with that genetic information, and that notion is false.
- Mathematical content. As an example, the students do not like the Hardy-Weinberg equation, simply because it is a mathematical equation, even if they know that it is valuable for understanding population genetics.

In addition to the above, the fact that the molecular processes of Genetics occur within the cell in molecular structures, with specific biochemical characteristics, makes their understanding more difficult compared to subjects that are located in the macroscopic field, for example, Botany and Zoology, in which observation and description are sufficient elements to guarantee learning (Méndez-Méndez & Arteaga-Quevedo, 2016).

1.2 Resources on the web with a high diversity of quality and levels

On the Internet there are hundreds of genetics websites with resources related to Genetics, however, in many cases their content was not reviewed by geneticists or genetics

teachers. Therefore, it is uncertain whether the material is appropriate for the level of study required in the undergraduate genetics class and whether there is an adequate student understanding of it.

For example, Chang et al. (2020) reviewed 1279 texts from Internet related to Genetics and only a smaller fraction was focused on people with a university level of education. This fact warns that the information on genetics websites may not be appropriate for undergraduate students.

Because of this situation, our research team decided to create a website with resources of Genetics for undergraduate students.

2. Pedagogical and Technological Frames

2.1 Knowledge building theory

The pedagogical frame of the website design, both in terms of content selection and presentation, was enclosed within the Knowledge Building theory (KB, Scardamalia & Bereiter, 1994, 2006). KB theory distinguishes learning from knowledge building; learning is seen as an internal process, not observable, but resulting in changes in beliefs, attitudes, and skills. Whereas KB is the one that creates public knowledge, i.e. knowledge whose representation allows it to be used or manipulated by others, and not only by the one who creates it. One way to achieve this attribute is to create explicit representations of knowledge. This element of KB theory is considered in the structural elements of the educational texts designed for the website. For example, educational texts include a section on "learning activity", where students are given tasks through which they can verify and confront their learning.

2.2 Usability and user interface design

Usability can be defined as the degree to which users can use a system to achieve specific objectives successfully in a specific context of use (Bevan et al., 2016). Several dimensions of usability have been proposed, such as efficiency, attractiveness, error handling, and simplicity, among others.

In order to have a functional prototype in a short time, the development of the website was focused on four axes of usability: Simple exploration, guide the user in their journey, feedback, and adaptability to the user. Usable web systems have been successfully developed whose usability design focused solely on these four axes (v.gr. Murguía-Romero et al., 2024).

3. Methods

3.1 Instructional design

Instructional design assumes that the educational process involves intentional learning, i.e., the teaching-learning process is planned, directed, guided, purposeful, formal, where the student and the teacher have defined roles (Branch & Kopcha, 2014). To develop the website, an instructional design model composed of the following five activities were considered:

- Analysis. Description and understanding of the educational context and the knowledge and skills that the student needs to learn.
- Design. Specification of the characteristics of the desired environment for effective and efficient learning, including artifacts and teaching strategies.
- Development. Construction of learning resources that will make up the designed environment.
- Implementation. Put the teaching strategies designed into execution.
- Evaluation. Summative and formative evaluation to identify strengths and weaknesses of the design.

The selection of the tools and topics included in the website considered the opinions of the specialist participants about the desirable skills and competencies in the Biology and Medicine professional, as well as works that analyze and make proposals in this regard (Tognetto et al., 2019). The instructional design process is presented here as linear through its five phases for synoptic purposes only, but it was actually carried out as a recursive, nested, and concurrent process over two years, with adjustments made at each stage, guided by the evaluation of previous cycles.

One of the types of resources that was specified in the design is educational texts: short documents that focus on specific topics in Genetics created by teachers and specialists participating in the project especially for the website following general guidelines (Table 1). As part of the evaluation stage, the efficiency of students' learning when using educational texts was estimated. Using a questionnaire of 10 multiple choice questions, the average percentage of correct answers in five groups of students who previously read an educational text on the topic to be evaluated was compared (using a Z test) against 5 groups of students who did not have access to the text.

Table 1: *Educational Resources Included In the Design of the Genética Website*

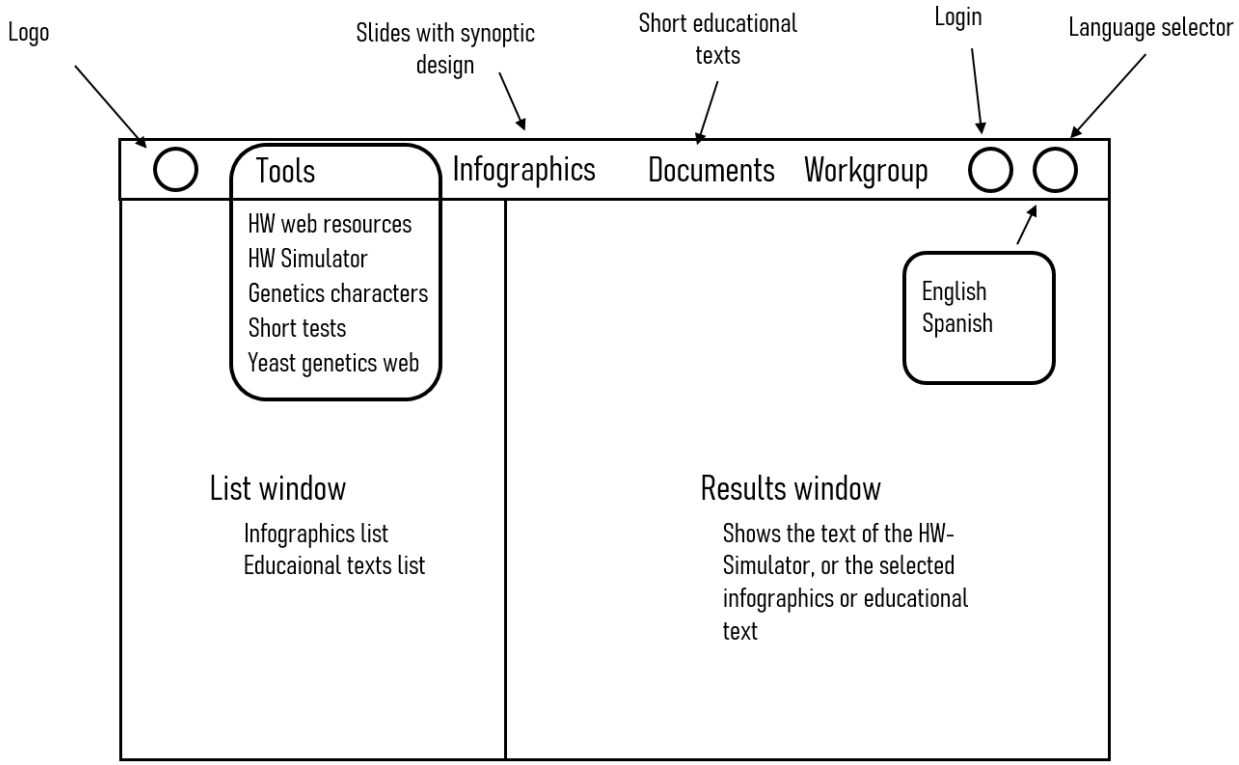
Educational resource	Design criteria
Educational texts	Short extension. Direct and precise language. Figures to illustrate concepts and processes. Few references but paradigmatic and that guide the student on the subject. Inclusion of a section of learning activities at the end of the document that are proposed to the student and that comprehensively consider frontal, group and individual organization strategies (Inogamova & Safarova, 2022).
Infographics	A slide combining visual information, accompanied by a short text that includes three elements: introduction, key message, and conclusion (Naparin & Saad, 2017).
Simulator of HWL	Reduced number of parameters that the student can interact with to receive clear feedback. The resulting tool must be a model, that is, a simplified representation of what is expressed by the HWL equation.
Compendium of HWL webpages	List of resources based on web research on HWL simulators that meet quality criteria in both content and design. Generation of a synoptic description of each resource page thus identified that includes, in addition to a descriptive paragraph: title of the resource, representative image of the resource, link to the resource.
Self-assessment questionnaires	Each questionnaire must correspond to one of the educational texts on the website and should be limited to multiple choice questions in order to maintain simplicity. Questions should be designed with the purpose of guiding the student, so the interface should provide the student with immediate feedback on whether their answers are correct or wrong.
Short biographies of geneticists	A list of characters and their main contributions should be provided, giving the context of the time and place, such as including date and place of birth.
Genetics outside the classroom	Include scientific or professional websites that illustrate to the student the application of genetics beyond the educational context.
Teaching strategies	Documents that propose to the teacher ways to assemble the resources on the website through educational techniques, such as didactic sequences (Rodríguez-Reyes, 2014).

(Source: Table created by the authors)

Thus, the artifacts that were designed, developed, and finally implemented on the website (Table 1) are the result of an initial instructional design whose general plan included the information architecture that is presented in the following section.

3.2 User interface design

Figure 1: *Information Architecture for the Genética Website*



(Source: Figure created by the authors)

In addition to the defined educational resources (Table 1), the information architecture also considers the integration of the four axes of usability on which it was decided to focus the design (Figure 1). Each of the axes has a different level of implementation in the system, since the development is incremental. The way in which it was defined how each axis should be integrated into the design is as follows:

Axis 1. Simple exploration. Simplicity is an important dimension in website design for education since the educational tool must minimize the obstacles that arise in learning complex knowledge. Intelligent handling of complexity can be viewed as simplicity (Allanwood & Beare,

2014). On the website designed, simplicity was implemented maintaining a command menu with few hierarchical levels: one or at most two.

Axis 2. Guide the users in their journey. The users, whether student or teacher, must be able to navigate the website knowing that they are in the correct and desired place. This dimension was implemented by placing a subheading at the top of the page, e.g. “Infographics”.

Axes 3. Feedback. The user must receive interaction from the system immediately. This dimension was implemented in the evaluation of the self-assessment tests: the student immediately receives a report of the successes and failures when finishing answering the questionnaire.

Axis 4. Adaptability to the user. The system must recognize the user as an individual, distinguishing one user from another. This was achieved by implementing the login command that allows the system to recognize which account is active, saving the evaluation history of the self-assessment questionnaire.

4. Results

4.1. The *Genética* Website

The implementation of the website (http://genetica.abaco2.org; Figure 2) includes the educational resources specified in its design (Table 1), and its structure respects the designed information architecture (Figure 1). The main commands are located in the top bar and in some group subcommands (Table 2).

The "Documents" command displays a list of educational texts designed by participating teachers. The selection of the topics to include was based on the greatest difficulty that the students show in their learning. Among others, topics include Genetic engineering, Cloning vectors, Population genetics, virus diversity, and restriction enzymes.

The information on the genetics characters was captured in the AbaTax tool (http://abatax.abaco2.org) that allows specifying an array of names with an association to their characteristics that will be displayed in a web interface where dynamic filtering is allowed. (Murguía-Romero et al., 2021).

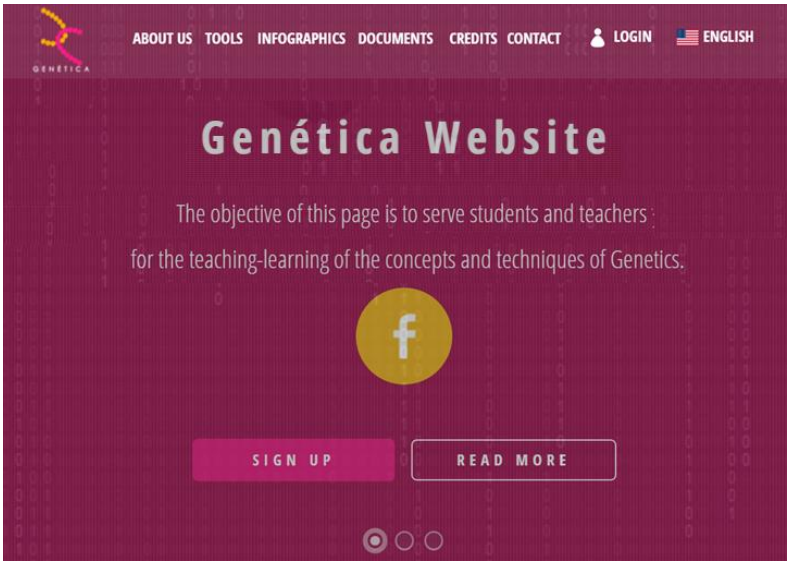
The Infographics included (Figure 4) were designed by students with the support of teachers. Students chose a specific topic, generally about a genetics concept or process that they were not clear about, during the design process. They also wrote the explanatory paragraph, always assisted by their teacher, they clarified their knowledge.

Table 2: *Commands of the* Genética *website*

Command	Content
About Us	Information about the website working group
Tools/Teaching Strategies	Didactic sequences documents that describe learning activities that the teacher could apply in the class.
Tools/HWL Simulator	Support to the student in the calculations of phenotypic and allelic frequencies based on the Hardy-Weinberg law equation (Figure 3).
Tools/HWL in the web	A list of learning resources in the web on Hardy-Weinberg law equation.
Tools/Tests	Self-assessment questionnaires for students of topics in educational texts.
Tools/Genetics characters	Link to the AbaTax web application (abatax.abaco2.org) where the student can filter a list of 16 geneticists according to nationality, occupation, and contribution, among other attributes.
Tools/DEHA website	Link to the DEHA website of the *Debaryomyces hansenii* yeast research group that investigates the transcription process.
Tools/Infographics	Infographics on specific concepts or genetics processes accompanied by an explanatory paragraph, designed by students with the support of teachers.
Documents	Educational texts designed by patient teachers in the project, which include learning activities, and a small number of selected bibliographical references.
Credits	Name, contact and institution of affiliation of the participants in the construction of the website
Contact	Allows sending a message to the website developers to give suggestions or report errors.
Login	Allows registration for logging in with a user account. This allows personalized monitoring of the student progress in test evaluations.
English/Español	Allows the student to choose the interface language.

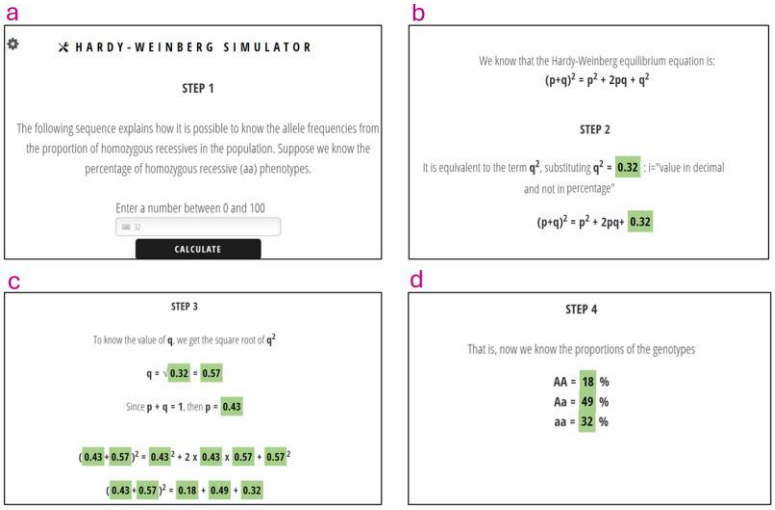
(Source: Table created by the authors)

Figure 2: *Aspect of the Initial Page of the Genética Website Http://genetica.abaco2.org*



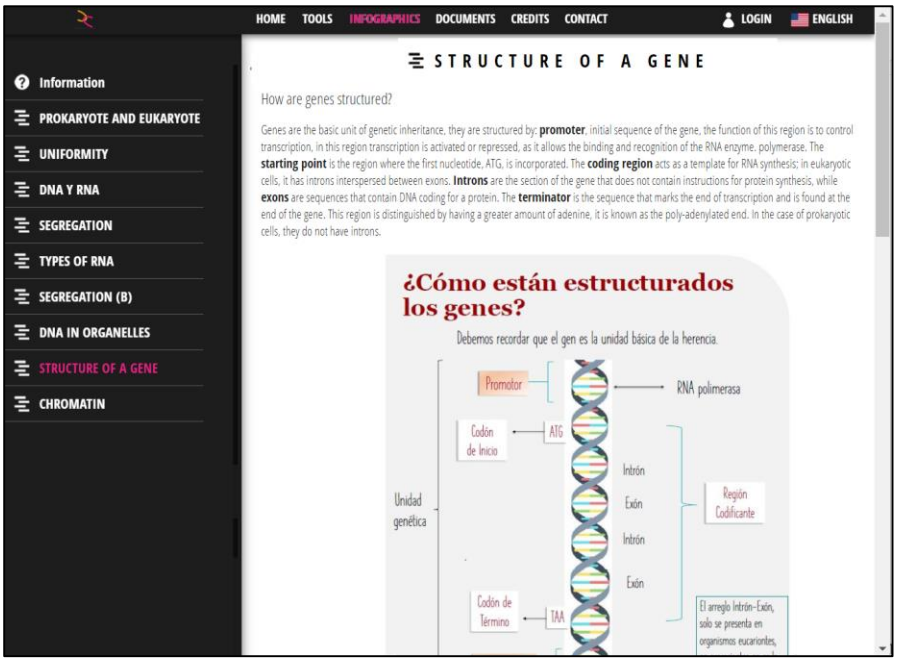
(Source: Figure created by the authors)

Figure 3: *Hardy-Weinberg Law Simulator of the Genética Web Page. Subsections A, B, C And D, Represent the Order of the Screens that are Displayed for the Student*



. (Source: Figure created by the authors)

Figure 4: *Infographics on the* Genética *Website. Left: List of Infographics; Right: Display of the Infographic "Structure of A Gene" And Associated Text.*



(Source: Figure created by the authors)

The Hardy-Weinberg law simulator was designed with an interaction with the student in four steps (Figure 3). Step 1: The student enters the percentage of homozygous recessive phenotypes in the population. Step 2: The Hardy-Weinberg equation is presented in equilibrium and the value entered by the user is substituted into it. Step 3: The value of q (frequency of the recessive allele) is solved and the numerical values of each term in the equation are obtained. Step 4: The proportions of the three missing phenotypes are presented.

To determine the use or consultation of the texts, infographics, and particularly the HWL simulator, a visitor counter was added to the website and over the last two years, four groups of students (120 in total) of the genetics subject, were invited to review, read and use the simulator. Although no structured evaluation of the simulator has been done, teachers observed enthusiasm in students when using it. The page has registered 1,850 views since its creation two years ago. Genetics professors at our institution use it in their courses and their students visit it to review specific topics.

The system has the option to register as a user and obtain an account. This has two advantages: on the one hand, students can be monitored by recording test evaluations; on the other

hand, teachers can add material, such as infographics and educational texts, when they have been completed. The website integrates an administrative module that allows teachers to register fields for infographics and educational texts.

4.2 Learning evaluation

To evaluate learning efficiency when using an educational text, we gave to five experimental groups (total 135 students) a DNA recombination text and after reading it they were given a quiz of 10 questions. On the contrary, to five control groups (total 119 students) we only gave the quiz. We found that the students who had access to reading the educational text had the highest percentage of correct answers in the quick test. The experimental groups had an average percentage of 75.6% of correct answers compared to the control groups with 55.8% (Z test $P<0.01$). In a second evaluation with an educational text on Genetic Engineering: Recombinant DNA Technology, the roles of the experimental and control groups were reversed and similar results were found: We gave to five experimental groups (previously the control groups; total 98 students) the Genetic Engineering text and after reading it, again they were given a quiz of 10 questions; while we only gave the quiz to five control groups (previously the experimental groups; total 136 students), In this second evaluation, the experimental groups had an average percentage of 76.0% of correct answers and the control groups obtained 43.8%, the difference between the two groups was statistically significant (Z test $P<0.01$). Thus, students who previously read the two educational texts had an average of 19.8% and 32.2% more correct answers than those who did not read it.

5. Discussion

One of the main contributions of this work is the construction of a universally available website so that it can be used by undergraduate genetics students and teachers. The design process is described in its different stages, including the information architecture and the prevalent usability criteria. This offers the possibility that this experience can be used by other work groups interested in creating websites for the educational process.

The pedagogical framework that delimits the context of the design is made explicit, which makes it possible to be analyzed by other researchers in education, identifying weaknesses and strengths, or proposing improvements.

Not only is the website a tool to facilitate the educational process, but the design process also contributed to this objective, since in addition to the participating teachers clarifying their pedagogical frameworks and strengthening their knowledge, the students also learned during the construction of the site, since they participated in the creation of the infographics.

Another contribution is the direct evaluation of the improvement in student learning when they previously review two of the educational texts contained on the website. These texts, designed by genetics teachers, are specific for biology students and meet the criteria for evaluating the information on a website: The target audience is university students. The name of the authors and their institution of affiliation are clearly identified. In terms of quality, the texts were edited and reviewed by genetics professors to offer well-written, grammatically correct educational texts with references, whether classic or representing the most recent advances on the subject. To our knowledge, this work is pioneering in the evaluation of the material contained in genetic pages designed for undergraduate students.

In general, research on the content of web pages has focused on evaluating whether elementary and high school students know and review the criteria to evaluate the validity of the information they find on the Internet, due to the problem represented by false or imprecise information, not reviewed by specialists. It has been reported that high school students rarely evaluate the veracity of the content of the web pages they consult (Walraven et al., 2009; Kaushik, 2012). There is little research on whether university students evaluate the validity criteria and determine whether the content of web pages is appropriate for solving problems proposed by teachers (Nagel et al., 2020). Worse still, very rare are the works in which questionnaires or problems to be solved on specific topics are proposed with the objective that the content creators can determine whether the information on the pages covers the teaching-learning objectives required by the students of science subjects; this type of research has only been done with high school students (Hämäläinen et al., 2021). For this reason, we believe that our work can be a model for the evaluation of the teaching-learning process that is supported by the resources contained on the Genética website.

One of the weaknesses of this work is that the website and its content was designed in the context of students at a public university in Mexico. The educational process is developed in specific contexts, with particular cultural and social frameworks, whose solutions to teaching-

learning problems require local attention; its extrapolation between different regions must be carried out after a detailed analysis.

6. Conclusions

The website to support the educational process can be beneficial if the computer methodologies of interface design such as usability are considered. Websites designed in this way, in addition to facilitating the teaching and learning process, allow criticism and analysis by making their design criteria explicit.

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