

# How to design culturally appropriate engineering solutions for vulnerable communities

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## Abstract

The group 'Ingenieros Sin Fronteras Colombia' (ISF-Col) is a group of students and professors from two prestigious universities in Colombia (South America) that work together with vulnerable communities in the country. Their aim is to improve the communities' living conditions through engineering projects that are technically innovative, economically, socially and environmental viable, as well as culturally appropriate. In order to design culturally appropriate engineering solutions, the author proposes an evolutionary framework to study the knowledge process that occurs in the interaction between ISF-Col and the vulnerable communities. This framework is proposed upon the evolutionary epistemology of Campbell [1], which considers human culture as part of a system of knowledge accumulated through year of biological and cultural evolution; and evolutionary economics stated by Dopfer [2], who argues that the knowledge of an organization allows and restricts its operations. These two approaches are synthesized in a model that is designed to study the knowledge process inside an organization; afterwards the model is used to study the interaction between ISF-Col and a vulnerable community in Colombia [3]. The result of this study is synthesized into some recommendations for engineer organizations that aim to design culturally appropriate solutions for vulnerable communities.

## Keywords

Ingenieros sin Fronteras, Evolutionary Economics, Culturally appropriate solutions, Vulnerable Communities.

## 1. Introduction

In Colombia the water access problem is very serious, as illustrated by the fact that only 11% of the rural population (13.6 million people) has access to treated water [4]. Facing this situation, government and international agencies have responded by creating new supply systems. However, these systems fell short of its expectations, because they gave greater importance to technical factors, leaving aside social and cultural factors, which generate the worst problems but also the best opportunities for development projects in vulnerable communities[5].

The group 'Ingenieros sin Fronteras Colombia (ISF Colombia) arises in this context, integrated by students and teachers from two prestigious universities in Colombia. The group's ultimate objective is to improve the quality of life in vulnerable communities, through Community Intervention projects. These projects are defined as the process of conceiving, designing, implementing and operating integrated engineering solutions that are technically innovative as well as economically, socially, environmentally viable and *culturally appropriate*; all this being done in partnership with the beneficiary community [4]. More information about the group is available at [3, 6].

ISF's proposal to design *culturally appropriate* solutions intended to address the problems and opportunities of social and cultural factors in projects with vulnerable communities. However, the definition what is *culturally appropriate* is problematic. The authors seek to address this problem from an evolutionary approach, specifically from the *evolutionary epistemology*. This theory aims to understand culture as part of the system of human knowledge, product of centuries of social and biological evolution [7].

This problem was investigated during one of the author's undergraduate thesis [8]. The document is available for further consultation. This article shows the main results of the research in the following order: 1) a literature review

of Evolutionary Economics, Evolutionary Epistemology and Theory of Organizational Routines, in order to obtain key theoretical concepts 2) based on these concepts, the Evolutionary Model of the Knowledge Process of the Firm (MEPC, Spanish acronym) was proposed 3) the interaction between ISF Colombia and a particularly vulnerable community was studied using MEPC 4) based in this study, some recommendations for the design of culturally appropriate community intervention solutions were proposed.

The partial research outcomes were developed under the trial and error methodology or *Selective elimination model of theories* [1]. In order to make a valid use of categories originated from biology in an organizational context, a method of theoretical *decontextualization* and *recontextualization* [2] was used. Finally, the paper concludes with recommendations rather than with universal methodologies; a position consistent with the rejection of the existence of a scientific truth criterion, proposed by evolutionary epistemology [1].

## 2. Evolutionary Economics and Evolutionary Epistemology

Evolutionary Economics is a recent approach, which is characterized by the influence of evolutionary thought, originally used in biology. This approach is a revision to the fundamentals of economics, which traditionally have been derived from Newtonian physics. Darwin's ideas on evolution emerge as an alternative paradigm.

This new paradigm proposes the Homo Sapiens Oeconomicus (HSO) as a critique to the economic agent in neoclassical theory, the Homo Oeconomicus (HO), and particularly, to the assumptions of 'Perfect rationality', 'Representative Agent' and the periodicity of decision rules. In contrast, the HSO is a rule maker-rule user animal. Rules are defined as "deductive schemes that allow economic operations to take place". Examples of rules are heuristic algorithms, techniques, designs and strategies. Rules can be classified into *cognitive*, *behavioral* and *blueprint* [9]. Dopfer proposed that *rules* evolve in the same way as genes do in the Darwinian theory, in a *three phases trajectory*: i) Generation of the rule; ii) Adoption of the rule; iii) Retention of the rule. At the end of the trajectory, rules are retained because of repeated use are called routines [2]. Routines also have been studied by the so-called Theory of Organizational Routines, and are defined as recurrent patterns of collective behavior [10].

For Evolutionary Epistemology, knowledge is a product of biological and cultural evolution. Campbell suggests that evolution, even in its biological form, is a knowledge process. He also argues that natural selection, as a paradigm of evolution can be generalized to all epistemic activities, such as learning, thinking and science. On the basis of these ideas, the author proposes the Blind Variation-Selective Retention model (BVSR) as a possible explanation to human knowledge processes [1, 7]. Campbell also suggests the possibility of *nested hierarchy* of *vicarious* (substitute) *mechanisms* in SR process [11].

## 3. MEPC: Evolutionary Model of the Knowledge Process of the Firm

To study the relationship between ISF and vulnerable communities, an evolutionary model of the firm was developed, based on the idea of observing the firm as a group of agents which are active in the processes of knowledge; the interaction between all these agents creates the knowledge system of the firm [12], which finally enables all operations in the organization [2]. The aim of this model is to provide a framework that places in a common language, some evolutionary approaches with the developments of the Theory of Organizational Routines, and at the same time, provide a general model that is appropriate to study various types of organizations, in this particular case, Ingenieros sin Fronteras Colombia.

This model was built based on the concepts from Evolutionary Epistemology and Evolutionary Economics, the Theory of Selection within Firms from Dickson [13], the concepts of 'Codex' and Darwinian Machine of Stoelhorst and Huizing [12], some ideas from the Evolutionary Theory of the firm proposed by Hölzl [14] and *systems thinking* [15] and *population thinking* [16] approaches. In addition, the proposal is consistent with the ideas of Ellerman [17] about variation mechanisms, in particular with *parallel experimentation*.

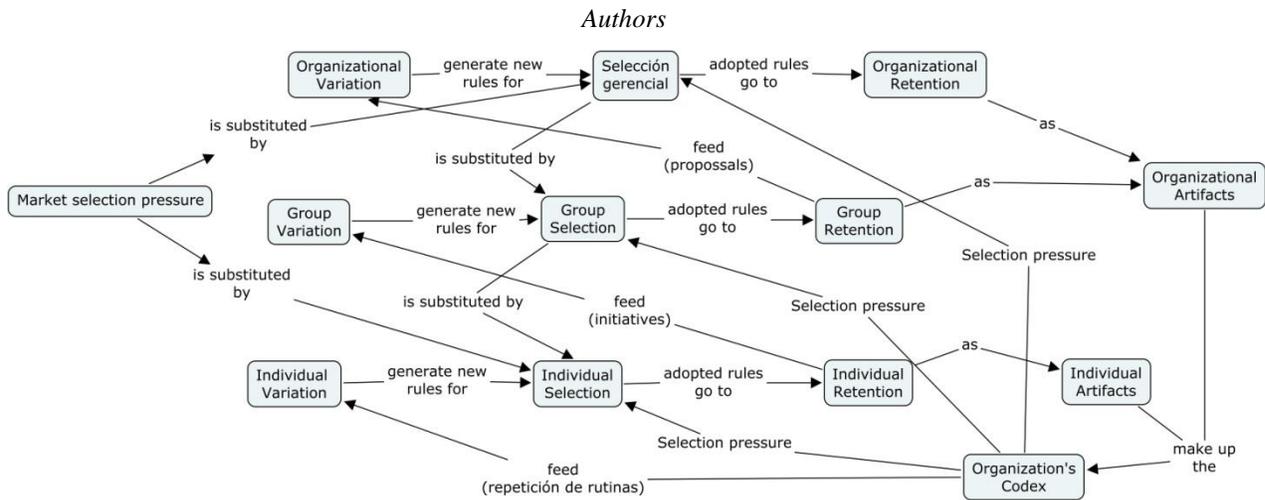


Figure 1: MEPC Summary

The firm is composed by HSO, individuals that create and use rules, which are the knowledge that allows and restricts all economic operations in the firm. Individuals are organized in *knowledge communities*, each one of them with dominance over a specific knowledge area in the organization. Each of these communities has a manager who leads the process of selection of knowledge, and also is part of the firm's management. Regarding previous evolutionary models of the firm (which MEPC is based on), this new model involves four new aspects:

- Knowledge-processes occur in three levels: individual, group (*knowledge community*) and organizational level; these levels are connected by two paths: first, retained rules in lower level feed variation mechanisms at other levels; second, selecting criteria in a level is a vicarious selection mechanism in an upper level. In the case of management, this level makes substitution of market selection pressures.
- Firm's environment selection pressures influence various parts of the process; besides the management selection, they also exert pressure on the external phase of individual selection.
- It is recognized that individual selection has two stages: internal and external.
- Dopfer [2, 9] notions of *efficacy* and *efficiency* are both incorporated as selection criteria.

#### 4. Studying an ISF Colombia project using MEPC

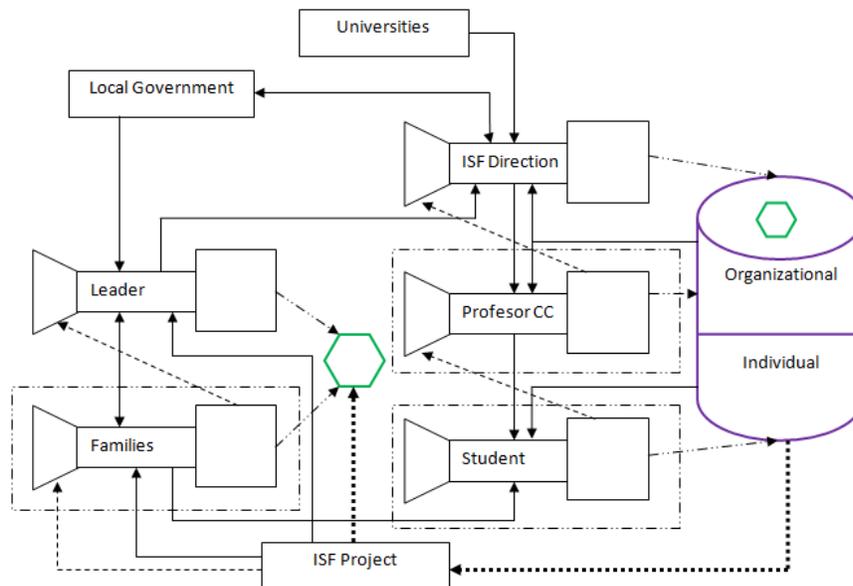


Figure 2: Graphic representation of the knowledge system in an ISF Project

In ISF Colombia, the individual level corresponds to students' knowledge processes, the group level to one of the groups within the organization, comprising several students who are led by one professor, who is in turn responsible for decision making at this level, even on the selection of routines. The organizational level represents the organization as a whole, where decisions are made by a group of professors. The following table summarizes the mechanisms of variation, selection and retention at each level of ISF:

Table 1: Summary of knowledge processes within ISF Colombia.

	Variation	Selection	Retention
Students	<p>-<i>Learning</i> from courses and library resources offered by the university.</p> <p>-<i>Creativity</i></p>	<p><u>New rules are evaluated by students as follows:</u></p> <p><b>Internal:</b> Consistency (efficacy) with the student's knowledge and with his/her knowledge about his/her knowledge community* and the beneficiary community. Also seeks to maximize the grade, resource efficiency and beneficiary community welfare (<i>vicarious</i> approach).</p> <p><b>External:</b> Those routines that are adopted by at least one person in the beneficiary community are chosen.</p>	<p>-Stored in artifacts or in memory.</p> <p>-When retained routines are used they generate a new individual trajectory.</p> <p>-Replicable routines can involve one or more actors (<i>initiatives</i>).</p>
Community*	<p>Generation of replicable routines by students constitutes a <i>parallel experimentation</i> process.</p>	<p><u>New rules are evaluated by professors as follows:</u></p> <p><b>Efficacy:</b> Requires consistency with group's codex, in the particular case of the <i>initiatives</i>, it requires coordination among stakeholders.</p> <p><b>Efficiency:</b> Using a similar criterion to those used by students, under University's labor restrictions and minimizing costs.</p>	<p>Replicable routines become <i>proposals</i>. Not replicable routines enter into organization's codex.</p>
Organization	<p>Communities* generate <i>proposals</i> that are taken to the organization's direction (<i>parallel experimentation</i>).</p>	<p><u>New rules are evaluated by a group of professors as follows:</u></p> <p><u>Efficacy:</u> Coordination of material resources, structuring internal communication networks and knowledge exchange with other organizations.</p> <p><u>Complementarity:</u> With organization's <i>codex</i>, with university policies, and with local government and beneficiary community selection criteria (substitute devices).</p> <p><u>Operational efficiency:</u> The selection is the result of a negotiation process between the professors' positions (defined in the last level). However, there are no rational routines defined.</p>	<p>Routines are stored in the organization's codex, which consists of <i>core</i> and <i>peripheral</i> routines. The Organization's mission is the most nuclear routine.</p>

\*Note: Knowledge communities are different than vulnerable or beneficiary communities.

To understand ISF's relations with the beneficiary community and other relevant organizations using MEPC, it is necessary to understand what *market selection pressures* means in this context. To do this we identified the organizations involved, specifying in which organizations internal dynamics are relevant. While these were studied by the MEPC; other involved organizations were studied as a fixed set of selection criteria, and just the pressures exerted on the system by them was studied. Next, feedback mechanisms were identified; those that allow external organizations to exert pressure on Colombia ISF and those by which ISF pressures other organization. The following organizations were identified as involved: local government, universities and the beneficiary community (the vulnerable community which is working with ISF). Only the internal dynamics of the beneficiary community will be relevant. The selection criteria and feedback mechanisms from other organizations are:

Table 2: Criteria and Feedback mechanism from other organizations in the environment of ISF Colombia

	STATE: Local Government	UNIVERSITIES
Feedback mechanism	The municipal government controls ISF’s access to the community, and also financial resources to support the project.	The universities control the flow of material resources and students that ISF needs to function.
Criteria	<p>Projects must:</p> <ul style="list-style-type: none"> <li>-Be consistent with the legal framework and with national and local government policies.</li> <li>-Have a degree of approval from the authorities.</li> </ul>	<p>ISF must:</p> <ul style="list-style-type: none"> <li>-Follow the policies and regulations of the university.</li> <li>-Fulfill its research goals.</li> <li>-Connect other research centers with the problems of vulnerable communities.</li> </ul>

When studying the beneficiary community, it was identified that the individual level corresponds to the individuals in the community; the *knowledge community* level to families, where the household head is the decision maker; and the level of the organization is the community as a whole. The beneficiary community is characterized for having a centralized leadership and for its existence as an informal organization (with the presence of formal organizations within it). Given that within families there is a centralized leadership, it was decided to simplify analysis, not to study the dynamics of individual family members and to directly analyze knowledge processes at this level. The following table summarizes the mechanisms of variation, selection and retention in the processes of knowledge within a target community:

Table 3: Summary of knowledge processes inside a beneficiary community

	Variation	Selection	Retention
Families	<ul style="list-style-type: none"> <li>-Family learning, from formal and informal education they have received (usually low).</li> <li>-Creativity</li> </ul>	<p><u>New rules are evaluated as follows:</u>  <b>Internal:</b> Consistency (efficacy) with own knowledge and with substitute knowledge about their community. It also receives various selection pressures from ISF projects, developing a certain degree of consistency. It also seeks to maximize its own welfare (<i>vicarious</i> approach).  <b>External:</b> Those routines that best meet the expected results are chosen <i>a posteriori</i>.</p>	<ul style="list-style-type: none"> <li>-Usually retained in memory.</li> <li>-They may use artifacts provided by ISF.</li> <li>-When retained routines are used, they generate a new individual trajectory.</li> <li>-Replicable routines can involve one or more families.</li> </ul>
Beneficiary community	Replicable routines retained by the families feed the variation at this level (parallel experimentation).	<p><u>New rules are evaluated as follows:</u>  <u>Efficacy:</u> This requires consistency with the collective knowledge, substitute knowledge about families’ and government’s interests, and the selection pressures that ISF exert. The best routine regarding coordination of material resources, communication and knowledge management in the community is chosen.  <u>Efficiency:</u> There are two types of leaders: a) those that prefer short-term and paternalist’s solutions that would have media coverage; b) those who favor solutions that impact the welfare of the community in the long term and are willing to learn and work.</p>	Replicable routines are retained in formal organizations that exist inside the community. There is opportunity for ISF to use artifacts that enable retention of certain routines, and also for the use of organizational routines that create new institutions that make projects sustainable.

## 5. Recommendations for designing culturally appropriate Community Intervention solutions

1. *Projects should be oriented to work with the State and not replace it:* In addition, this work should be characterized by a transparent, participatory and continuous evaluation, in order to generate a selection pressure that makes the state assume its responsibility, with the institutional ability and legitimacy required [5].

2. *Projects should be designed to work with people, i.e. active knowledge agents.* This implies to recognize the existence of variation-selection-retention processes logic inside knowledge process of those involved, and properly handle each one of these elements.

Variation: To stimulate the creativity of project beneficiaries, in order to be a source of solutions previously unavailable [7] and to be a source of information for the *contextualization* of knowledge [18].

Selection: It is important to recognize that routines transferred in these projects are not automatically retained by agents, but first are subjected to a selection process, which involves competition with previously held routines, as well with other rules that have been generated by the agent. For this reason, an approach to knowledge held by the community is proposed as follows: first, identify the most important routines for these people, such as those associated with religion and traditions; second, identify which routines associated with the problems belong to the *core* and which ones to the *periphery* of the knowledge system [14]. From this distinction, one must begin by working with the peripheral routines, and only when is strictly necessary, intervene nuclear routines. According to Brooks, this situation occurs when there are routines that generate inequality and environmental destruction [5]. It is important to note that culture and social rules not only act as a barrier to the development of projects, but also as facilitators (see for example [19]).

Retention: It is important to remember that the history of the particular relationship and trust between the organization leading the project and the beneficiary community decisively affects the development of projects. Furthermore, in order to ensure that projects are sustainable, it is necessary to design artifacts [20] that generate the appropriate selection pressures which ensure that the routines will be retained by the beneficiary community. Regarding this matter, an interesting approach is designing institutions that promote entrepreneurship in the communities, generating socially inclusive businesses [21].

3. *Projects should include appropriate strategies for working with community leaders.* Given the importance of community leaders in decision-making (selection) of communities, it is important to study leadership specific interests and communication processes between leaders and the community.

4. *Remember that individual knowledge processes precede social ones.* Consistent with the ideas of Dopfer [2, 9] and Salas [22], in the process of transferring knowledge to a community, individual learning is previous to social learning. Therefore, special attention should be paid to each participant, an aspect that sometimes is not taken into account by focusing on the group as a whole.

## 6. Limitations

The robustness of the results is affected by certain limitations, which also represent opportunities for future research. First, given the sequential nature of work, each of the partial results "inherits" the limitations of previous results. For example, MEPC formulation "inherits" the literature reviewed's limitations. Secondly, the literature reviewed was limited to evolutionary approaches, leaving out other approaches such as '*knowledge management*' that could be used when formulating a model of the firm, or Social Work literature, which would have strengthened the proposed recommendations. The third limitation is the use of assumptions, which could be relaxed for further study. In formulating the MEPC, several simplifications of the complex reality of the firm were made. Some assumptions were made for modeling requirements, others for gaps in the evolutionary literature. To study the work of ISF Colombia with a vulnerable community using MEPC, several simplifications were used, if these were eliminated, other aspects could be considered such as: projects in urban communities, conflicts of interest within families and within communities, the impact of electoral dynamics in projects and projects capacity for replication when it involves more than one community.

## 7. Conclusions

Present research illustrates the potential of evolutionary approach to study organizations where knowledge is a key element, such as Ingenieros sin Fronteras. In addition, there was evidence that the study of knowledge systems of organizations not only is used to identify ways in which they can effectively manage their knowledge, but also helps

### *Authors*

to approach complex problems such as cultural ones. This particular work has allowed us to formulate guidelines for developing culturally appropriate solutions when working with vulnerable communities.

Given the importance of social and cultural problems in these projects, it is expected that recommendations for designing solutions that are culturally appropriate will have a multiplying effect on the impact generated by ISF Colombia projects and similar organizations, thus contributing effectively to the solution of social problems such as access to water resources in Colombia. On the other hand, despite the limitations of the study, this work opens new opportunities for community intervention research and the development of evolutionary theory of the firm.

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