Brazilian Grassroots Engineer's Education: Achievements, Flaws, and Challenges

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In the early 2000s, a particular form of engineering practice emerged in Brazil. It is called *grassroots engineering* (GE) and articulates the social technology and solidarity economy movements.

GE is one of the latest university offspring of Paulo Freire's pedagogy of the oppressed. It is precisely from Freire's ideas that GE gets not only part of its own name (*grassroots* or *popular*) but also the fundamentals of its very working. Based on that, back in 2008, three engineers coined a concept that became the identification of a professional profile capable of GE: *educator engineer*. A profile that, besides the regular technical skills and knowledge usually developed/learned in the engineering courses, also encompasses: empathy, ability to dialogue, critical sense, and openness to learn from local (or grassroots/traditional) knowledge. To achieve this profile, different pedagogic approaches and activities have been developed in many Brazilian universities.

In this manuscript, after presenting a brief account on grassroots engineering's history, I will: 1) analyze the four non-technical skills of grassroots/educator engineers, making explicit their Freirian roots; 2) present the three main engineering education approaches (and corresponding activities) aimed at the development of (part of) grassroots engineer's skills; and 3) highlight the strengths and weaknesses of each as well as the challenges each has to face to get the desired result.

For so doing, I will mainly draw on academic papers, some institutional documents, and my perception as a member of the GE network.

Introduction

Grassroots engineering (GE) is a Brazilian engineering practice that started to take shape in the early 2000s when Lula da Silva was first elected as the country's president. It is a result of the conjugation of three different movements or traditions that were supported by Lula's administration with specific funding and public policy: solidarity economy; social technology (or solidarity technology [1]); and university extension (which also encompasses community engagement) [2]. Currently, GE is mostly being applied as community service practiced by teams of teachers and students that are usually linked to institutionalized and permanent university initiatives called "extension centers" [3]. In some cases, along with service learning, such initiatives also develop research, taking challenges posed by their support to grassroots groups as matters of academic investigation either on methodological or technical-theoretical ground [4].

GE is distinguishable from some other forms of community engagement (such as humanitarian engineering, engineering for (sustainable) development, engineering in emergency, etc. [5]) by its commitment to social (or social-technical) change, which involves the government taking responsibility to fund and promote such initiatives. This has to do with GE's leftist roots and influences, such as Paulo Freire's, which take the hegemonic capitalist mainstream way of life

and ideal of development as something to be overtaken; an ideal that must be replaced with "another possible (social-technical) world" and the myriad of the possible good living (*buen vivir*) it might support. Another possible world, anyway, constructed from the bottom-up, by grassroots, local groups, and the other 90% or 99% of us, as we get empowered and become more conscious (or less alienated).

The aim of grassroots engineering goes far beyond simply identifying local groups' needs or urgencies and designing solutions for them. It goes even beyond designing the desired solutions to incorporate (or in dialogue with) local group's values and worldviews as some traditions of design for values [6], such as participatory design [7] and value sensitive design [8], have been doing very well for decades now. GE, in addition to all these and by actively incorporating local groups' traditional or popular knowledge, aims to develop a popular education process [9] through which, during the design process, grassroots people can also enlarge their consciousness, empower themselves, and co-construct and try a different socio-technical reality [3]. Empowerment and disalienation (that is, overcoming alienation, enlarging consciousness) are the fundamentals for both dreaming about this "other possible world" (socially fairer, ecologically more sustainable, more democratic, where different good living ideals can bloom, etc.), and fighting for this world to come true, for its social-technical construction to realize.

This democratized (or popular) technological development that grassroots engineering stands for and is committed to fostering is grounded on the prevalent understanding of engineering practice and technical design that philosophers, sociologists, and historians of technology currently sustain. Such understanding is fourfold:

1) Any technical problem allows for more than one solution. Food production, for instance, can be done according to agro-ecological techniques and technical arrangement or according to the mainstream green revolution paradigm; electricity can be generated (solely) on large and isolated power plants (macro-generation) or (also) on small and distributed photovoltaic units installed, for example, on the roof of consumers' houses (micro-generation); transportation solution of people living in big cities can rely on private automobile or public system, etc.

2) Each one of these possible solutions impacts and shapes society (and the environment) in a specific way. Agro-ecology depends on peasants' knowledge, which empowers them; it is ecologically sustainable and labor-intensive (providing a lot of jobs in the countryside), not allowing mechanization. On the other hand, the green revolution agriculture does not rely on peasants' knowledge, which disempowers them; it is ecologically largely unsustainable and labor non-intensive; for being capital intensive, it also contributes to land concentration and rural exodus.

3) Since any technical problem can be technically addressed in multiple ways and also as even the supposedly unsuspected concept of efficiency is socially shaped [10], a solution to a problem is chosen and considered good also based on its expected social consequences. In other words, if we do not rely on sets of elements such as ethical-political values to choose among the available solutions, we will be unable to pick one [11] (actually, we will be unable to even conceiving such solutions [12], [13]).

This holds for agriculture, transportation system (or urban planning), energy production, and everything else, as it has held for child labor and steamboat boilers [10]. It is because values such as profit maximization, subjection of nature, and control over society are part of the hegemonic ones nowadays that green-revolution-like agriculture is largely preferred over agro-ecology. That is, not only does technology shape society (item 2 above), society (or those particularly powerful there), on its turn, does also shape technology, choosing its development pathway based on those ethical-political values taken (for some) as the preferred or best ones. They, indeed, shape one another, constituting a non-divisible *social-technical* unit or order [10].

4) There is not a technically pure rationality that presides (or could preside) over technical development. Any technology is inevitably also a social construction, the result of a social-technical process and reasoning [14]. Even the supposedly more technical realm of engineering design practice, the conceptual design construction of desired functionalities and its subsequent material and/or procedural implementation, is a lot like art [13], something necessarily contaminated with "non-technical" elements such as image collection, aesthetic values, and ordinary know-how [12]. All these make the democratization of technology development not only technically legitimate but also politically mandatory if we are to construct a society that is really democratic, fair, pluralistic, ecologically sustainable, etc. [10], [15], [16]. In other words, a society for the other 90% or 99%.

So, when grassroots engineering takes clear responsibility for the social side of social-technical designing, it is not becoming less technical; it is merely acknowledging the inseparability of society and technology and picking a side in this power game, the side of the poor(est). Practicing a liberating engineering is not the same as practicing the mainstream capitalist one. Unless engineering and technical codes are subverted, we will only be able to produce consumerism, environmental destruction, social inequity, etc. [15]. Thus, the alternative to subverting engineering (be practicing GE or another one) is to leave it as it is already. That is, to keep producing or strengthening this capitalist order, which turns out to be deleterious to almost every human being and the environment as a whole.

In what follows, 1) I start deriving from Paulo Freire's ideas four skills an engineer able to practice popular education must possess. Such a professional profile, which is complementary to the "technical" one usually developed in mainstream engineering courses, is also mandatory for grassroots engineering. Such an engineer is an *educator engineer*. Then, 2) I briefly present some of the characteristics and requirements of Brazilian higher education in general and engineering education, in particular. It is dealing with the potentialities and limits posed by such regulations that engineering teachers and/or students 3) conceived the three main types of educative initiatives aimed at forming, to some extent, this grassroots/educator engineer profile: service learning (out-of-classroom and immersive) practices; theoretical and in-classroom practices; and mixed (both in-classroom and out-of-classroom) practices. Then, in the penultimate section, 4) I focus on one of such initiatives' main challenges: assessing its impacts on the students that undertake them. I conclude the manuscript with some closing remarks.

Methodologically, section 1 is a theoretical reflection based on two of Paulo Freire's books: *Pedagogy of the Oppressed* and *Extension or Communication?* It is a formalization that grassroots engineering practitioners acknowledge as appropriate for an ideal practice they have been trying to improve more and more. Section 2 draws on some Brazilian laws and papers that analyze them.

Section 3 mainly results from a literature review of the annals, from 2000 up to 2016, of the main Brazilian forums of engineering education discussion: COBENGE (*Brazilian Conference on Engineering Education*) and ENEDS (*National Meeting of Engineering and Social Development*). The review is supplemented by a) non-published information from direct conversations with people involved in those initiatives; b) documents from universities' official websites; and c) academic works obtained directly from those in charge of such educative initiatives. As can be noticed, the literature review undertaken is not exhaustive. Nonetheless, from what I can see after three years as a member of the Brazilian Grassroots Engineering Network (*Repos*), the formative practices presented are, to my knowledge, the best that have been implemented so far in the country.

Finally, section 4 draws on the scarce formal evaluations that the papers reviewed present, on interviews conducted with some of Repos' leading actors, and on personal observations. As will be discussed later in this section, this lack of formal or institutionalized assessment has both bad and good consequences. It, however, does not mean that evaluations are pointless. Part of my current post-doctoral research is precisely on the construction of metrics and assessment instruments. These instruments will allow us to identify better impacts of such an education on the students' formation, the communities served, and grassroots engineering practice, providing, at the same time, information for improving them.

Grassroots engineer and Paulo Freire

Most grassroots engineering practitioners get much inspiration from one of Paulo Freire's books: *Extension or Communication?* [18] This work was written in the first years of Brazilian civic-military dictatorship (1964-1985), during which Freire was exiled in Chile. There, he was involved in the agrarian reform process that was undertaken by the government, both implementing a process of popular education and witnessing and somewhat mediating the technical support that was being offered by agronomists to peasants. From this experience, Freire highlighted some skills an engineer or technician must possess in order to be able to promote or encourage liberation along with the technical support they provide, instead of promoting what he later called cultural invasion [9]. To be able to support liberation, the central challenge engineers/technicians must face is not to impose the usually oppressive academic knowledge and worldview on grassroots groups. Rather, they must promote both a dialogue of knowledge and *praxis*. By *praxis*, it is meant a critical reflection about our individual and collective action in the world; a reflection that lets us better understand life and society, progressively disalienating ourselves, and, in so doing, allowing us to come up with more effective transformative actions.

The relevance of *Extension or Communication?* for grassroots engineering is twofold. One, it specifically analyzes the engineer/technician supporting work of grassroots groups' initiatives from a liberating perspective. Two, when Freire criticizes the support engineers/technicians can

offer to grassroots groups, he is also criticizing the traditional [and colonizing] one-way relationship between university and society, which goes from the former to the latter, but never the other way around. A university – and engineering! – committed to liberation, however, must establish a two-way relationship, not only teaching society, but also learning from traditional/popular knowledge and taking society's – or marginalized people's – real problems as matters of academic research, teaching, and action.

Extension or Communication? has, in its very title, the essence of Freire's critique of traditional engineering and university ways of being. Instead of staying one-way, which characterizes what the author calls "extension" (or overflowing university into society), they must evolve into a two-way form, a communicative or dialogic one.

There are four skills such an *educator engineer* (as some authors will later call this professional profile [17]), an engineer capable of developing popular education alongside his/her technical support, must possess. Drawing on *Extension or Communication*? and *Pedagogy of the Oppressed* [9], such capabilities can be summarized as:

- *Empathy* and *ability to dialogue*. In order to better understand someone's condition, necessities, worldview, values, and desires, we must be able not only to have a dialogue with her/him in a way that s/he can understand us but also to put ourselves in her/his shoes. In addition to allowing us to know the other's "knowledge-belief system," as Freire calls it [18], empathy and ability to dialogue are also essential for the construction of trust relationships. It is only in such a relationship that liberation or disalienation can be co-constructed. To be clear, liberation or disalienation occurs for both engineers/technicians and grassroots people. And it is only then that "another possible world" can be co-imagined or co-dreamed, offering grassroots groups and engineers/technicians alike a future they may find worth fighting for (and constructing) together.

- *Critical sense*. Alienation is a condition that also affects engineers/technicians. They can only overcome it if they can critically question the very basis of their life experience and their professional performance with canonical and partially contingent supporting codes, values, technical-scientific knowledge, and know-how [10], [12]. Critical sense is, as it could not be otherwise, essential to *praxis*. Only a critical engineer can de-reify, de-naturalize the contingent structure that produces the oppressing *status quo*. A structure that, among many other things: 1) establishes engineering practices in a way that engineers can only bring about this oppressing and colonizing order we have; and 2) makes us believe that formally uneducated or non-westernized people (such as many grassroots groups) are devoid of proper reflection and sound judgment, so they must be denied any agency.

- *Openness to learn*. Finally, since liberation and disalienating learning is something we can only develop together, through dialogue, an educator engineer, in addition to being empathic, critical, and capable of dialoguing, must also be open to learn throughout his/her life. S/he must be willing to learn from the endless *praxis'* exercise and even to be taught by the supposedly naive grassroots group s/he is serving:

> learning from the group's knowledge, strategies of political action, worldviews and values, etc.

Since a grassroots engineer is supposed to be able to develop popular education alongside – or as an integrant part of – the technical support they provide to grassroots groups, they must be an educator engineer. Defined like that, it can be said that "grassroots engineer" and "educator engineer" are synonyms.

It is at least part of these *non-conventional* and complementary engineering skills that each of the educative initiatives I am going to analyze tries to develop in the students. There are, nonetheless, some limits and potentialities for such initiatives that are set by the characteristics and requirements that Brazilian higher education must attain. Thus, before presenting the initiatives themselves, we must give a brief exposition of these legal parameters.

Brazilian university and engineering education

According to article 207 of the Brazilian Constitution [19], every university must provide teaching, research, and extension. "Extension" encompasses a wide variety of activities ranging from community engagement to junior company; from cultural production to juridical assistance to the poor; from university hospitals to extension courses that present academic knowledge and research to non-specialized audiences.

More recently, in 2018, this constitutional understanding was made clearer through the establishment of the Brazilian Higher Education Extension Policy Guidelines [20]. The Guidelines' third article defines extension as:

> Extension activities are, in Brazilian Higher Education, integral parts of the curriculum and research organization, being characterized by a process that is interdisciplinary, political-educational, cultural, scientific, and technological. A process that promotes a transformative interaction between higher education institutions and other sectors of society, through the production and application of knowledge, in permanent articulation with teaching and research.

The document also presents extension as a dialogic interaction between academia and society. An interaction, moreover, that should cause mutual and beneficial transformations in both academia and society.

In order to achieve such results, the Guidelines define a minimum of undergraduates' course load that must be dedicated to extension activities: 10% of the total course load.

All Brazilian higher education institutions must have implemented these rules by 2021.

Despite the Guidelines' apparent commitment to a dialogic or communicative extension (if we keep Freire's terminology), an attentive reading of their articles allows us to say that its prevalent intent is not questioning the established, colonizing and oppressive order we live in, but making the university more instrumental to its maintenance and deepening. Liberation and disalienation,

to be sure, can also be developed, and are by no means prevented by the law. Following this way, however, is not something that stands out from the Guidelines' recommendations or is clearly encouraged by them. Moreover, the development of such a pathway will usually require a continuous fight from those committed to it.

Brazilian law also establishes specific national regulations for each particular higher education course. Regulating the engineering courses, we have the National Undergraduate Engineering Curriculum Guidelines that were approved in 2019 [21] and which replace the 2002 equivalent Guidelines [22].

As we will see in the next section, the 2002 Guidelines were particularly important for progressive perspectives such as grassroots engineering and liberating technical support to grassroots groups because:

1. They made the curriculum more flexible, allowing local faculty to adapt it to specificities the institution could identify as worth considering [23];

2. They made explicit an ideal education that should form a generalist, humanist, critical, ethical, and socially and environmentally sensitive engineer [22];

3. They encouraged a multidisciplinary education and made curricular internship mandatory [22].

In the 2019 Guidelines, a lot of these potential gains for the formation of educator/grassroots engineers are kept; they are mainly seen in article six [21]. Nonetheless, a relevant loss also occurred: "Humanities, Social Sciences, and Citizenship," which was a mandatory matter in the 2002 Guidelines (article six) [22], is no longer even mentioned, as a content to be worked on, in that of 2019. As it will be seen, it was through disciplines such as STS (Science, Technology, and Society), where this specific content used to be developed, that many engaged teachers offered a critical part of the curricular educator engineer formation that could be provided in their institutions.

Despite the undeniable potentiality for progressive and liberating formative initiatives, both 2002 and 2019 Guidelines clearly choose or privilege an education for the "market," of engineers somewhat sensitive to society's needs and to environmental responsibility, but who take for granted and do not de-reify or structurally criticize the technocratic-capitalist *status quo*. For no other reason, engineering education in Brazil is mostly concerned with forming skilled labor for the mainstream developmental needs that industry and the country might have. This is what the 2019 Guidelines explicitly state in their first 19 pages (out of 41) [21] when it is presented the biggest challenges engineering schools must deal with for the undergraduate education they provide: reducing the astonishing evasion rate of their students (of some 50% countrywide); developing the students' soft skills; tightening the relationship with industry; forming engineers that could better fit the demands of their future employers (in industry) or of innovation and entrepreneurship.

Formative initiatives aimed at forming grassroots engineers

So far, we have briefly: presented grassroots engineering (GE) and its theoretical legitimacy; derived from some Freire's works the four complementary skills an educator/grassroots engineer must possess in addition to the conventional mainstream (or "technical") ones; sketched some aspects of the Brazilian regulation of both higher education in general and engineering education in particular that either make it possible or limit this complementary educator engineer formation. In this section, I present some educative initiatives undertaken at Brazilian engineering schools that aim to develop (some of) these educator engineer skills.

Most of these initiatives have as their clear goal to train one to practice GE or something very close to that, while others are committed to engaged engineering in general[1] [24] or simply to the development of some specific skill, such as critical sense.

The educative experiences mapped in the literature review undertaken can be divided into three main types: extension or service-learning activities, which take place outside the classroom and, in many cases, are immersive; theoretical and in-classroom activities, usually linked to regular courses; some mixed arrangement of both service learning and theoretical activities.

Extension or Service Learning

There are two main types of service learning that are instrumental in the development of the educator engineer's skills. The first one is institutionalized in what is called *Núcleo de Extensão Universitária*, that is, University Extension (or Service Learning) Center: a center linked to a university, formed/managed, in the cases relevant to this study, by teachers and students from engineering and other technical and non-technical areas. These centers provide either short- or long-term technical assistance to grassroots groups, intending to be a place where the extension is practiced alongside research, with the one (extension/ research) learning from and teaching to the other. Examples of such centers are: Soltec, at Federal University of Rio de Janeiro [3]-[4],[25]-[28]; ITCP, at State University of Campinas [3], [29]-[31]; Pegadas, at Federal University of Rio Grande do Norte [3], [32]; and Incop, at Federal University of Ouro Preto [33]-[35].

[1] As such, engaged engineering, as it is defined by Kleba [24], is a broader concept which encompasses GE as well as engineering practices such as social entrepreneurship, engineering for (social) development, and humanitarian engineering. The demarcating lines between these engaged practices are usually not clear-cut. This is even more the case when GE is compared to humanitarian engineering (HE) initiatives, such as Engineers Without Borders (EWB) and Techo. On the one hand, both GE and HE seem committed to listening the assisted people and somehow incorporating them into the design and/or building process. Plus, things like empowering the supported people is also sought, to a certain extent at least, on both types of engaged engineering. For grassroots engineers, however, GE is also highly committed to the co-construction of another possible world, not only to improving the conditions of the supported people's lives and their inclusion into the hegemonic capitalist order and worldview. Such commitment, or the degree to which it is taken by GE, is thus considered as one of the GE's differences with respect to HE. A difference that is materialized in methodological options such as developing a popular education process alongside – and as part of – the technical assistance provided; nurturing bonds, affect, and confidence with the assisted group; enduring a respectful and careful dialogue of knowledge; establishing a supportive process that can never be short in time (as many (most?) EWB's and Techo's initiatives seem to be), nor can be developed, in a short time, with foreign groups (as many EWB practices do).

These centers, which turn out to be home to some of the leading GE teams in Brazil, currently tend to opt for long-term technical assistance (lasting for up to a couple of years) [25]-[27] and for supporting enterprises linked to social movements, rather than isolated initiatives [2]- [3], [31], (except for Incop). Enterprises assisted usually range from cooperatives of waste pickers [35], [36] and landless rural workers settlements camps [37] or fairs [35] to worker-recovered companies [37], support to social movements with ICT (information and communication technology) challenges [37], and solidarity economy in general [30], [31], [34], [35]. The technical assistance provided is usually associated with managing productive processes, ergonomics, building artifacts (that can be a material or non-material one, such as a computer program/app), and designing infrastructure [3]. Methodologically, it is employed action research, which is usually supplemented by a popular education process [3], [25]-[39].

Undergraduate students take different roles in the GE processes undertaken by these extension centers, from the compilation of the gathered information during the field activities to supporting and performing field activities. To be able to act alongside local groups or support their GE team's field action, students are given specific formation. At Soltec, for instance, such formation encompasses constant interaction with the supported local group, studies, and critical reflection [3]. The aim is to foster both *praxis* and a better understanding of the local group's situation, also providing some theoretical grounding for action research and popular education. The formative process, which is supplemented with a personal orientation by the project's coordinator, intends to form a full-fledged educator engineer [28] progressively. The same, with some local specificities, holds for the other three centers [3].

The second type of service learning is called *Estágio Interdisciplinar de Vivência*, that is, Interdisciplinary Living Internship (ILI). It is a three-week-long immersion experience in which students are introduced to some oppressing reality with the help of a group that endures it (about three days), take part in such group's work and other social activities (about fifteen days), share the experience they had, reflect on it, and try to make a long-lasting commitment to the community they lived in and worked with. These experiences usually take place in the countryside, being always organized by undergraduate students and social movements such as the Landless Rural Worker Movement, Peasant Way, etc. [40]. ILI's main objective is to contribute to the formation of students capable of "transformative *praxis*" [41].

The first ILI was organized in 1988, in the wake of the Brazilian return to democracy, by students of agronomy [42]. Ever since, the event has spread widely all over the country. It is currently offered on a regional basis in addition to the national one [41]. In both regional and national formats, ILI is managed by students, many of whom underwent the experience the year before [43]. Organizing the event is deemed as part of the formation process of a grassroots/educator professional. Students from all disciplines are allowed to take part in the experience, not only from agronomy or engineering [41]. This interdisciplinary perspective constitutes part of what makes ILI attractive.

Even though university students are those who both (co-)organize and undergo ILI, the event has no official or formal link to the university institution. Indeed, students' autonomy, independence and leadership constitute one of ILI's four principles. The other three are: co-organizing the

event along with social movements; being interdisciplinary; during the internship experience, seek to learn from local grassroots groups, not to teach them [41].

Both types of service learning – University Extension Centers and Interdisciplinary Living Internship – develop or encourage the development of students': empathy (through the construction of affective bonds with the local group, the practice of caring, the exercise of trying to be in the group members' shoes, etc.); ability to dialogue (via the constant need of conversations, of knowing the other and allowing him/her to know oneself, etc.); critical sense (through studies, reflection, direct contact with oppressed realities, *praxis*, etc.); and openness to learn (via appreciating the groups' knowledge, realizing the limits of one's own knowledge, taking transformative *praxis* and its endless learning process as the intended horizon, etc.).

Concerning the attractiveness of these non-mandatory initiatives, one of them is their being practical, hands-on activities. Plus, something that holds for the Extension Centers' activities, the Guidelines on Extension made the service learning provided by them worth at least part of the 10% minimum of course load that each student has to dedicate to extension activities. For ILI, however, as long as the movement sustains its total independence from university, nothing like this is supposed to happen. On the other hand, what experience seems to keep showing is that such encouragement is not necessary for ILI. Indeed, there are usually more people that apply for the internship than the available spots.

Either way, there are some limits too. Extension centers seem to have more impact on students' formation than on the supported communities or enterprises [3]. It does not mean that local communities gain nothing. Many (or some of the) local people empower themselves and there is some degree of disalienation [3]. According to Paulo Freire's liberating perspective, these are the most important results that such a sort of initiative can help to produce [18]. However, the social-technical fruits of the supporting process may not last long [3]. Examples of that range from worker-recovered companies that go bankrupt after some (unanticipated) market change [25] to rural workers' camps that end up being closed or displaced by the public power. In addition to that, despite being now worth some course load, service-learning activities like those offered by the abovementioned centers are not mandatory. Moreover, many Brazilian universities do not even have centers like these. So, the amount of (potential) educator engineers formed is just a tiny little quantity compared to the number of engineers that graduate every year in the country.

ILI limits are even broader. With respect to extension centers, ILI lacks a more in-depth or longer formation process, being just a punctual experience. In this sense, ILI is a robust "entrance door" to the transformative *praxis* it aims to foster. A door, nonetheless, that, in order to lead to the results being sought for (professionals capable of transformative *praxis*), demands to be supplemented with a lasting formative program, either a university-based or an "independent" one. Plus, given its non-institutionalized structure and the continuous renovation of the team in charge of each ILI's edition, ILI seems to face significant challenges concerning accumulating, consolidating, and maturing its own experience.

Another area in which service learning needs some improvement is in the assessment of students' formative progress. It is presented in the final section.

Theoretical Activities

The second group of educative activities that can develop some of the four educator engineer's complementary skills consists of two main kinds of initiatives: participatory, reflexive and critical technical classes; and STS disciplines. Both types are usually in-classroom activities and can be developed by teachers who are not committed to any sort of engaged or grassroots engineering.

Critical and participatory technical classes are meant to both widen students' social-technical understanding and worldview and to encourage them to leave – or not to accept occupying – a passive role of uncritical receiver of the established technical knowledge. What is sought here is not to outsource critical reflection to the humanities but to perform it in the technical core of engineering courses. Participation can be encouraged via more active methodologies, such as problem-based learning, inverted classes, etc. Reflexivity and critical sense can be advanced through discussions concerning the implementation of the technical content studied, its limits to serve certain demands, its potentialities, etc. Sandra Rufino, at the Federal University of Ouro Preto, managed to prompt participation and critical thinking, in the discipline "Organizational Theory and Work Organization" of the university's Production Engineering course, with debates motivated by movies [44].

Science, Technology, and Society (STS) disciplines entered most Brazilian engineering curricula after the homologation of the 2002 National Guidelines on Engineering Education [22]. It may change after the latest version of these Guidelines (2019), which, as stated earlier, do not mention such content, let alone make it mandatory. For most Brazilian engineering courses, critical thinking and social responsibility tend to be mostly addressed in these disciplines. In some institutions, teachers managed to conceive very interesting implementations of such classes. It is the case, for instance, of the Aeronautics Technological Institute, which incorporated a community engagement project to its STS discipline [45]. "Computer and Society," the STS discipline of the Computer Engineering course at Federal University of Rio de Janeiro, mixes participatory pedagogy, community engagement project, and an innovative assessing process [46]. The Mechanical Engineering course at the Federal University of Santa Catarina developed a solid STS reflection that, besides having become referential to other courses throughout the country, is worked at two mandatory disciplines of its syllabus: "Introduction to Engineering" and "Technology and Development" [47].

On average, these two types of theoretical activities – participatory and reflexive classes, and STS disciplines – develop or encourage the development of critical sense. The ability to dialogue may also be developed or encouraged. But a dialogue with "equals" (or equally educated people, pertaining to the same social class, having the same general worldview, etc.), not with "different," which is usually more demanding, especially when the different is portrayed by the mainstream technocratic understanding as devoid of knowledge and/or sound judgment. Empathy with grassroots people and openness to learn from them are not practiced in these activities.

Since these kinds of initiatives are mandatory or implemented in compulsory disciplines, all students are somehow impacted by them. One setback of being obligatory, however, is that

students' motivation and commitment can be (very) low to some of them, regardless of the methodologies applied in the classes.

Mixed arrangements

The last set of educative pathways that can form an educator engineer is a radical conjugation of service learning and theoretical activities. To my knowledge, the most remarkable implementation of that is the agronomy course at Pará Federal Institute of Education, Science, and Technology (IFPA), campus Castanhal [48].

A key pedagogical element in the course is the *curricular living internship*, which is an integrative project developed in three phases. In all the phases, the students are sent in pairs, for about ten days, to some rural community or family. In the first one, their task is to know how their hosting community or family interacts with surrounding nature, taking part of every working and social activity their hosting family participates. In the second, the focus is on better knowing how their hosts work and the possible technical challenges they may face in that realm. Finally, in the third phase, they study the territory, paying particular attention to those institutions that support the rural development of that locality [48].

In order to be able to perform each of the internship phases properly, students are previously prepared by the disciplines and other on-campus activities they undertake. During the phases' execution, they receive support from teachers who visit them. After returning, they must write and present a report on the experience they had. As such, every phase creates a space for the integration and application of what they learned theoretically, as well as a space to both learn from practice and local people's knowledge, worldview and values, and to criticize the theory learned at school, based on how the social-technical reality manifests itself [48]-[50].

As it is presented, this *curricular living internship*, along with the course structure that makes the three phases possible, conjugates the best achievements, concerning the development of the educator engineer's skills, of service learning and theoretical activities previously discussed. They also overcome one of service learning weaknesses: not impacting all the students doing the course. Plus, the internship is usually highly evaluated by both students (many of whom are existentially touched by the experience of knowing, caring about, and liking poor rural families whose reality of life most of them did not know beforehand) and hosting families (that very frequently develop a deep affection for their guests). Nonetheless, challenges concerning the impact of these internships on local communities/families remain. Besides, the realization of all the potential such a mixed arrangement brings with itself relies heavily on the commitment of all faculty members to its ideal, which is a challenge at IFPA/Castanhal (and other institutions where such a model is being tried).

Summarizing table

Summarizing the main characteristic of these three types of formative initiatives leads to a table like this:

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="2">EXTENSION</th><th colspan="2">THEORETICAL ACTIVITIES</th><th rowspan="2">MIXED ARRANGEM.</th></tr>
<tr><th>Extension Center</th><th>ILI</th><th>Method-ology</th><th>STS Discipline</th></tr>
<tr><td rowspan="4">Development of Educator Engineer Skills</td><td>Empathy</td><td>High</td><td>High</td><td>--</td><td>--</td><td>High</td></tr>
<tr><td>Dialogue</td><td>High</td><td>High</td><td>Medium</td><td>Medium</td><td>High</td></tr>
<tr><td>Critical sense</td><td>High</td><td>High</td><td>High</td><td>High</td><td>High</td></tr>
<tr><td>Open. to learn</td><td>High</td><td>High</td><td>--</td><td>--</td><td>High</td></tr>
<tr><td colspan="2" rowspan="2">Attractiveness or Assets</td><td colspan="2">Hands-on activity</td><td colspan="2" rowspan="2">Being mandatory</td><td>Being mandatory</td></tr>
<tr><td>Up to 10% of course load</td><td>Conviviality & Interdisciplin.</td><td>• Theory + hands-on experience;
• Reflection + immersion;
• Internship as integrative activi.</td></tr>
<tr><td colspan="2" rowspan="3">Flaws</td><td colspan="2">Not being mandatory</td><td colspan="2" rowspan="2">Not dealing directly with grassroots groups</td><td rowspan="3">--</td></tr>
<tr><td rowspan="2"></td><td>Limited formation</td></tr>
<tr><td>Not accumulating / maturing its experience</td><td colspan="2">Mostly rational; non-bonding</td></tr>
<tr><td colspan="2" rowspan="3">Challenges</td><td>Attracting students</td><td rowspan="3">How to improve?</td><td colspan="2" rowspan="3">How to deal with students’ motivation?</td><td>Realizing its potentiality</td></tr>
<tr><td>Multiplying centers</td><td>Assessing/ improving impacts on assisted families/communit.</td></tr>
<tr><td>Assessing impacts</td></tr>
</table>

Table 1 – Main Characteristics of the Formatives Initiatives

Future work: assessment challenges

Among the challenges that Brazilian educative initiatives meant to form educator engineers must face, evaluation is one that seems to demand a better approach. Evaluation as an instrument that can help both students develop the skills that are thought of as necessary to make them educator/ grassroots engineers and the group in charge of this educative process (teachers and/or students) to continuously improve it.

When assessment is considered, at least four questions demand plain answers: 1) What do we want with the formation to be provided, i.e., what kind of professionals do we want to have once the process is concluded? 2) How can such a formation be obtained, i.e., what educative

pathway(s) should we follow so to get these professionals formed? 3) How can we be sure that the formation was obtained or to which extent it was, i.e., what evaluative instruments can/should we use? 4) How can we make the formative process more effective, i.e., how to learn from the assessments performed?

From what I observe from within the Repos (the Grassroots Engineering Network), even though different researchers and practicing teams (like extension centers and other places that perform grassroots engineering (GE)) agree that GE must lead to a post-capitalist, non-oppressing, democratic, and ecologically sustainable social-technical order, they do not focus on the same part of the transformative process that could bring about this "other possible world." In some cases, there are even differences, minor but existent, concerning the conceived transformative process itself. For instance, while Soltec ([4], [25]-[27]) tends to spend significant effort on institutional politics change (lobbying for specific policies, for example), this does not seem to be the case at Alter-Nativas [51] and some other GE teams, which focus almost exclusively on supporting grassroots groups. Likewise, while most GE teams tend to prioritize supporting initiatives linked to social movements, Incop ([33]) assists isolated enterprises too.

To be sure, this plurality of viewpoints and focuses is much more of richness than fragility. The point, however, is that, depending on the specific perspective of a particular GE team, practitioner or educator, the complementary skills an educator engineer must possess so to be able to play the specific transformative and supporting role s/he is supposed to play may vary. So, even though empathy, ability to dialogue, critical sense, and openness to learn are essential to all GE practices, they are usually supplemented with some others.

It seems that most formative processes committed to GE or engaged engineering, in general, do not explicitly define the students' skills they are trying to develop. It does not mean that GE educators do not know what practicing grassroots engineering is about. But they usually do not spend much time specifying its details. Instead, they tend to take GE science-arts as a whole (as we saw earlier, engineering inevitably is a mix of science and arts [13]), as something we learn studying, imitating (senior educator engineers), and critically practicing. On the one hand, it is undeniable that GE educators establish a (somewhat) clear formative pathway, stick to it, and assess students' evolution or the supporting process they all offer to grassroots collectives [3], [28]. On the other hand, however, they usually seem not to spend enough time on this, which can result in failures and inefficiency that could be addressed, were they to pay more careful attention to such evaluative processes.

To a certain extent, such fluidity may allow innovative educational approaches to emerge, as it does also happen in other types of engaged engineering formation [5]. Even when the pedagogical initiative takes place inside established and well-regulated institutional formats, like on regular in-classroom disciplines, teachers committed to GE (or engaged engineering) are very creative, coming up with compelling, innovative pedagogical solutions [44]-[46].

On the other hand, what is missed with an ill-defined and/or non-evaluated formative process is not only the possibility of improving it and, with that, of increasing the effectiveness of the provided education, but also: a) a better understanding of the fundamentals of GE practice; b) a better definition or delineation of the skills demanded for such a practice; and c) an opportunity

to identify commonalities with other educative initiatives in engineering, foreclosing potentially beneficial exchanges with them.

In this sense, part of the work I am turning to now is precisely the development of metrics and assessing tools that could help evaluate and, with that, allowing GE's formative initiatives to be improved.

Closing remarks

This manuscript aims to offer a brief overview of Brazilian grassroots engineering, along with pedagogical initiatives that somehow foster the formation of professionals capable of performing it: educator/grassroots engineers. These professionals, in addition to the regular or conventional skills already developed at most engineering schools worldwide, must also have empathy, be able to have dialogue, have critical sense, and be ready to learn throughout their lives and especially from uneducated people.

In Brazil, three main types of pedagogical initiatives have been offered for more than a decade now: extension or service learning; theoretical activities; and mixed arrangements. All of them proved useful to develop not only (part of) the educator engineer's complementary skills but also to attract more students to (and form them to practice) grassroots engineering. Indeed, if we only consider the self-declared GE practitioners, individually and collectively, their number has been increasing throughout the years (which, for instance, led to the creation of Repos, the Grassroots Engineering Network [2]) as well as the amount and the social-technical density of the support they provide.

In addition to that, a harsh change in Brazilian national politics after the removal of President Dilma Rousseff from office (2016) has meant the adoption of ultraliberal pro-market policies and reforms, all of which are the opposite of what GE stands for and of the policies that funded GE. Despite all this, GE still survives and takes steps. As another proof of that, it can be mentioned that GE's main introductory event, the annual national and regional Meetings of Engineering and Social Development, keep attracting between 1.000 and 2.000 undergraduate students altogether yearly [2].

The same point can be made with respect to extension scholarships, which financed undergraduate students' work at the extension centers: their amount was reduced enormously after 2016. But left-wing transformative ideals embraced by GE teams, plus the acceptance of this kind of work (GE's) for the 10% minimum course load at extension activities, have kept attracting students to such initiatives.

However, a common challenge that most of these initiatives face has to do with assessment. Assessment of students' evolution in the acquisition or development of the required skills and of the provided formative process concerning its effectiveness as well as its adequacy to what might be necessary for the GE practice being sought for.

Notwithstanding, even if (or when) GE's educators and collectives take evaluation more strictly, this will certainly not lead to a uniform/universal, scalable and/or easily replicable practice or

formative process. As part of its de-colonialist way of being, GE can only realize its liberating, empowering, dis-oppressing, ecologically sustainable, bottom-up support if it remains local. That is, GE practice must remain as attuned as possible to the local reality, with its particular challenges, limitations, and affordances, which are both environmental, social-technical, and humane. The price for such commitment to the singularity of any territory is to give up the search for universality (but not what can be learned from allegedly universal knowledge). Likewise, each formative environment constituted by faculty, students, institutional specificities, etc., is, to a certain extent, unique. Thus, forming educator engineers in any of these environments must always be a somewhat unique process.

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