Equity Aspects from Adoption of Online Laboratories in Engineering Education

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Abstract Beyond the technical aspects, it is crucial to observe human factors that affect the adoption of online laboratories in Engineering Education (OLEE). This chapter presents propositional pathways for considering equity aspects concerning OLEE adoption. Practical examples and theoretical foundations are provided from the Digital Divide and the Capability Approach.

1 Introduction

Professor Jirafales[1] is in the middle of an important meeting of his engineering course. The professors are convinced to explore new pathways to teach engineering to their students. Prof. Jirafales is excited because his program will begin to adopt online laboratories (OL), starting with using a web digital logic simulator that emulates a physical project for digital systems called WebLogisim[2]. He is responsible for the Digital Systems course, and he knows that his teaching experience will serve as a reference for choosing future OLs to be adopted by his colleagues. However, Jirafales is concerned because of Chavo[3], an undergraduate in his program who lives in a disadvantaged region near his university and has difficulty accessing a stable internet connection. He doesn't know if adopting WebLogisim could negatively

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[1] Teacher Jirafales is one of the characters of Chespirito, a Mexican sitcom written by Roberto Bolaños.

[2] Logisim (http://www.cburch.com/logisim/) is a classical graphical tool for designing and simulating logic circuits. WebLogisim is a fictitious name, but there already are tools like that (e.g., CircuitVerse: https://circuitverse.org/).

[3] Chavo is the main character of Chespirito, a homeless person who sleeps inside a barrel.

affect Chavo's learning. His question is how to appropriately consider the Chavo's situation pedagogically. Prof. Jirafales wants to promote this curricular change, but considering the potential implications that laboratory virtualization can provoke in his students. What should he do?

Adopting online laboratories can be a potential pedagogical resource in Engineering Education (EE) [15]. Their ubiquitousness and scalability are singular features that allow teachers to explore new learning situations when designing their educational interventions. Concerning equality of learning opportunities, online laboratories (OL) can promote better access conditions to students, providing a virtual use without common restrictions like staff availability to guarantee access to physical spaces, limited functioning opening times, or even reduced lab size [14, 12].

This situation presented at the beginning of this chapter is a fictitious story, but it illustrates important pedagogical aspects to consider during the implementation of OLs in EE (OLEE). Prof. Jirafales' question indicates that there are equity aspects that can emerge from the adoption of OLEEs. At first sight, it does not seem to be an essential concern in the middle of several potential benefits of its use. But some aspects, like the problem of educational infrastructure shift from university to student home [2] and the access assurance to all students independent of their ableness (universal design [6]), put in perspective structural and contextual dimensions that must be considered.

This chapter presents propositional pathways of how to consider equity aspects of the adoption of OLEEs. We will present this discussion from three dimensions: (i) access (Section 2), (ii) literacy (Section 3), and (iii) social (Section 4), deepening set of crucial equity concepts to consider during the adoption process. The digital divide [7] and the capability approach [18, 20] will be theoretical references to introduce and discuss these equity concepts.

2 Access

The suspicion of Professor Jirafales was right. The internet stability of Tagamandapio[4] is not so good. In addition, he found out that WebLogisim didn't adequately run on the laptop of Chilindrina[5] (another undergraduate in his engineering program). This OLEE requires a minimum quantity of memory to visualize on the screen appropriately. Her internet connection is excellent, but her laptop is old, so it doesn't have a good configuration to run applications that demand a certain level of graphical processing (even as a client). Should Prof. Jirafales ignore this specific reality and concentrate his efforts in the classroom in a general way, or should he invest part of his energy to come up with a solution for these two students?

[4] Santiago Tangamadapio is a little city in Mexico southwest (`https://en.wikipedia.org/wiki/Tangamandapio`). It is referred to in Chespirito as the city of the postman Jaimito.

[5] La Chilindrina is the daughter of Don Ramón, an unemployed widower known in the Chespirito sitcom for delaying payment of his house rent.

Prof. Jirafales is facing a kind of question that does not strictly belong to Engineering or Pedagogy. This kind of question resides in the meeting of several areas and is addressed by many authors in different ways. Some authors will refer to this problem domain as the digital divide. Digital divide is the existing abyss between the people with ready access to information and communication technology (ICT) tools (and, as a consequence, the knowledge provided by them) and those without such access or skills [7]. We will present, as follows, the relations between equity and access (Section 2.1) and an equity theory from the Capability Approach (Section 2.2).

2.1 Equity and Access

One of the existing barriers is physical access to ICT. To introduce this discussion, let's observe this classical illustration[6] (Fig. 1). The natural tendency in our day-to-day life is to associate equal treatment as a default solution for justice problems. But equal treatment is not what we are looking for. We use equal treatment aiming for equality of opportunities. In this way, it will be necessary to discern when to make use of equal treatment or not.

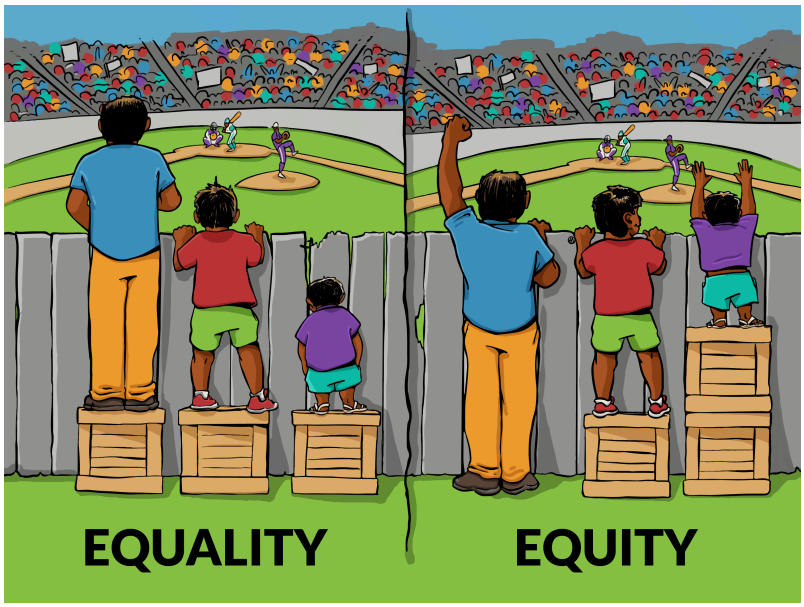

Fig. 1 Illustration about the differences between equality and equity.

[6] Angus Maguire created this illustration and made it available in his portfolio: `http://madewithangus.com/portfolio/equality-vs-equity`.

In Fig. 1, the equality of conditions does not guarantee the real equality of opportunities. So that everybody can have a real chance to watch the match, there must be a differentiated and intentional treatment. Think now that instead of a match, we can refer to authentic learning in EE [19, 22]. Instead of a fence, we can refer to the minimum requirements that an OLEE needs to be accessed by undergraduates. Instead of boxes, we can refer to the actual infrastructure your students have to access a given OLEE outside their university. If you and your program are concerned about equality of learning opportunities for all students [3], it will be necessary to consider and contextualize these scenarios.

In this way, physical access can be a barrier when the necessary infrastructure is not guaranteed for OLEE use. All potential OLEE users should be considered in terms of required infrastructure during the feasibility stage of the adoption process of OLEEs. Not only undergraduates can be regarded as here, but also professors, monitoring students, and other educational stakeholders.

? Access Question 1

Does my student (or other essential user) have real conditions to access the OLEE outside of university?

It is essential to highlight that the main aim of OLEE is to serve as an educational mediator [4] for authentic learning in EE. Bearing this in mind, we can amplify our understanding and shift our focus on OLEE access to EE authentic learning as a common good in our equity analysis (see Fig. 2). If the OLEE is down, what would be the alternative to guarantee undergraduate learning? In project management terminology, what would be the contingency plan for ensuring the learning in case of an OLEE unavailability?

? Access Question 2

Are there alternatives to learning in case it is impossible to access the OLEE (e.g., a physical lab version)?

2.2 Theorizing about Equity: Capability Approach

One of the emerging challenges in Engineering Education (EE) refers to diversity [6, p. 19:2]. Existing differences in a classroom can be a source of wealth and beauty. But they can also be a source of tensions that can generate conflicts. These conflicts are directly associated with the existence of privilege deriving from these differences.

According to Parker and Guzdial [13, p. 1], privilege is “an unearned, unasked-for advantage gained because of the way society views an aspect of a student’s identity,

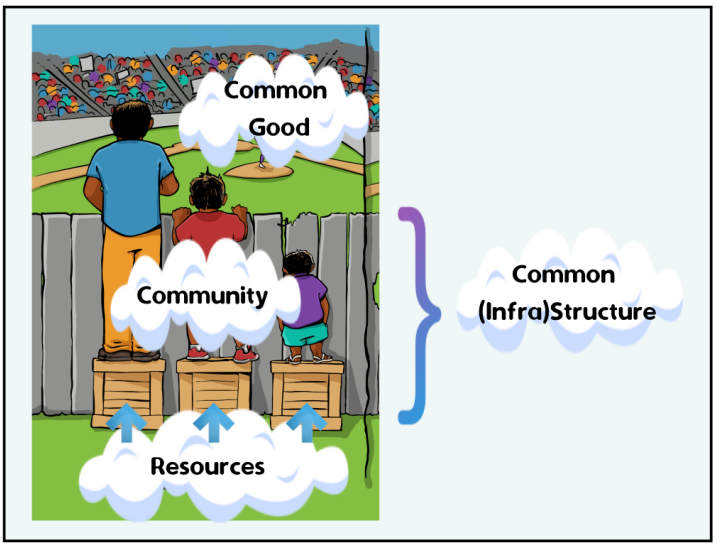

Fig. 2 Key terminologies in an equity analysis. Common good is what is aimed to be shared with all members of a community. Resources are the individual means used to overcome potential barriers imposed by the common infrastructure (or structure, from a macro perspective).

such as race, ethnicity, gender, socioeconomic status, and language". The Brazilian Institute of Geography and Statistics (IBGE[7]) conducted the Continuous National Survey by Domicile Sample (PNAD *Contínua*[8]) in 2018, relating the theme of Information and Communication Technology. This survey revealed that one in four Brazilian people does not have internet access. Suppose we admit that a fraction of these Brazilians who do not have internet access were composed of students in an undergraduate computing program. What would be the impact of this reality on their formation quality? What would be the difference in the formation quality of these students relating to other ones? Scenarios like this show that the differences can convert in privilege to a specific social stratum of the scholar community.

The understanding that there is inequality in the conditions in student context is fundamental for promoting social justice in Engineering Education [11]. This perception allows the professor to reorganize their priorities and build a more honest frame of emerging problems deriving from the diversity of their scholar community.

Some concepts are essential when we refer to inequality of opportunities in education. Lewis and colleagues [10, p. 482] assert that:

> "*Equality* refers to the state where everyone has or is allocated the same things in the same degree, whereas *equity* typically refers to having access to what is needed. [...] In general, [...] equity, and not equality, defines fair and just learning opportunities" (our emphasis).

[7] IBGE stands for *Instituto Brasileiro de Geografia e Estatística* in Brazilian Portuguese.

[8] PNAD *Contínua* stands for *Pesquisa Nacional por Amostra de Domicílios Contínua* in Brazilian Portuguese.

Although the authors signalize to equity and equality concepts, they does not define equity in a strict way. Aiming to theorizing equity appropriately, we will present the capability theory.

The capability approach was proposed by Amartya Sen and puts the focus on other aspects when analyzing equity issues. Sen is an Indian economist and philosopher in the liberal tradition (like John Rawls). He is known for his contributions to the creation of the HDI [5] and for winning the Nobel Prize[9].

The main question raised by Sen [18, p. 12] is "equality of what?". Sen's concerns concentrated on the higher risk of reducing the efforts to deal with inequalities to a single-dimensional analysis. The inequality problem is complex and multidimensional by nature. Thus, when we analyze the problem only with the incoming inequality lens, for instance, probably other sources of inequalities can be neglected and, in some cases, even aggravated. Although the race lens, for example, can contribute to informing essential aspects that can not be overlooked by all stakeholders responsible for analyzing a given scenario, this one is not enough to inform a decision maker with quality and robustness if isolated from others.

The unifier key point for Sen is the freedom to achieve well-being. Well-being is an issue of primary moral importance in Sen's perspective. The well-being prism is the umbrella that can allow the more diverse analysis from different sources of inequities to dialog for achieving a single (but complex) commitment. In summary, the first normative claim of the theoretical framework of the capabilities approach (CA) is that the freedom to achieve well-being is of primary moral importance. Drèze and Sen [9, p. 2] assert in this direction that:

> "It should be clear that we have tended to judge development by the expansion of substantive freedoms - not just by the economic growth (for example, of the gross national product), or technical progress, or social modernization. This is not to deny, in any way, that advances in the latter fields can be very important, depending on circumstances, as 'instruments' for the enhancement of human freedom. But they have to be appraised precisely in that light - in terms of their actual effectiveness in enriching the lives and liberties of people - rather than taking them to be valuable in themselves".

The second CA claim is that the understanding of well-being is directly related to people's capabilities and functionings. When Sen attaches the proper comprehension of well-being to the concepts of functioning and capability (see Section 3.2), he shifts the concern to defining what is well-being exactly, exploring these two crucial CA concepts in more detail. To be honest, Sen's contribution resides primarily in this shifting, indicating the primacy of well-being, but does not exhaust it. Sen allows a certain plasticity level of his approach not to define well-being categorically. But he establishes three concepts[10] for guiding in discernment of how to deal with an analysis from a multidimensional inequity perspective.

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[9] Available at Nobel Prize site: `https://www.nobelprize.org/prizes/economic-sciences/1998/sen/facts/`.

[10] Beyond functioning and capabilities, Sen also defines conversion factors (see Section 4.2).

3 Literacy

> Today is the first term class. Professor Jirafales has already prepared his plans for all Digital Systems' activities, considering the use of WebLogisim. He received the first feedback from some students, praising the initiative and the OLEE adopted. However, there is another particularity in this classroom. Don Ramón, the Chilindrina's father[5], received a social benefit that allowed him to continue his academic studies. He has always dreamed of studying Electrical Engineering, and he is amazed by this opportunity to do this in the same classroom as his daughter. Don Ramón and Chilindrina have already scheduled the times when he or she will use the single laptop of their family. The problem is not their laptop. The problem is that Don Ramón is not familiar with digital devices. Chilindrina is usually the family person who pays online bills or helps him with any technological demand. Don Ramón needs to develop some digital skills to help Prof. Jirafales for establishing a good learning pace for the whole class. How can Prof. Jirafales conduct this demand?

Prof. Jirafales is dealing with a new barrier to effective OLEE use: literacy. The lack of ICT[11] skills also matters because Don Ramón has physical access to a laptop but cannot use it for learning. A minimum of ICT literacy is required to enjoy WebLogisim fully. We will present, as follows, the relations between equity and literacy (Section 3.1) and the definitions of functionings and capabilities (Section 3.2).

3.1 Equity and Literacy

There is a false presupposition that all STEM[12] undergraduates have basic ICT knowledge. Mainly in Global South countries, starting a higher school program does not guarantee digital literacy. A range of public policies aim to reduce the inequality of opportunities in several countries around the world. Thus, it is unavoidable that some of your undergraduates can not meet the desired requirements previously established in your curriculum program[13] or, more specifically, can not deal with an OLEE appropriately.

? Literacy Question 1

What are the desired skills and competencies that an undergraduate should have to use my OLEE fully?

This perspective does not consider the lack of classical digital literacies as realized in the example with Don Ramón. Adopting OLEE can trigger existing challenges

[11] ICT stands for Information and Communications Technology.

[12] STEM stands for Science, Technology, Engineering, and Mathematics.

[13] There is an effort towards reforming old curricula to equity-based curricula (see part of this discussion in [8]).

in online education, like ubiquitous learning [21]. The use of online platforms requires the activation of specific competencies concerning concentration, for instance. Personal computers usually provide the possibility to open and/or use several applications, exploring their multitasking feature. The risk of distraction in online platforms can be higher than in in-person activities, requiring the development of this competency set simultaneously with other technical competencies usually present in an engineering curriculum.

3.2 Theorizing about Equity: Functionings and Capability

As mentioned previously, Sen does not define well-being but characterizes it in terms of functionings and capabilities. About functionings, he asserts that:

> "The well-being of a person can be seen in terms of the quality of the person's being. Living may be seen as consisting of a set of interrelated 'functionings', consisting of beings and doings. A person's achievement in this respect can be seen as the vector of his or her functionings. The relevant functionings can vary from such elementary things as being adequately nourished, being in good health, avoiding escapable morbidity and premature mortality, etc., to more complex achievements such as being happy, having self-respect, taking part in the life of the community, and so on" [18, p. 39].

Thus, functionings are beings and doings that are "various states of human beings and activities that a person has achieved" [17].

In an educational perspective, we can exemplify this concept from a political pedagogical project of a computing program. When a professor's group delineates an egress profile, it idealizes all the expected functionings that a student should achieve after the completion of course. In this way, beings like "to be proactive" or "able to work in groups", and doings like "sorting a vector" and "modeling a database" are functioning descriptions. All these would be relevant functionings that an egress should have. Thus, there is a vector of interrelated functionings that describes an egress profile appropriately.

A concrete example can be extracted from the Computing Curricula 2020 (CC2020) proposed by a task force conducted by ACM[14] and IEEE-CS[15]. The CC2020 embraced competency lens for all its computing curricula, giving examples of competency statement like this:

> "Identify and document system requirements by applying a known requirements elicitation technique in work sessions with stakeholders, using facilitative skills, as a contributing member of a requirements team" [1, p. 52].

A competency is a vector of interrelated functionings. When it is present in a political pedagogical project, it is an expected set of functionings. When we have any egress with this competency, it is an achieved set of functionings (or just achievement).

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[14] ACM stands for Association for Computing Machinery.

[15] IEEE-CS stands for Institute of Electrical and Electronics Engineers (Computer Science).

We know, for instance, that students only develop a complex software if they understood loops and conditionals previously. Thus, bearing in mind an achieved functioning (understood loops and conditionals) can be an expected functioning (develop a complex software) in another context, it is interesting to differentiate them. Sen amplifies this difference for a freedom perspective and defines the capability concept.

Concerning capabilities, Sen [18, p. 39,40] continues developing his definition as follows:

> "Closely related to the notion of functionings is that of the capability to function. It represents the various combinations of functionings (beings and doings) that the person can achieve. Capability is, thus, a set of vectors of functionings, reflecting the person's freedom to lead one type of life or another. Just as the so-called 'budget set' in the commodity space represents a person's freedom to buy commodity bundles, the 'capability set' in the functioning space reflects the person's freedom to choose from possible livings".

Thus, capabilities are "the real, or substantive, opportunity that they [human beings] have to achieve these doings and beings" [17].

We can return to the same educational example in the previous section. Professors should conduct their students to potentially achieve the expected functionings of the political pedagogical project. Bearing in mind that these students have a potential different set of achievements (e.g. achieved functionings), it is possible some students may (or not) have a vector of functionings necessary to achieve what is required by the program. If this vector of necessary functionings exists for students, we say they have capabilities for it.

Let us materialize with a concrete example. Anne, Bill, and Carla are three students that know how to develop programs satisfactorily. Anne and Bill know the Theorem of Pythagoras, but Carla does not know. The professor asks them to create a program that returns the distance between two points in a Cartesian plane after receiving the four coordinates as parameters. In a naive analysis, Anne and Bill have the capability for it, but Carla has not. Even if Bill does not want to develop what the professor asks him, Bill continues to have this capability. He has the freedom to do it if he would want. It does not matter if he did or not when we conduct a capability analysis.

We will complicate this situation more. Imagine that Anne wants to develop the program, but she does not have a computer in her home. She is in the middle of a critical wave of cases during a pandemic scenario like the COVID-19[16] one. In this aggravated situation, she does not have the capability to do it. Anne has two limitations: she does not have a computer (resource), and can not go to the lab in her university (mobility). A complete capability analysis needs to consider the complexity and multidimensionality of the equity issues can achieve.

To encompass this complexity that a capability analysis should have, Sen also establishes the concept of conversion factors (see Section 4.2).

[16] COVID-19 stands for Corona Virus Disease (2019).

4 Social Factors

> Professor Jirafales is so happy with the use of WebLogisim in his classroom. He realizes that there is tremendous enthusiasm among his students in general. Many students like to attend his classes and often correlate the subject to the possibilities to be explored in the OLEE. The students complained about overloading activities, but they approved the adoption of OLEE.
>
> However, Prof. Jirafales is concerned about a difficult challenge. One of his students, Quico, grumbled about the graphical interface of WebLogisim. The color contrast is not so good, and this fact interferes with correctly identifying some logic gates, leading him to confuse OR and XOR gates. Quico[17] is color-blind and loves to use WebLogisim. But this causes frustration, forcing him to take more time to do OLEE homework than his classmates. What should Prof. Jirafales do?

Although our teaching plan can be designed carefully, it is possible that some new (and challenger) demands can arise. Prof. Jirafales did not know about the existence of color-blind students in his classroom. Groups in disadvantaged conditions must be considered previously in an equity analysis. We will present, as follows, the relations between equity and social factors (Section 4.1) and the definitions of conversion factors (Section 4.2).

4.1 Equity and Social Factors

As mentioned in Section 2.2, a difference can become a privilege depending on how it is interpreted in a given group. Color blindness becomes a disadvantage when all things are designed primarily from the perspective of non-color blindness. An OLEE that does not follow the WCAG[18] guidelines has a higher risk of leading color-blinded students to unequal learning opportunities.

? Social Factors Question 1

Is any student group disadvantaged compared to others due to OLEE use?

The differences among students concerning their income can also become a privilege. If a student can not afford the OLEE use license, there is a masked digital divide of access here. This scenario divides the classroom into two groups: the first can pay for the OLEE use, and the second can not. This difference provokes an inequality of learning opportunities in an engineering class.

[17] Quico is the son of Doña Florinda and a late naval captain. The Chespirito sitcom presents him as a spoiled and overprotected 9-year-old boy.

[18] WCAG stands for Web Content Accessibility Guidelines (see `www.w3.org/WAI/GL/WCAG20/`).

4.2 Theorizing about Equity: Conversion Factors

An illustrative example helps us to understand a deeper discussion about resource provision. Fig. 3 presents a man facing difficulties to see over the wall[19]. Although he has a bunch of stairs at his disposal, he does not make use of them appropriately. There is an expression in the figure asserting that: "It doesn't matter how many resources you have... if you don't know how to use them, it will never be enough". The resource possession can not be enough to convert it into the expected benefit.

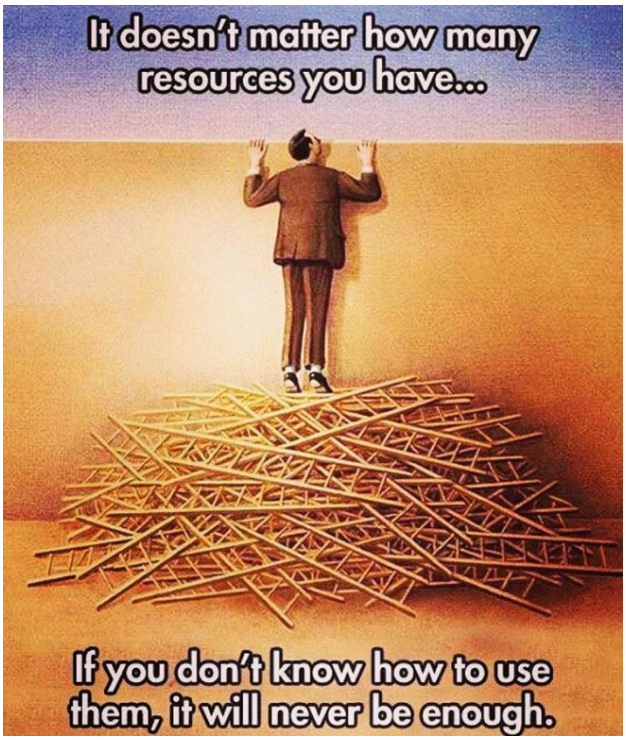

Fig. 3 Illustration showing that the resource possession can not be enough to convert into the expected benefit.

Sen [18, p. 37,38] asserts that there are conversion factors to be considered during a capability analysis:

> "The resources a person has, or the primary goods that someone holds, may be very imperfect indicators of the freedom that the person really enjoys to do this or be that. [...] The personal and social characteristics of different persons, which can differ greatly, can lead to substantial interpersonal variations in the conversion of resources and primary goods

[19] Unknown authorship. The illustration is available in `www.reddit.com/r/brasil/comments/8l4qyp/dont_matter_how_much_resources_you_have_if_you/`

> into achievements. For exactly the same reason, interpersonal differences in these personal and social characteristics can make the conversion of resources and primary goods into the freedom to achieve similarly variable".

Robeyns and Byskov [17] categorizes the conversion factors into three groups: personal, social, and environmental.

Personal conversion factors "influence how a person can convert the characteristics of the commodity into a functioning" [16, p. 99]. I can list as examples of these factors as metabolism (Do you have thyroid problems? Are you old or young?), physical condition (Are you tired? Are you disabled?), sex (Are you a woman? Are you a transgender?), reading skills (Do you know how to read? Do you know how to read English?), and intelligence (Are you competent at this? Do you have all the pre-requirements for it?). Requesting engineering students to do a reading task, for instance, can face the problem if they are well-nourished. If they are not, we should ask ourselves what (and how) may we require of them even knowing their food vulnerability to respond to our requirements adequately?

Social conversion factors are directly related to the society in which people live. I can list as examples public policies (affirmative actions, minimum income), social norms ("boys dress blue, girls dress pink", handshaking), discriminating practices (racism, homophobia), gender roles ("ladies first"), societal hierarchies (monarchy, patriarchalism), and power relations (professor-student, boss-employee). Requesting engineering students to do an OLEE task on Saturdays, for instance, can face religious barriers. If you have one that is a member of the Seventh-day Adventist Church, for instance, this student can allegate impossibility to do this therefore Saturday is a holy day for them.

Lastly, environment conversion factors "emerge from the physical or built environment in which a person lives" [17]. I can list as examples climate (arid, rainy), geographical location (rural, urban), proneness to natural disasters (earthquake, hurricane, flooding), and availability of natural resources (river, wood). Requesting engineering students to do an OLEE activity immediately after a hurricane hit, for instance, can be unfeasible and, by consequence, they would not have the capability for it.

I conclude this section with another Sen [18, p. 38] assertion about conversion factors:

> "If we are interested in the freedom of choice, then we have to look at the choices that the person does in fact have, and we must not assume that the same results would be obtained by looking at the resources that he or she commands. The moves towards resource-based interpersonal comparisons in contemporary political philosophy (such as those of Rawls and Dworkin) can certainly be seen as taking us in the direction of paying attention to freedom, but the moves are substantially inadequate. In general, comparisons of resources and primary goods cannot serve as the basis for comparing freedoms".

Equality of opportunities involves resources, but not only. The CA approach provides us with a possible common vocabulary to analyze equity issues from different theoretical standpoints. After this discussion, we can define equity as the equality of capabilities. The challenge is identifying the crucial capabilities in an engineering education program and proposing policies to guarantee them.

5 Final Remarks

This chapter discussed the equity aspects of adopting online laboratories in engineering education. We used the digital divide and the capability approach as a theoretical reference, providing practical examples of potential scenarios for engineering education practitioners and researchers. We summarize, as follows, a small list of four questions discussed here to guide you in an initial equity analysis considering the adoption of OLEE.

Guiding Questions to consider Equity in OLEE adoption

1. **Access Dimension**
   - Are there alternatives to learning in case it is impossible to access the OLEE (e.g., a physical lab version)?
   - Does my student (or other essential user) have real conditions to access the OLEE outside of university?
2. **Literacy Dimension**
   - What are the desired skills and competencies that an undergraduate should have to use my OLEE fully?
3. **Social Dimension**
   - Is any student group disadvantaged compared to others due to OLEE use?

Each educational context is unique and needs to be considered in its singularity. We hope that the whole discussion presented here, including the theoretical foundations, can be helpful to you when conducting the equity analysis at your university. Involving all educational stakeholders in this process is fundamental to promoting equal opportunities in your engineering program.

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