Board 337: NSF RED: Opening Student Pathways Through the Capability Approach

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NSF RED: Transformative Change through the Capability Approach

Abstract

One of the future challenges facing academic disciplines—traditional STEM as well as the social sciences and humanities—is how to prepare students to address complex socio-technical problems that require a range of disciplinary perspectives to address. The National Science Foundation RED project at Bucknell University is focused on enabling students to gain a more intersectional engineering education by expanding individual pathways for students through an electrical and computer engineering degree program. Towards this end the department undertook significant curricular reform prior from 2014 to 2017 to seeking support from the RED program in 2019.

While there has been much discussion of student pathways, the concept is likely under-theorized; that is scholars have difficulty coherently and concisely defining it, and it lacks a commonly agreed upon framework. To better align the difficult work needed to expand student pathways through a curriculum in the highly constrained structure of most engineering degree programs, the Bucknell RED project utilizes the capabilities approach as a theoretical framework. In the capability approach the freedom for individuals to develop capabilities they value is viewed as both the means and end of development. Individuals convert their capabilities—which are real and accessible opportunities—into functionings they have reason to value. Functionings are societally recognized achievements that have real value. The capability approach is used across many disciplines in areas of human development. In the space of engineering education, the capabilities approach shifts the discussion from educational outcomes as the sole goal to additionally include opportunities (capabilities) and achievements (functionings).

This poster presents the results and process by which the capabilities approach framework was specifically adapted for an engineering degree program to create a list of student capabilities. Capabilities are identified at multiple levels, from general human capabilities to those specific to engineering students. The ways the capabilities intersect with the rest of the curriculum is highlighted as are how the capabilities approach can be used to highlight barriers to pursuing a wider array of curricular pathways.

Introduction

The National Science Foundation RED grant program was designed to make revolutionary changes at the department level in engineering programs. When talking about change, people often consider changes on a spectrum from "revolutionary" to "evolutionary", depending on the degree of change they introduce and its impact on existing paradigms, systems, or knowledge. On the revolutionary end of the spectrum, changes are broadly agreed to have several common characteristics. First, revolutionary ideas often result in a paradigm shift, fundamentally changing the prevailing systems, theories, or beliefs in a field [1]. Second, revolutionary ideas have the potential to disrupt the status quo, challenging and often displacing existing

methodologies or beliefs by introducing new frameworks and ways of thinking that were previously unimaginable in a given domain. Third, such ideas have the potential for wide-reaching impact with effects that are felt broadly and deeply. Fourth, in the domains they affect revolutionary ideas have novelty, presenting solutions or concepts that break from conventional wisdom or practices. Ideas towards the evolutionary end of the spectrum focus more on incremental improvement, maintain continuity with the past, have more localized or specific impact, and are compatible with existing systems or beliefs. These distinctions are nuanced. Ideas that are revolutionary in one context might be evolutionary in a broader or different context.

Here we report on progress on developing the ideas underlying the NSF RED Project *Enabling Convergence in Undergraduate Engineering through Structural Change* which is seeking revolutionary impact by proposing an alternative to the dominant engineering education paradigm of outcomes-based education. In this project we have adopted the framework of the capability approach [2], [3] which was developed in economics by Amartya Sen as an alternative to GDP-based models.

The Capabilities Approach and Outcomes-Based Education

The capabilities approach represents a paradigm shift in assessing human well-being and development away from societal/economic metrics like GDP to more individual measures. Central to Sen's framework is the idea that development should be measured not merely by economic growth or income levels, but by the expansion of individuals' freedoms to lead the kind of lives they have reason to value [2]. In this framework *capabilities* are defined as the substantive freedoms or opportunities to achieve various valuable states of being and doing, such as being healthy, having access to education, and participating in community life. Individuals who have real access to capabilities choose how to convert them to individualized *functionings*, which are defined as the achievements individuals have chosen to attain based on the capabilities they have access to.

The capability approach framework is inherently flexible, allowing for the identification of relevant capabilities based on context and individual valuations. This is both an advantage in that it is widely applicable, and a disadvantage since it needs to be interpreted for various contexts. The capabilities approach has found applications across a broad spectrum of disciplines, including economics, philosophy, social policy, and development studies since it is able to address complex issues of human development and social justice. Although the application domain of capabilities/opportunities is broad, applying the capability approach to a specific context requires considerable work to place the lives of individuals into the broader structures that affect their lives [3].

In this paper the authors apply the capability approach as a framework to reconsider program metrics and actions in engineering education with the goal of creating more flexible pathways through engineering degree programs. This paper presents one aspect of this work,

understanding student capabilities. Throughout the rest of the document will be use the word 'opportunities' instead of 'capabilities' (the more formal term) since it frames the issues in a way that is more approachable and understandable for engineering educators. Other authors have extended Sen's framework to education by creating lists of opportunities [3]-[6]. This work builds upon this based by: 1) devising general sets of universal opportunities students should have in order to attain achievements in an electrical and computer engineering degree program, and 2) devise specific condition- or context-specific opportunities. The rest of this paper focuses specifically on the process the RED team used to develop draft sets of opportunities for undergraduate engineering education in a particular program and institution.

Before looking at capabilities as an alternative to the current outcomes-based education framework used to structure and guide activities in engineering education it is worth quickly reviewing the major points of the dominant current paradigm. The origins of outcomes-based education dates back more than sixty years, but came to prominence in the 1980s, focusing attention primarily on the outcomes or outputs of the education process. Outcomes-based education has certain characteristics that have informed education practice and policy from the primary to higher education spaces, with particular variants in engineering education. One of these is a focus on accountability (e.g. *No Child Left Behind* in 2001) and standards (e.g. *Common Core* in 2010s) that makes programs responsible for learning outcomes. Another aspect is a procedural focus, which is exemplified by ABET through its emphasis on iterative program improvement. The continual quality improvement movement from which these ideas are drawn arose in the 1980's due to concerns about competitiveness of the US economy and is adapted from industrial continual quality management methods such as ISO 9000, Six Sigma, and Kaizen. Another aspect of outcomes-based education is that the unit of analysis is the program or sub-elements of it. This focus on the program can emphasize the intended curriculum rather than the received curriculum. The intended curriculum is what programs believe that students learn rather than what is actually experienced by students. The wide adoption of the outcomes approach in engineering education is likely due to its alignment with engineering epistemologies [7], [8].

The capabilities approach, on the other hand, shifts the unit of analysis to the student, looking not just at the outputs of education processes, but also considering the inputs by defining them as substantive opportunities, which are termed capabilities since they represent a person's real options for living a life they personally value. This is illustrated below in Figure 1, showing how students have different access to opportunities (capabilities) prior to arriving college, convert their existing opportunities to societally-recognized achievements (functionings) in college which then provide access to a life they personally value. From this perspective college not only serves to help students generate achievements, but also to point out alternative life pathways students might have reason to value.

In this model, which will be expanded upon and formalized later, the authors have initially focused on understanding and defining capabilities or opportunities. To identify potential opportunities the authors began with a significant literature review as part of a weekly book club

to familiarize ourselves with the literature around the capability approach, and to and understand the evolution of the capabilities approach over time. We started off with Amartya Sen's *Development as Freedom* [2] as grounding literature, created a shared Zotero repository of papers we discussed (c.f. [9], [10], [11], [12]), and read Robeyn's *Wellbeing, Freedom, and Social Justice* [3] since it provided a comprehensive overview of the capability approach.

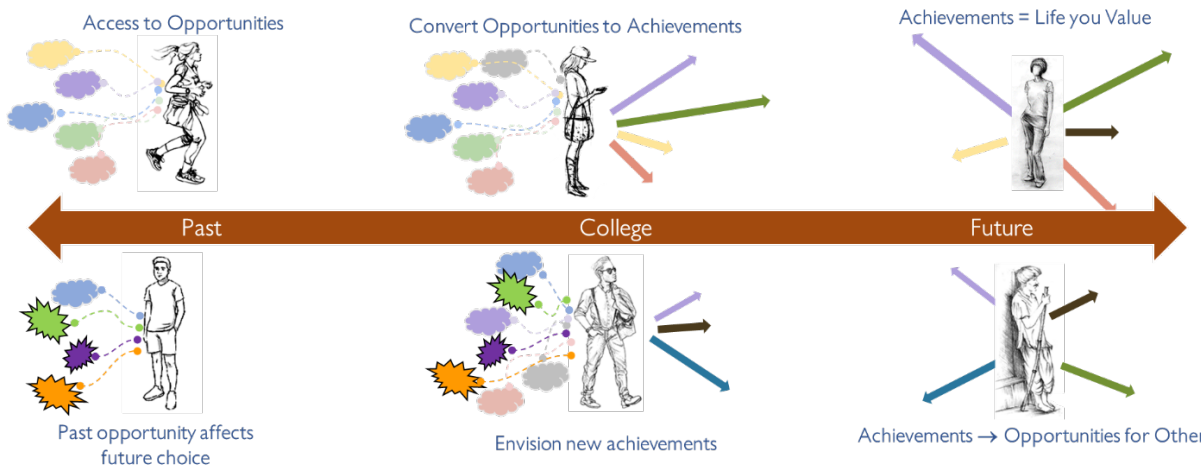

Figure 1: Illustration of the capability approach in terms of looking at past access to resources and opportunities (shown as cloud shapes), a student's time in college as converting opportunities to achievements (vectors), and how achievements results in future freedoms.

Adapting the Capabilities Approach to Engineering Education

A key part of the process of developing opportunities was coming to a shared understanding of the various terms used in the capabilities approach. The language varies between authors and can be somewhat daunting since meanings of terms have changed over time. An additional issue is that the capability approach is designed to encompass many disciplinary perspectives. While the ability to align definitions with particular contexts is a strength of the framework, it was important for the authors to adapt terminology to develop a contextually relevant understanding.

The list below provides a high-level description of the core elements of the capability approach. The relationship between these elements will be further articulated later (see Figure 3). We have adapted the language used in the literature, replacing the term 'capability' with 'opportunity' and 'functioning' with 'achievement' since this makes the framework more approachable for engineering educators. The list below comprises our working definitions:

- *Opportunities* (capabilities) are a person's real freedoms or affordance to achieve a life they desire, including their capacities—both innate and learned—and the beings and doings that contribute to their identity.
- *Outcomes* are included since they represent the current paradigm. They are educational milestones that reflect goals of the program and processes students go through in engineering education.
- *Achievements* (functionings) derive from the opportunities a student has and the outcomes they achieve. Achievements result from opportunities that have been selected and

pursued because they are seen to contribute to a valued way of living. Achievements are often externally recognized.

- *Resources* include money, time, shelter, goods & services, etc. that enable the development of capabilities and are consumable or usable to create opportunities.
- *Conversion Factors* either help or inhibit the transformation of resources into opportunities and/or achievements that are value-neutral and vary from person to person. Conversion factors may be categorized as:
  - Personal (innate interests, cognitive & physical abilities, personal histories, etc.)
  - Social (prior education, social groups, extended family knowledge and support, etc.)
  - Environmental (country of origin, pollution, etc.)
- *Structural Factors* enable or inhibit opportunities and/or achievements such as legal, policy, social norms and value system, etc. These may include structural barriers or affordances, and may impact different individuals differently.
- *Agency* is implicit in the capability approach (see Figure 3), and captures an individual's interest in pursuing particular achievements. Agency determines which opportunities are capitalized on and is affected by the options open to a student, their learning preferences, and choices in which achievements to pursue to support a life they desire to live.

Once the RED team had a working set of definitions for the context of our engineering education program, we set out to explore the inputs to the capability approach framework, focusing on the opportunities afforded to students. Opportunities are the basis of the capability approach since expanding real opportunities leads to more freedoms and eventually societal development. There is a significant debate in the literature about the value and utility of creating lists of opportunities [3]. Creating a list that focused on opportunities students needed to succeed in an electrical and computer, however, seemed the most direct method to begin to understand how the capability approach could be applied in an engineering education context.

To begin the process of defining opportunities, the RED team brainstormed both inductive and deductive ways to identify particular opportunities. Twenty-seven ideas were generated, including drawing from existing opportunity lists, deriving opportunities from student and faculty interviews, determining opportunities from existing engineering education literature, using engineering education guidelines such as ABET criteria and KEEN, and looking at institutional mission statements. These approaches were divided up among the group and each person developed lists of possible opportunities from these sources. To capture the large number of opportunities generated, each participant set up a separate worksheet on the common Miro board, and created opportunity lists from literature in the area(s) they had volunteered to review.

As we reviewed the literature on opportunities, we realized that many of the existing opportunity lists were focused on very broad, or high-level aspects of human existence. As our goal was to understand specific opportunities in our institutional degree program that were available or missing for students, we needed to develop a more nuanced and hierarchical understanding of opportunities, something that was not addressed in the existing literature base. After several false starts we arrived at an ecosystem metaphor we dubbed the “prairie grass” model shown in Figure 2.

The prairie grass metaphor draws from the ecological observation that in challenging environments plants develop root systems that allow them to draw water and nutrients from different levels of the soil depending on specific environmental conditions at a given point in time. While the shallow root system is high density and provides the most water, the deeper roots allow the plant to survive in times of drought. The deepest level in this metaphor corresponds to core opportunities such as those identified by authors such as Nussbaum [4] and Sen [2]. At the middle level are opportunities relevant to higher education such as those developed by Walker [13]. At the shallowest level are engineering education and institution-specific opportunities. This ecosystem model has proven extremely helpful to the RED team in developing and characterizing opportunities.

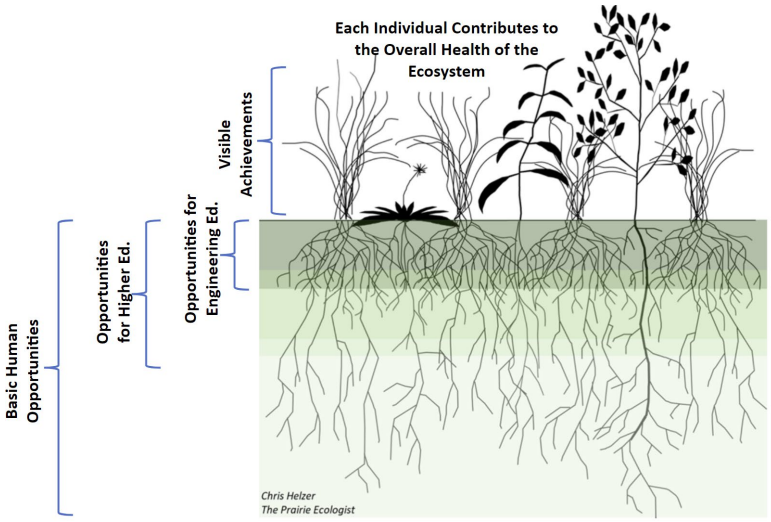

Figure 2: The prairie grass model derived from considering our degree program as part of a higher education ecosystem. The image is from [14].

Once candidate opportunities were identified, each member of the team put them on a virtual post-it note in Miro. As some of the candidate opportunities stimulated new ideas, new post-its were added in an *ad hoc* fashion during this brainstorming phase. Through several rounds of iteration, the group interactively reorganized candidate opportunities into similarity groups. Once groups were established to everyone's satisfaction the grouping were summarized, defining a specific opportunity.

The above process is subject to biases and omissions since the knowledge and experience of the faculty members involved strongly influenced how the opportunities were defined. We observed that since the team was experienced educators but relative neophytes to the opportunity approach, the list of opportunities that was created used language common to outcome-based education. Opportunities, however, are not what students can do, but rather what they are actually empowered to pursue based on their life circumstances. This difference, which is central to the capability approach, has two key aspects which are central to the revolution in engineering education we are trying to foment. First, an outcome can be required by a program without providing a correspondingly accessible opportunity. Second, even if an opportunity is available, the degree of attainment of the outcome is dependent on student interest and choice. The RED team adopted the capability approach out of a desire to understand and provide needed opportunities to students. Elucidating opportunities was more difficult than anticipated

due to the depth to which outcomes-based education habits and mindsets are embedded in our thinking. The oldest member of the team, who obtained his undergraduate degree in the 1980's, was in college when continual quality improvement was adopted and entered a tenure-track position about the time EC-2000, ABET's CQI-based criteria, was implemented. The authors note that the entire current generation of engineering educators have foundational assumptions about education that have been strongly influenced by outcomes-based education paradigms.

Defining Capabilities

To explore the more comprehensive and student-focused model represented by the capability approach, the RED team spent a significant amount of time framing opportunities in a way that could distinguish them from outcomes. In the work done to date, the RED team has defined opportunities for students in an undergraduate engineering degree program. We have not yet focused on identifying opportunities for faculty or staff, although a similar exercise is planned in the future. To identify opportunities, we drew from the literature cited previously to set up a list of criteria that helped us distinguish opportunities from outcomes. This list is neither comprehensive nor inviolable; the capabilities approach is normative in character and implies flexibility [15]. The following list of the characteristics of an opportunity was used as a mental aid to enrich discussions of possible opportunities:

1. The "unit of analysis" for the opportunity is an individual student and the opportunity is accessible to an individual student.
2. Opportunities are articulated in a way that enables future achievements or provides some potential advantage to the student in a relevant context.
3. The opportunity should be ideally mapped on to a structural element of the institution that supports its attainment. This is more of an aid to understand what partnerships are needed to create actual opportunities.
4. The opportunity is phrased in a value-neutral way. Although we as faculty may disagree whether the opportunity (or achievement derived therefrom) will benefit the student, discipline, or society the capability approach prioritizes individual agency and choice.
5. Has value as an end in itself rather than (or as well as) as a means to an end.
6. Form core elements or a basis set for future achievements; that is opportunities can combine with each other to lead to a range of achievements that are relevant in the context of an engineering education degree program.
7. Opportunities require agency or initiative to take advantage of, and this agency may vary between people. In other words, an opportunity is not a curricular requirement that is mandated for all students.
8. The presence or lack of an opportunity can identify social class, privilege, advantages, benefits, or special rights that a person may enjoy due to their social status, position, or circumstances that may be outside their control.
9. The opportunity is also an affordance, that is it suggests how it could or should be enabled, or be needed for, pursuing a desired achievement or identifying new directions for personal development.
10. An opportunity is not an outcome (what a student can do) or content (what students are expected to know).

To briefly recap, once the RED team developed a working definition of opportunities, we engaged in multiple rounds of conversation to create draft sets of opportunities that were derived from multiple relevant sources. The opportunities generated this way were often overlapping and many were phrased as outcomes, so we worked to refine them and reduce the overlap. The next step was to follow the ecosystem model and start at the deepest, most fundamental level and build upwards, first to higher education opportunities then to engineering education-specific opportunities. We started with 15 core opportunities for living in the United States drawn from various sources for the base, or deepest, level in our prairie metaphor shown in Figure 2. From there we populated the higher education level with 32 opportunities which were then clustered together and mapped onto the base opportunities from which we believed they derived. We pre-populated the shallowest engineering education level with 34 hypothesized opportunities and again mapped them to the opportunities at the higher education level to help group them, show dependencies, and reduce redundancy.

At this point in time the RED team has developed extensive, yet incomplete, lists of opportunities at the different levels articulated in Figure 2. Table 1, below, is a partial list of these outcomes for illustrative purposes. Here we focus on education-related opportunities since basic human capabilities have been well-described in the previously cited sources on the capability approach. Opportunities at the university level have to do with institutional values and support for students. Those at the level of engineering are more specific to the College of Engineering and all engineering students, while those at the program level are under control of faculty in the department and affect students in the major. As can be seen by this illustrative list, creating opportunities relies upon other entities and thus serves as a guide for partnerships.

Table 1: Illustrative list of opportunities developed from RED effort.

University Level	Engineering Level	Degree Program Level
Provide real and substantively supported opportunities to:		
• recover from failure; • access to and inclusion in peer social groups; • coordinate employment and academics; • have access to role models and mentors and time to build meaningful relationships; • have return on investment for degree; • sufficient nutritional meals; • disengage and re-engage as needed per your own life circumstances without penalty; • protection from abuse, maltreatment, harassment; • access affordable health care; • be in an environment that allows one to manage and work through emotional issues; • be one's authentic self in all spaces; etc.	• work with students from different disciplinary backgrounds; • gain access to engineering beliefs and epistemology; • understand differences and commonalities between disciplines; • obtain then use knowledge relevant to the discipline, particularly mathematics; • obtain relevant internships; • engage in leisure activities outside of engineering; • access to cultural norms; • build a relevant set of experiences that affirm engineering as worthwhile; • be in an engineering community that does not tolerate harassment, bullying, etc.; • obtain relevant technical work while a student; etc.	• develop skills in programming; • manage a project; • understand ECE in a societal context; • have open access to facilities; • be a creator; • build friendships, trust, and belonging with those in the major; • transfer learning by experiencing multiple contexts; • have transparent and equitable assessment practices; • develop an engineering identity appropriate to one's goals, culture, and background; • study abroad or experience engineering outside the classroom; • schedules & curriculum flexible to accommodate student life circumstances; • learn about alternative career pathways; etc.

The list of opportunities in Table 1 highlights factors that contribute to students' ability to choose to (or choose not to) develop achievements that enable them to live a life they desire. However, when we talk about educational opportunities in comparison to educational achievements it is important to emphasize that education is both an opportunity and an achievement. Since there has been considerable debate about education in the capability approach literature–i.e. is education an opportunity, an achievement or both–the RED team clarified the relationships by laying out the model shown in Figure 3. This model is similar to a more generalized representation of the capability approach articulated by Robeyns [3], but explicitly includes academic elements that are intermediate between the opportunities which lead to achievements in education. Although learning is complex and individual, to simplify the model we identified two broad learning pathways that represent different pedagogical styles in our curriculum: coherence and correspondence. Coherence is teaching students to continue refine their understanding of, and relationship to, their environment and is aligned with contingent and social/human forms of doing and knowing and is the left branch under opportunities. Coherence aligns with students becoming their future selves and incorporates mindsets often attributed to 'designerly ways of being' [16], [17] and is shown by the right branch. Correspondence, on the other hand, teaches students to create valid mental models of an objective reality aligning with necessity and more scientific/theoretical forms of knowledge and skill.

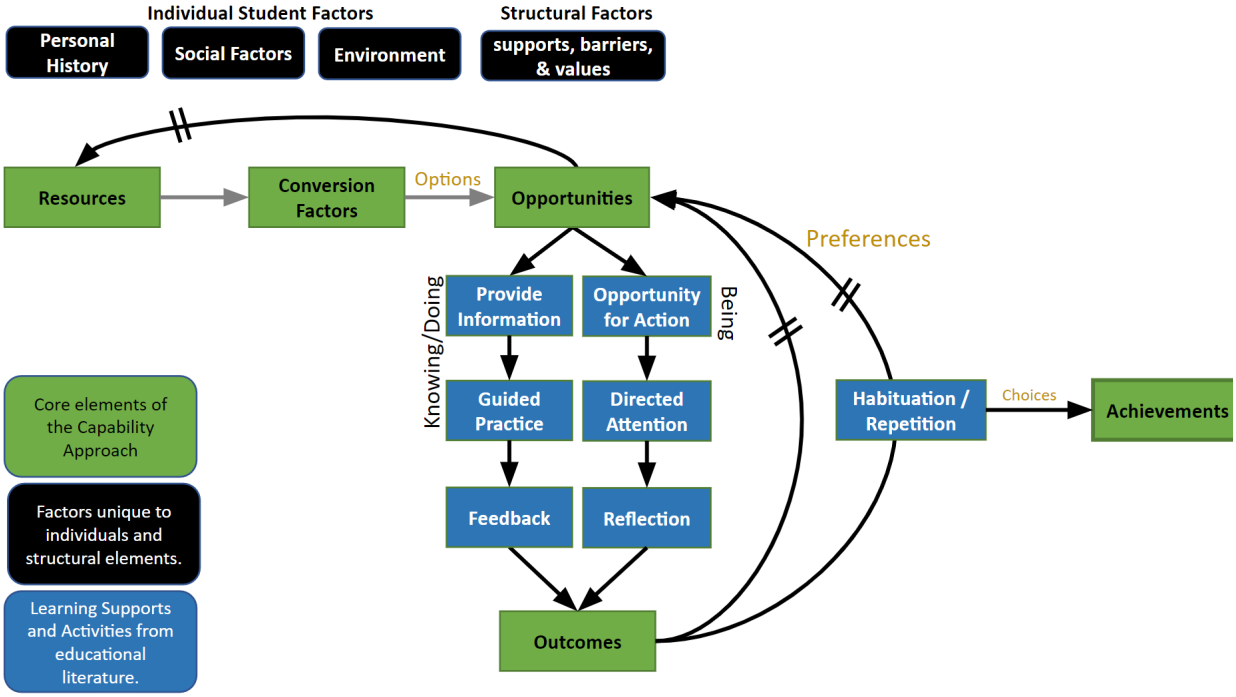

Figure 3: Adaptation of the capability approach to engineering education. The green boxes are the core elements while black boxes represent supporting or mitigating factors. The blue boxes adapt the capability approach to the higher education domain.

Each box in Figure 3 can be thought of as a repository for different factors that affect a student's progression through higher education to achieve a life they desire. Table 2 lists some factors in the opportunity box of the model. The "factors" that go into these categories are highly

contextual, relational and defined by action, and may move from one category to another in different scenarios. The goal is not to classify student characteristics, experiences, identities, or activities into bins, but to develop a language to describe the processes that enable or inhibit real freedoms in the engineering education space.

Additionally, we put educational outcomes in the interstitial space between opportunities and achievements. Outcomes are program goals that serve as proxies for things a student can do, but they are not achievements since the student may not now, or ever, find value in an given educational outcome. Additionally, internal curricular outcomes are not necessarily recognized outside an educational institution. This is not to say outcomes are not important. Outcome can guide program decisions, serve as ways to articulate and measure program efficacy, and serve as markers on the way to achievements. Rather as shown in Figure 3 learning processes result in outcomes which in turn serve to support additional opportunities or, if they reflect student preferences, can be reinforced through repetition into habitual ways of being which serve as educational achievements. Figure 3 is intended to clarify that both opportunities and outcomes are needed to develop the habituated behaviors that lead to achievements and thereby enable students to live a life they value. An assumption inherent in the model of Figure 3 is that unless educational outcomes are chosen by a student and the student is given opportunities to reinforce the outcome it does not result in an achievement.

Future Work

At this point in time the RED project continues to refine the list of opportunities that support pathways to becoming an engineer through surveying students, composing an 'opportunity audit' for campus offices and organizations, and further learning about opportunities in our campus environment. The project is also shifting our focus to the achievement end of Figure 3 to develop a similarly research-based and nuanced understanding of achievements and how they are distinguished from outcomes.

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