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A Critique of EC 2000 from Amartya Sen's Capability Framework

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EC2000 Viewed through Amartya Sen's Capability Framework

Abstract

Most engineering programs in the United States are accredited by ABET under the guidelines known as EC-2000. The EC-2000 framework is broadly based on the continual quality management (CQM) movement in industry where programs are striving to constantly improve the quality of their output, in this case the skills of graduates. Broadly speaking, ABET evaluates engineering programs on eight different criteria; some are related to processes, some to resources, but those central to CQM are program educational objectives, that define hoped for long-term accomplishments of graduates, and outcomes which articulate what students can do when they graduate. Degree programs must convince ABET they have a documented and effective process to improve outcomes to gain accreditation.

CQM of course is not the only framework by which educational development can be framed or measured. This paper explores ABET processes through the lens of the economist Amartya Sen's capability approach, which is broadly applied in the developing world in areas of inequity, poverty, and human rights. The capability approach is often used when a focus on diverse individuals is desirable for understanding aspects of development. Central to Sen's approach are capabilities and functionings. Capabilities are the resources and supports in an individual's environment that provide opportunities to pursue a life they value. Functionings are what they actually become and do. Thus capabilities can be thought of as the potential for functionings; alternatively capabilities are opportunities and functionings are outcomes. This paper compares ABET's accreditation criteria with a published set of capabilities in education. The comparison shows there are some areas where criteria overlap with capabilities, but also several areas where the overlap is low. The capabilities that aligned most with ABET criteria overlap with engineering epistemologies and a view of students as the 'product' of engineering education.

Introduction

Most engineering programs in the United States, and many globally, are accredited by the Accreditation Board for Engineering and Technology (ABET). ABET is a national, not-for-profit 501(c)(3) organization [a] that maintains and modifies the criteria for engineering, computer science, and engineering technology program accreditation. ABET has an annual revenue of almost $13M (2020 IRS filing) from accreditation fees, but is structured as a primarily volunteer organization with individuals donating their time to serve as the evaluators of degree programs or on an oversight board with representatives from many engineering societies [b]. ABET was initially established in 1932 as the Engineers' Council for Professional Development and renamed to ABET in 1980. Based on pressure from large engineering industries who saw that engineering graduates lacked some characteristics needed to thrive in changing workplaces [1], around the year 2000 ABET significantly revised its accreditation criteria. Prior to the revision, criteria had little flexibility and the one-size-fits-all approach was perceived as an exercise in box-checking [2]. Based on the work and influence of a small group of insiders, ABET responded to the pressure from industry by releasing revised accreditation guidelines, commonly known as EC-2000, around the year 2000 which adopted ideas from industry and global business that in turn came from the ongoing shift towards supply-side economics and neoliberalism.

Over the ensuing decades the EC-2000 framework has been modified numerous times, but the core ideas underlying EC-2000 have not changed. ABET itself has grown; at the time of this writing there are over

2,200 volunteers and 35 professional societies who accredit 4,564 programs at 895 colleges and universities in 40 countries through campus visits on a nominally six year cycle [c]. Because of the consequence of accreditation and growth of ABET—there were 3256 accredited programs in 2010 [d] corresponding to a 2.9% compound annual growth rate—it has exerts significant influence in engineering education. Because of this influence and the ability to set standards engineering faculty are sensitive to changes in accreditation practices. In the past, changes to ABET policies have received strong pushback [3] from members of the engineering education community. While putatively focused on accreditation, ABET, like any entity that sets educational policies and practices, cannot remain fully outside the continuing political dialogs.

This paper engages in this space of educational policies and practices, approaching the practice of accreditation from the bottom-up by examining the philosophical foundations of EC-2000 and contrasting these to another framework that is emerging within the space of economic development. In terms of organization, the paper first undertakes a quick review of the EC-2000 framework; only a brief summary is provided since there are many good works that explore this topic in depth [1], [2], [4]. Next the 'philosophy' of quality improvement, on which EC-2000 is broadly based, is outlined with a brief history of the events that led to wide-scale adoption. Here we use the term philosophy as Rescher [5] describes it, a form of rational questioning to try to better understand the meanings underlying the events and structures that shape our lives. Such inquiries are worthwhile since one of the foundational assumptions of this paper is that systems left to themselves rarely evolve beyond the boundaries of their starting assumptions without a great deal of external pressure. Thus to understand the limits of what engineering accreditation can and cannot do it important to understand its implicit assumptions. Next the paper discusses an alternative framework to quality improvement, the capability approach, drawn from Amartya Sen's work on economic development [6], [7] and expanded upon by the philosopher Martha Nussbaum [8]. Finally, ABET accreditation is compared with the capability approach to contrast how different starting assumptions highlights areas current accreditation practices are both perceptive of and potentially blind to with regards to the structures, processes, and actions that comprise engineering education.

In undertaking critiques of established organizations and processes it is important to remember that behind ABET the organization are the people of ABET who deeply believe in the importance of accreditation; many of whom volunteer significant amounts of their own time. Critiques also suffer from the limitation that systems-as-they-are such as ABET establish policies and procedures based internal logic informed by events and information that may not be available to outsiders. Additionally, one's own positionality with respect to what is being critiqued should be clear. The author has managed ABET accreditation within an engineering department for nearly two decades, served as an ABET evaluator for over five years, but is not involved at the higher levels at which decisions are made.

EC-2000 and Continual Quality Management

As has been well documented by historians of engineering, the EC-2000 framework which forms the basis for modern accreditation in engineer is broadly based on the continual quality improvement (CQI) movement in industry [1]. EC-2000 is not the first, nor likely will be the last, shift in engineering education policy; engineers have a long history of self-analysis of educational programs with regular release of policy reports seeking to shift its emphasis and direction [1], [9], [10]. While this history informs current accreditation practices, the relevant history to this paper begins prior to the late 1990's with the trade imbalances with the Carter and Reagan era trade imbalances with Japan which were captured in the popular imagination by movies such as the 1986 Ron Howard directed film "Gung Ho" about the shut-down of a Japanese-owned auto plant in Pennsylvania. Such concerns about national competitiveness led to scrutiny of the processes that produced engineering graduates with much of the focus on accreditation, particularly the much maligned "bean counting" approach that was widely viewed as inflexible since it focused on inputs and prescriptive criteria [2]; such inflexibility made accreditation seem a waste of time for well-resourced programs and a significant burden for under-resourced ones. With support from the National Science Foundation, various stakeholder groups participated in workshops which informed the shift to EC-2000.

Implemented over roughly a decade, EC-2000 shifted the specific requirements of the prior ABET accreditation process to one in which programs had more flexibility in explaining how they met eight broad criteria required for accreditation. The criteria focused on processes to identify and measure programmatic goals, how the program connected to stakeholders within and outside the institution, the extent to which access to needed resources was available, and additionally set some general curricular goals that programs were required to demonstrate they met. The key difference with the prior detailed accreditation process was to increase flexibility – programs had considerable latitude in defining how they met the eight criteria and how they planned to improve upon their self-imposed metrics. Subsequent evaluation in the years immediately following the roll-out of EC-2000 indicated that changing accreditation processes had in fact enacted changes in how degree programs operated and what they did, even down to the level of the classroom [2], [11].

Broadly speaking, engineering programs are evaluated on eight separate criteria. Some criteria are related to the effectiveness of processes, some to having access to sufficient resources, and others to defining and evaluating compliance of ABET-mandated outcomes. Where continual quality management is most visible is in measuring and evaluating student outcomes to ensure that educational processes meet broadly defined learning outcomes that ABET has deemed essential for engineering. Student outcomes articulate what students can do when they graduate. While currently seven outcomes are mandated, degree programs can define their own outcomes and must further specify the evidentiary standards required to meet the outcomes. One stage removed are program educational objectives (PEOs) that define hoped for long-term accomplishments of graduates; these are informed by internal and/or external program constituents. While more complex and nuanced in practice, at the most basic level accreditation is achieved by convincing ABET (represented in an on-site visit by a trained volunteer program evaluator with follow-on review) that the degree program has documented their compliance with the criteria and they have implemented effective processes to maintain the quality of their program.

Stepping back from the history and processes of ABET specifically, as discussed previously the shift to the current, evaluation-based criteria stemmed from the wide adoption of Continual Quality Management (CQM) principles in American businesses in the decades of and adjacent to the 1980's. CQM is also known as Continual Quality Improvement (CQI) or Total Quality Management (TQM) and instantiated through frameworks such as ISO 9001 [12], Six Sigma [13], and Kaizen [14]. The origins of CQM go back at least as far Taylor's work on scientific management in the 1880's. The importance of standardization became more visible during the Second World War due to issues of cross-compatibility in ammunition between Allied countries. The adoption of standardization systems among militaries expanded during the Cold War in parallel with W. Edwards Deming's work in the 1950's and 1960's which culminated with 14 principles for management to improve effectiveness in the 1982 book *Out of the Crisis* [15]. The movement into the commercial sphere really gained momentum in the 1980's, first in manufacturing and then service-oriented industries.

Using ISO 9000 as an example, CQM system are based on principles that sound simple but can be difficult to execute well in practice. For example, there are eight principles in ISO 9000: customer focus, leadership creating a quality-focused culture, involvement of people across the organization, managing processes to produce results, using a systems approach to management, continual improvement, use of data and analysis to make decisions, and building mutually beneficial relationships with suppliers. Other frameworks have more similarities than differences. Kaizen, for example, includes most of the same principles but puts emphasis on eliminating waste and making small, incremental improvements.

As with all widely adopted systems that make claims for self-improvement based upon adoption, it is very easy to go down a rabbit hole and become distracted by increasing levels of detail and specificity, or to over-interpret guiding principles with almost a religious fervor. Such a focus on interpretation is the opposite of what this paper seeks to do in adopting a philosophical perspective. Rather than understand how to effectively apply the principles of CQM, the goal here is to understand the beliefs encapsulated in CQM and how these affect, often in subtle ways, systems that adopt (elements of) these principles. The claims being made are that: 1) ABET has, and continues to have, significant influence on how engineers are educated; 2) as EC-2000 process was derived from CQM principles, the philosophy underlying these principles affects in indirect but important ways how engineers are educated; and 3) one cannot operate without a framework, but the choice of framework needs to be occasionally re-examined through the changing lens of what a society values.

The Challenge of Quality

Any system or process that makes judgments is based on beliefs, values, and assumptions that underlie the judgments being made. If the judgments are objective the assumptions may be well-supported, for example judgments about the mass of an object are grounded in widely accepted theories about the physical world and methods of measurement. As judgments become increasingly subjective, identifying assumptions is of greater importance if the judgments are 'weighty' as judgments of educational attainment can be. The importance of assumptions is as true of quality-based system as any other since the notion of 'quality' is slippery.

The idea of quality goes back at least to Aristotle's attempt to define categories of classification [16]. One of Aristotle's systems of classification was to define 'highest kinds' or categories corresponding the highest level of generality. Quality is one of the ten 'highest kinds'; others include substance, quantity, and relatives. Each of the highest kinds has subcategories, those for quality include habits and dispositions, natural capabilities and incapabilities, affective qualities and affections, and shape. Other philosophers including Thomas Aquinas also looked to quality as a basis for classification. Quality as used by Aristotle and those who followed focuses on the qualities of an item as characteristics, that is a way to classify it or to create an ontology. However in modern language quality more often is used a basis for hierarchical judgment or sorting – i.e. rating items of higher or lower quality. Etymologically the word 'quality' arises from the proto Indo-European word *kwo* which forms the root of modern words that establish relationships or are interrogative – e.g. question, qualify, qualitative, what, when, where, why. Thus to speak of 'quality' is to establish a relationship with other entities and interrogate some aspect of the entity or object being scrutinized either to sort it to rate it. As the term is used in CQM determining quality implies some sort of rating and thus is an inherently judgmental act.

But what exactly are we judging when we speak of quality? The 'what' is highly contextual and for engineering often of a tacit "I know it when I see it nature". Perhaps one of the best modern attempt to define quality was made by Pirsig in the popular 1974 book *Zen and the Art of Motorcycle Maintenance* [17], [18] which preceded the wide adoption of the CQM movement. Through the context of a cross-country motorcycle trip Pirsig contrasts quality and aesthetics and relates the notion of quality to a deep subjective care for, or engagement with, something that leads on one to see beyond an objects surface features. Quality as a concept allows us to navigate both the objective and the the uncertain and subjective spaces created by postmodernism or to make choices between contingent truths. Quality in Pirsig's sense is also related to the medieval notion of 'crǽft' from which the modern word 'craft' emerged. While the term craft can be used derogatorily by engineers to distinguish professionals from hobbyists, the English king Alfred the Great in the ninth century used crǽft to mean 'the organizing principle of the individual's capacity to follow a mental and moral life' in the context of their work [19]. Arthur the Great's crǽft and Pirsig's notion of quality are close to the sense of quality used in CQM, as a guiding principle that provides a compass which helps navigate unavoidable uncertainty.

From this perspective CQM systems make the assumption that the flexible notion of quality can be defined sufficiently well to make some sort of measurements of a product or service which then inform efforts to improve processes and operations. To reiterate, it is taken as a given in this paper that the assumptions that underlie any system or process impact the operation and results in ways that are important but not always direct or causal; for example one way assumption affects outcomes is through confirmation bias [20]. From the basic assumption that quality is definable, measurable, and can be improved, CQM systems incorporate a series of other hypotheses and assumptions that are outlined briefly below [21]:

a) CQM systems are based on top-down management which then involve all employees in pursuit of quality; it is assumed management can affect positive changes. For example Deming's assertion that increasing quality was a way to increase revenue and productivity simultaneously was based on the premise that "Both reaction chains are driven by top management focusing on the development and propagation of quality throughout the organization." [15] Changes come from top-down to create an environment for quality.
b) Production is accomplished through processes, processes have variation, and excessive variation leads to wastage and rework. Thus CQM systems prioritize similarity and adherence to defined standards. Models based upon 'conformance to requirements' in turn imply that the requirements must be known *a-priori*.
c) Pursuit of quality is both a means to a desired end and an end in itself since quality is perceived to be a 'guiding value'. As both a means and end, the pursuit of quality is a self-sustaining model that operates by showing measureable increases in desired outcomes, e.g. Deming's chain reaction theory [21].
d) In quality-as-means to some other end—usually profitability—the pursuit of quality can either be considered as always cost effective, or alternatively that the costs must be considered [22]. In the second case there is an optimal level of quality. While the optimal levels of quality are highly contingent on context [23] quality still remains the guiding principle.
e) The determination of quality is negotiated between producers and customers rather than being defined a-priori by the producers [24], [25]; it is important to be customer-driven.
f) Quality processes should be externally, as well as internally, validated to determine alignment with best practices.
g) Because pursuit of quality becomes measurable, CQM systems incorporate notions of gamification, hierarchy, and expertise. In the CQM literature experts in CQM are often called gurus and under the Six Sigma model practitioners who lead efforts can become 'black belts' to demonstrate mastery and expertise.

While there is not an exact correspondence between CQM and ABET accreditation processes, each of the assumptions above aligns to some degree with current accreditation practices. In terms of (a) above, ABET puts degree program leadership and faculty in the role of management, responsible for improving the quality of the program. Thus outcomes-based accreditation processes ask 'management' to determine the quality of student learning. To point (b) although the requirements implied by ABET are generally flexible and ABET gives awards for innovation [e], it can be argued that implying equality between degree programs implies some level of conformance. A previous study of accreditation found that emerging and lower status programs are more invested in this perception of equality [26]. ABET's criterion 4 emphasizes continual improvement of student learning, point (c). The assumption of sustainability—point (d)—is inherent to ABET processes but interviews with faculty involved with ABET show they struggle to find an optimal level of effort in accreditation activities. Furthermore, different types of colleges approach ABET accreditation differently since the perception of the value of ABET accreditation varies across institutions. The customer focus of CQM, point (e), also is integrated into accreditation, but 'customer' is replaced with constituent with a corresponding a focus on service rather than selling. ABET is of course an external review that requires documentation of adhering to an internal quality process, point (e). The notion of expertise and hierarchy outlined in (f) is not externally visible—there are no ABET black belts—but internally one element of status is time in service, for example the number of accreditation visits one has been on.

The widespread success of ABET is likely helped in part because CQM has the advantage of being epistemologically aligned with engineering ways of thinking, thereby making it an easier conceptual framework for engineering faculty to adopt [27]. Although this is advantageous since engineering faculty themselves have notions of quality, there is no *a priori* reason why CQM, rather than some other framework, should be the framework upon which to build accreditation. In fact several authors have identified reasons that CQI can be misaligned with higher education. Roffe [28], in commenting on implementation in Great Britain, highlighted that the pressure to adopt CQM came from higher education itself becoming more global and competitive. CQM can be a poor fit to the culture and processes of higher education since systems designed for manufacturing processes do not always work well with people-focused organizations. In manufacturing processes a relatively small range of indicators can be used to determine quality, but the same is not true with individuals; differences between CQM in manufacturing and service companies demonstrate this effect [29]. Another issue, common to much of education, is that the variance of people is high so CQM methods that seek to implement long-term, incremental improvements may have challenges in measuring change. Variations are also built in to internal processes in higher education through electives or offering multiple appropriate pathways to a degree [30]. Another issue is that to be effective higher education needs to respond to changes in society, models focused on control by management may not be able to respond sufficiently rapidly [28].

Other authors have noted that since implementing effective CQM methods requires an organization-wide cultural change it can 1) be difficult to implement in higher education [31] and 2) changing university cultures to emphasize pragmatic outcomes and relativism can be in conflict with disciplinary ideologies [32]. Another cultural mismatch is the autonomy of individual faculty; CQM is predominately a team effort. The value placed on autonomy, individual excellence, and academic freedom means that it is hard to get sufficient buy-in to modify processes continuously. Finally the very broad array of stakeholders, disconnect between results and budget, and mission to benefit society at large rather than customers and shareholders complicates shifting to a CQM culture. The moral dimension of higher education makes it difficult to identify clear quality goals and since changing processes is often seen as changing values there is resistance to change.

The Capability Approach, an Alternative Framework to Continual Quality Management

Continual Quality Management is of course not the only framework that can be applied to higher education. As Roffe [28] points out, the CQM framework claims to improve efficiency and provide quality assurance, smoothing its adoption in higher education due to a perceived increase in the competition for students and resources. In order to better understand how the assumptions of CQM have been instantiated—to greater or lesser degree depending on the university—throughout engineering education through ABET accreditation we look at the ABET criteria through the lens of Amartya Sen's capability approach [6], [33].

The capability approach, like CQM is a broad framework but one that prioritizes freedom rather than quality. Freedom, like quality, is not a simple construct; see for example Isiah Berlin's conception of positive and negative freedoms [34]. However in the context of the capability approach Sen frames freedom as necessary to support various forms development—e.g. personal, economic, educational, intellectual, etc.—that in turn enable individuals to live a life they value. The capability approach "*is an intellectual discipline that gives a central role to the evaluation of a person's achievements and freedoms in terms of his or her actual ability to do the different things a person has reason to value doing or being*." [33]. Thus freedom to achieve serves as both a means and an end to personal well-being. In the capability approach developmental freedom is defined in terms of 'capabilities' and 'functionings'. The things a person can be and can do (determined by their opportunities, experiences, and cultural affordances) are their capabilities. The things they actually achieve are their functionings. In Sen's framework each individual has a unique functionings vector based on what they achieve, and this functionings vector is different for each person because what they value doing or being is different from others. Although someone's functionings vector in an indication of valued goals (since they have expended effort to achieve them), persons will be unsuccessful in achieving their goals unless they have the capabilities needed to enact the desired functionings. Capabilities are thus precursors to achievement and are both dependent upon a person's freedoms to achieve *and* freedom from conditions that would inhibit achievement such as poverty, disease, conflict, lack of education, etc.

Amartya Sen introduced the capability approach as an alternative to GDP to measure societal prosperity and progress. Some of his first work compared progress metrics such as life expectancy, literacy rate, and immunization against GDP and found they were not always related [35], [36]. This opened up a conversation on what metrics actually should be used to determine overall wellbeing and how such wellbeing can be achieved at the policy level. Since its introduction, the capabilities approach has been broadly adopted across a variety of disciplines [33] including public health, development economics, philosophy of justice, environmental policy, and education. This broad adoption arises because the capabilities approach has 1) wide applicability across different disciplines, and 2) it is framed generally enough to be adapted to specific contexts. Within the growing literature the capability approach is distinguished from capability theories which are applied to specific situations or groups. In the rest of this paper the lens of capabilities and functionings is used to examine ABET criteria and processes; the goal is to contrast how two different sets of starting assumptions—wellbeing vs. quality—could lead to alternative models of engineering accreditation.

The interest in using Sen's framework in education stems from its alignment with two macro-level goals of education. The first is that education is widely seen as enhancing students' capacity to achieve functionings (expanding future capabilities) by providing personal resources such as knowledge, skills, a social network, etc. The second, less widely recognized role of education is to expand students' set of possible functionings by giving them new perspectives and experiences, thereby growing their functionings vector. Similar to Sen's work in shifting focus in development away from GDP, the capabilities framework refocuses the goal of education from economic utility or workforce preparation to maximizing a student's future freedom by trying to increase their capability (what they can do) in a way that is aligned with their functionings vector (what they value and want to actually achieve).

There has been considerable prior work using the capabilities approach in education [37]. Much of this work focuses on developing list of basic capabilities students need to have achieved or be achievable to be able to learn. For example, an educational capability list from [38] includes: practical reason educational resilience knowledge and imagination; learning disposition; social relations and networks; respect, dignity, and recognition; emotional integrity; emotions; and bodily integrity. Each of these capabilities is further defined. For example, the very Aristotelian practical reason is defined as: "*Being able to make well-reasoned, informed, critical, independent, intellectually acute, socially responsible, and reflective choices. Being able to construct a personal life project in an uncertain world. Having good judgement*." Many these capabilities are in turn are derived from Nussbaum's list of basic capabilities [8]. While there is considerable debate about the utility and validity of such lists in the capability literature, there is general agreement that they have value at a local level but become problematic when they are claimed to be 'universal'.

Contrasting CQM and the Capabilities Approach

As the separate descriptions of CQM and the capabilities show, the rationale, justifications, and values that underlie them are quite different. This is, of course, not surprising since the quality of a product or service is certainly not the same thing as ensuring the freedom to achieve. But as outlined previously, the premise of this paper is that the underlying assumptions of any belief system have an outsize effect on the policies, practices, social norms, organizations, etc. that come into existence over time in support of the goals drawn from that belief system. Here a comparison is made between CQM and the capabilities approach to try to gain some insight into differences and similarities between these two frameworks. The goal is to provide insights into areas that ABET, the system currently in place, might be overlooking which could lead to overall better educational results in engineering education.

To contrast the two approaches, the eight most recent ABET criteria [39] were broken down into individual statements and then organized by four hierarchical categories: students, faculty, program, and institution. Similarly Walker's list of eight educational capabilities was broken down into sub-areas. These were put into matrix form, with ABET in rows and Walker in columns. For each cell in the matrix the level of overlap was determined on a three point scale: 0 = little overlap, 0.5 = some overlap, and 1 = considerable overlap. "Overlap" refers to the similarity between the two items being compared: ABET's criteria and Walker's educational capability. The summarized results are shown in Table 1 with the full results available online [f]. The results should not be over-interpreted since the comparison is not 'scientific' for several reasons. First, since both ABET criteria and Walker's capabilities need to be interpreted, the interpretation determines the overlap and thus the comparison is somewhat subjective. A consensus comparison from multiple raters would provide potentially less biased results. Second, at some level the comparison is between two disparate things – criteria and capabilities. The goal of the comparison, however, is to gain insights into the differences between these two categories so in this respect the comparison is fit for purpose.

Table 1: Category-level comparison between Walker and ABET

	Practical Reason	Educational Resilience	Knowledge & Imagination	Learning Disposition	Social Relations & Networks	Respect, Dignity & Recognition	Emotional Integrity, Emotions	Bodily Integrity	
Student Level	0.26	0.14	0.38	0.02	0.09	0.04	0.00	0.00	**0.16**
Faculty Level	0.11	0.15	0.05	0.00	0.00	0.02	0.00	0.00	**0.05**
Program Level	0.11	0.21	0.05	0.00	0.08	0.03	0.00	0.00	**0.01**
Institution Level	0.17	0.13	0.02	0.04	0.00	0.00	0.00	0.00	**0.04**
	0.19	**0.15**	**0.19**	**0.01**	**0.05**	**0.03**	**0.00**	**0.00**	

Before looking at Table 1 and the more detailed table [f], some clarifications are needed. Many of the ABET criteria are not framed as capabilities—what needs to be present to develop—rather they refer to processes or resources, which are deemed necessary for the pursuit of quality. In the capability approach resources are instrumental, that is they are relevant to capabilities if they actually lead to support of those capabilities [33]. This gave a way to compare the resource availability within the ABET criteria to Walker's capabilities: to what extent do the resources mandated by ABET lead to the capabilities identified in Walker assuming reasonable conversion factors? A similar argument applies to processes since they determine how well resources are converted to capabilities or support the achievement of capabilities. There is thus overlap between the role of resources and processes between quality and capabilities, i.e. in ABET resources and processes are intended to lead to quality.

Another clarification is the organization of ABET criteria into student, faculty, program, and institutional categories and how that intersects with capabilities. In the CQM framework quality suffuses the organization and thus ABET criteria are defined at multiple levels of the organization. In the capability literature the unit of analysis is ultimately individuals, although they can be treated collectively. Thus in this analysis the ABET categories of students and faculty represent individuals. The categories of program and institution represent the culture (including structural constraints) that determine the mindset and capabilities of the individuals that are part of that organization – i.e. faculty, staff, administrators, students, etc.

The comparison derived under these assumptions provided several insights into differences between the CQM and capabilities frameworks. First, there is not a great deal of overlap. Perfect overlap would give a score of one and the condition of no overlap a score of zero, and the overall level of overlap was 0.1. The low level of overlap is not surprising since the starting values of the two frameworks differ. The highest overlap is between ABET's student-focused criteria and Walker's knowledge and imagination capability which is not surprising given that ABET criterion 3 mandates certain knowledges for students. Across the four ABET categories the most overlap is with the practical reason (0.19), educational resilience (0.15), and knowledge & imagination (0.19) capabilities with social relationships & networks a distant second (0.05). Again this is not surprising since these are values that overlap with achieving quality in production or service. The finer grained analysis showed that certain elements of ABET criteria and Walker's capabilities had little overlap within these broader categories. For example Walker's capability of practical reason includes 'being able to construct a personal life project in an uncertain world' which includes the element of knowing what to do, the medieval concept of synderesis [40]. The overlap of this element of Walker's practical reason capability with ABET was much less, only 0.04 [f], and reflects the fact that the quality of a defined product or service does not include individual preferences and values which is central to the capability approach.

The above observation is borne out by looking at areas of little overlap which include: the capabilities of learning disposition(0.01); respect, dignity & recognition (0.03); emotional integrity & emotions (0.0), and bodily integrity (0.0). While these low-overlap capabilities certainly are important to students becoming engineers, they do not fall under the aegis of quality except where their presence or lack interferes with established process outcomes that can be measured.

It is also worth commenting on the low overlap of the program level of ABET criteria (0.01) with Walker's capabilities. The low overlap arises because much of the criteria for programs revolve around having and enforcing policies which when examined in more detail do not have much direct overlap with educational capabilities. This likely partly reflects a bias of the author since it is possible to construct a theory of change whereby rigorous enforcement of policies *does* lead to better outcomes; this aligns with the management-centric focus of CQM but such a theory does not fit with the author's experience and thus the overlap was rated as low. The one ABET criterion where there is significant overlap is that about defining and regularly reassessing program objectives in concert with stakeholders (overlap of 0.19). Such activities were determined to help the culture of the program support ongoing development of the individuals that constitute the program level of ABET.

Discussion and Conclusion

In this paper the continual quality management (CQM) framework that formed the basis for the EC 2000 engineering education accreditation changes was contrasted with Amartya Sen's capability approach. By determining the overlap between Walker's educational capabilities and statements from the ABET criteria it was seen that ABET preferences some capabilities over other while Walker's framework does not adequately capture conversion of resources into capabilities or the processes needed to do so. These differences are not surprising since the two different approaches start from different assumptions of value. CQM sets quality as the guiding principle and aligns organizational processes to achieve quality of output, in this case students. The capability approach values freedom in the service of development and seeks to enable individual capabilities—what a person values doing and being—that are expressed as functionings which contribute to society at large.

Comparing ABET and Walker's educational capabilities showed some areas of overlap and other areas with little to no overlap, where overlap was defined as the degree of similarity of items being compared such that one could reasonably be believed to support the other. Overlap occurred primarily in areas of practical reason, educational resilience, and knowledge & imagination which align with engineering epistemologies [41]. There was little overlap in areas of learning disposition, respect and dignity, emotions, and bodily integrity since these are less aligned with engineering epistemologies. Walker's capabilities aligned most with ABET criteria focusing on students since they are the 'product' of engineering education for which quality is determined and less with criteria focused on faculty, the degree program, and the institution. The low overlap with faculty, who are also humans with developmental needs, is notable.

The contrast between CQM and Sen's capability approach opens up several directions for further inquiry about how the value system embedded in accreditation activities do or do not support the development of engineering students. While ABET's criterion 3 defines outcomes—which in ABET's terminology is student abilities—these are not the same as capabilities. In English usage an ability typically refers to the potential or the skill that someone possesses for doing something while a capability includes their power to act. This definition is congruent with Sen's framework since capabilities are what individual's choose to do or be. An important distinction is that under ABET students need to demonstrate abilities, but they do not need to value them. Under the capability individuals need to value doing or being in order to turn capabilities into societally relevant functionings.

Another area of inquiry opens up from the point of view of taking Walker's educational capabilities as a minimum set needed for students to learn [38]. As shown above while some of Walker's capabilities overlap with ABET, others—which are focused on more humanistic aspects—do not. There is thus the possibility that within the CQM approach students are not fully supported in learning. Of course all factors that affect quality fall under CQM, but what is not measured is often not seen. The quantitative emphasis on measures of quality may undervalue some capabilities. While ABET leaves open the possibility for a program to add outcomes to the seven specified in Criterion 3, in reality few program do this since it creates additional work.

The emphasis of quality is additionally interpreted differently by different institutions as found in a prior study [26]. High status schools have relatively little need for additional indications of quality since there is no shortage of ranking systems that maintain their position. Low status schools do need the stamp of quality approval ABET offers since it is through accreditation they show their programs are at the same level of quality as better-known institutions. Additionally, ABET certification may be necessary to ensure resources and funding. Undergraduate-focused colleges often buy into the procedural aspects of quality since it aligns with their missions and values while the majority of schools adopt a compliance mentality given the stakes involved in accreditation. These different perspectives may affect the consistency that is a hallmark of engineering accreditation. If ABET is not asking faculty to evaluate the full set of capabilities needed for students to succeed, the counterintuitive situation may arise that those schools who most rigidly adhere to the criteria are the most harmed by the omission of needed capacities. In reality this is unlikely since universities offer many student support services outside what is examined by ABET, but these services vary by the resources available to the institution and may harm under-resourced programs that most need the quality seal of ABET.

There are additionally a wide range of questions and challenges that arise when adopting quality-centric frameworks for processes of education that are ultimately person-focused. As the variants of CQM seek to define characteristics in order to measure quality and assume quality is achieved through top-down managerial control, the natural variation of persons becomes a confounding factor. The capabilities approach, in contrast, takes such variation into account as it promotes individual development based on what each person values. Thus the capability approach seamlessly embraces diversity by explicitly accounting for the differing resources, functionings, and capabilities students bring to college. This contrast between the two frameworks leads to some troubling observations. Currently accreditation processes invest the faculty with the authority to design the program to achieve needed outcomes both because of the management-centric approach of CQM and because faculty are the authorities on curricular topics related to teaching engineering. But when combined with the managerial mandates to ensure quality through evaluation, enforcement, and monitoring of existing processes such authority becomes close to authoritarianism. Authoritarianism has many definitions, but generally has characteristics of strong central authority figures, authority invested through need to combat perceived threats, the maintenance of economic prosperity, and long tenure of authority figures all of which is utilized to accomplish goals of the regime rather than the goals of citizens.

In closing, this paper compared two separate frameworks, emphasizing how the value systems upon which they were based led to different ways to conceive of engineering education. While speculative, such comparisons can help to view existing systems and structures in new light. As a host of system thinkers has pointed out [42]–[44], one of the most effective methods to effect systemic change is to see systems from new perspectives. Shifting the framework on which engineering accreditation is based is not a feasible change, however systems should be questioned and examined, particularly over time as societal goals may have shifted. As ABET arose out of the CQM framework which was widely adopted at a time when US economic competitiveness was being questioned, similarly as questions of justice, equity, and opportunity rise in societal importance, it is worth exploring other frameworks upon which accreditation systems could be based. While no changes are proposed in this article, it is worth noting that there is increasing interest in exploring structural change in engineering education to which this paper makes some contribution.

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End Notes

a) Information on ABET's public filings can be found at ProPublica: https://projects.propublica.org/nonprofits/organizations/510243571
b) ABET's website lists member societies: https://www.abet.org/member-societies/
c) Information on ABET can be found on their website: https://www.abet.org/about-abet/history/
d) ABET keeps historical records: https://www.abet.org/wp-content/uploads/2015/05/10-AR-Stats.pdf
e) ABET gives annual awards for innovative programs: https://www.abet.org/awards/abet-innovation-award/
f) The full table is a bit of an eye chart, but can be viewed online at: https://drive.google.com/file/d/1YA8Do6FQDudhQkLSrKiD7P7noSyVga_Z/view

Citations

[1] A. Akera, "Setting the Standards for Engineering Education: A History [Scanning Our Past]," *Proc. IEEE*, vol. 105, no. 9, pp. 1834–1843, Sep. 2017, doi: 10.1109/JPROC.2017.2729406.
[2] J. W. Prados, G. D. Peterson, and L. R. Lattuca, "Quality Assurance of Engineering Education through Accreditation: The Impact of Engineering Criteria 2000 and Its Global Influence," *J. Eng. Educ.*, vol. 94, no. 1, pp. 165–184, Jan. 2005, doi: 10.1002/j.2168-9830.2005.tb00836.x.
[3] D. M. Riley, "Mind the Gap - What the ABET Crisis Can Teach Us about Connecting Research and Practice," *American Society for Engineering Education Annual Meeting*. 2016.
[4] L. R. Lattuca, P. T. Terenzini, J. F. Volkwein, and G. D. Peterson, "The Changing Face of Engineering Education," *The Bridge*, vol. 36, no. 2, pp. 3–13, 2006.
[5] N. Rescher, *Philosophical Inquireis: An Introduction to the Problems of Philosophy*. Pittsburgh: University of Pittsburgh Press, 2010.
[6] A. Sen, *Development as Freedom*. New York: First Anchor, 1999.
[7] A. Sen, J. Muellbauer, and G. Hawthorn, *The standard of living*. New York: Cambridge, 1987.
[8] M. C. Nussbaum, *Creating Capabilities, the Human Development Approach*. Cambridge, MA: Belknap Press, 2011.

[9] B. Seely, "'Patterns in the History of Engineering Education Reform: A Brief Essay,'" in *Educating the engineer of 2020: Adapting engineering education to the new century*, Washington D.C.: National Academcy Press, 2005, pp. 114–130.
[10] R. A. Cheville, "Defining Engineering Education," *American Society for Engineering Education*. 2014.
[11] J. F. Volkwein, L. R. Lattuca, P. T. Terenzini, L. C. Strauss, and J. Sukhbaatar, "Engineering Change: A Study of the Impact of EC2000," *Int J Eng Educ*, vol. 20, no. 3, pp. 318–328, 2004.
[12] "ISO - International Organization for Standardization," *ISO*, Feb. 09, 2023. https://www.iso.org/home.html (accessed Feb. 13, 2023).
[13] "Lean Six Sigma Certification | International Association for Six Sigma," *International Association for Six Sigma Certification*. https://iassc.org/ (accessed Feb. 13, 2023).
[14] M. Imai, *Kaizen (Ky'zen), the key to Japan's competitive success*. New York: Random House, 1986.
[15] W. E. Deming, *Out of the Crisis*, Reprint edition. Cambridge, Mass.: The MIT Press, 2000.
[16] P. Studtmann, "Aristotle's Categories," in *The Stanford Encyclopedia of Philosophy*, Spring 2021., E. N. Zalta, Ed. Metaphysics Research Lab, Stanford University, 2021. Accessed: Feb. 13, 2023. [Online]. Available: https://plato.stanford.edu/archives/spr2021/entries/aristotle-categories/
[17] R. M. Pirsig, *Zen and the Art of Motorcycle Maintenance*. New York: Harper-Collins, 1974.
[18] EpicDylan, "A Critical Reading of Robert Pirsig's Metaphysics of Quality in Zen and the Art of Motorcycle…," *Serious Philosophy*, Aug. 29, 2020. https://medium.com/serious-philosophy/a-critical-reading-of-robert-pirsigs-metaphysics-of-quality-in-zen-and-the-art-of-motorcycle-ee8da4fc485 (accessed Feb. 13, 2023).
[19] A. Langlands, *Craeft: An Inquirty into the Origins and Meanings of Traditional Crafts*. New York: Faber & Faber, 2017.
[20] D. Kahneman, *Thinking, Fast and Slow*. New York: Farrar, Strauss, and Giroux, 2011.
[21] G. N. Kenyon and K. C. Sen, *The Perception of Quality: Mapping Product and Service Quality to Consumer Perceptions*. London: Springer London, 2015. doi: 10.1007/978-1-4471-6627-6.
[22] P. B. Crosby, *Quality is free: the art of making quality certain*. New York: McGraw-Hill, 1980.
[23] J. M. Juran and A. B. Godfrey, Eds., *Juran's quality handbook*, 5th ed. New York: McGraw Hill, 1999.
[24] K. Ishikawa and K. Ishikawa, *Guide to quality control*, 13. print. Tokyo: Asian Productivity Organization, 1996.
[25] A. V. Feigenbaum, *Total quality control*, 3rd ed. New York: McGraw-Hill, 1983.
[26] A. Akera *et al.*, "The Modalities of Governance in Engineering Education," in *2020 ASEE Virtual Annual Conference Content Access Proceedings*, Virtual On line, Jun. 2020, p. 35348. doi: 10.18260/1-2--35348.
[27] A. Akera *et al.*, "ABET & Engineering Accreditation - History, Theory, Practice: Initial Findings from a National Study on the Governance of Engineering Education," in *2019 ASEE Annual Conference & Exposition Proceedings*, Tampa, Florida, Jun. 2019, p. 32020. doi: 10.18260/1-2--32020.
[28] I. M. Roffe, "Conceptual problems of continuous quality improvement and innovation in higher education," *Qual. Assur. Educ.*, vol. 6, no. 2, pp. 74–82, Jun. 1998, doi: 10.1108/09684889810205723.
[29] Z. Huq and J. D. Stolen, "Total quality management contrasts in manufacturing and service industries," *Int. J. Qual. Reliab. Manag.*, vol. 15, no. 2, pp. 138–161, Mar. 1998, doi: 10.1108/02656719810204757.
[30] S. Malcolm and M. Feder, "Barriers and Opportunities for 2-Year and 4-Year STEM Degrees: Systemic Change to Support Students' Diverse Pathways." National Academies Press, Washington, DC, 2016.
[31] L. Harvey and D. Green, "Defining Quality," *Assess. Eval. High. Educ.*, vol. 18, no. 1, pp. 9–34, Jan. 1993, doi: 10.1080/0260293930180102.

[32] J. Muller, “The future of knowledge and skills in science and technology higher education,” *High. Educ.*, vol. 70, no. 3, pp. 409–416, Sep. 2015, doi: 10.1007/s10734-014-9842-x.

[33] I. Robeyns and Open Book Publishers, *Wellbeing, freedom and social justice: the capability approach re-examined*, 1 online resource (266 pages) : 1 illustration vols. Cambridge: Open Book Publishers, 2017. Accessed: Jan. 05, 2023. [Online]. Available: https://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=1682818

[34] I. Carter, “Positive and Negative Liberty,” *The Stanford Encyclopedia of Philosophy*. 2022. [Online]. Available: https://plato.stanford.edu/archives/spr2022/entries/liberty-positive-negative/

[35] OECD, *How Was Life?: Global Well-being since 1820*. OECD, 2014. doi: 10.1787/9789264214262-en.

[36] J. Drèze and A. Sen, *An uncertain glory: India and its contradictions*. Princeton, New Jersey: Princeton University Press, 2013.

[37] M. Walker, *Higher education pedagogies: a capabilities approach*. London : Maidenhead ; New York: Society for Research into Higher Education ; Open University Press, 2006.

[38] M. Walker, “A Human Capabilities Framework for Evaluating Student Learning,” *Teach. High. Educ.*, vol. 13, no. 4, pp. 477–487, Aug. 2008.

[39] “Criteria for Accrediting Engineering Programs, 2022 – 2023 | ABET.” https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2022-2023/ (accessed Feb. 13, 2023).

[40] B. J. Kallenberg, *By Design: Ethics, Theology, and the Practice of Engineering*. Eugene, Oregon: Cascade Books, 2013.

[41] J. R. Dakers, “Defining Technological Literacy, Towards an Epistemological Framework.” Palgrave-Macmillan, New York, 2006.

[42] P. Senge, *The Fifth Discipline: The Art & Practice of The Learning Organization*. New York: Doubleday, 2006.

[43] D. H. Meadows, *Thinking in Systems: A Primer*. White River, Vermont: Chelsea Green Publishing, 2008.

[44] R. L. Ackoff, “A Systemic View of Transformational Leadership,” *Syst. Pract. Action Res.*, vol. 11, no. 1, pp. 23–36, 1998.