What is Lost When Education is Decomposed into Outcomes? A Critical Look Across Disciplines.

Abstract

In summarizing the state of engineering education in the United States the 1918 Mann Report articulated a vision for engineering as "*harmonizing the conflicting demands of technical skill and liberal education*" and the engineer "*not as a conglomeration of classical scholarship and mechanical skill, but as the creator of machines and the interpreter of their human significance, well qualified to increase the material rewards of human labor and to organize industry for the more intelligent development of men*." While later reports shifted the direction of degree programs, elements of the vision articulated in the Mann report remain defining characteristics of an engineering education. The focus on industry emphasizes current, contingent, and contextualized knowledge while synthesis of technical, organizational, and liberal forms of knowing and doing remains a strong theme in engineering education.

Engineering, however, is not the only discipline to address such issues. Management, teaching, and medicine also educate people for practice and must continually engage with a changing world to remain relevant. In this paper it is hypothesized that degree programs in these disciplines confront, with varying degrees of success, a tension between providing the knowledge needed to act and inculcating the ability in students to act spontaneously and in the right way. This paper explores this tension by looking across these disciplines to identify practices that are believed to be effective in giving students the knowledge and abilities needed to act professionally. The general approach that has emerged is having students actively address problems of varying degrees of difficulty and constraint through techniques such a problem-based learning.

The broad use of problem-centered techniques in disciplines which deal with "the world as it exists now" is to develop a difficult-to-describe characteristic in students – a pervasive mode of being that allows graduates to address challenges and adapt themselves to new situations as need arises. Because this goal is difficult to articulate or measure, it is often described through analogies such as "T-shaped" engineers or the development of professional or transferable skills. Here it is proposed that this objective is achieved by synthesizing diverse lived experiences, a process which is aided by developing forms of transfer that allows experiences developed in one context to be drawn upon effectively in another. Such experiential transfer is likely different than knowledge transfer across disciplinary domains and may be enhanced by supporting the development of goal-based concepts. Furthermore, although this characteristic is often decomposed into discrete educational outcomes such as teamwork or communication, defining and assessing outcomes necessarily emphasizes skill within a domain rather than synthesis across domains. Thus outcomes-based assessment may be counter-productive to developing sought after characteristics of graduates.

Introduction and Background

This paper examines one of the foundations of modern engineering education, defining and measuring educational outcomes, through the lens of philosophy, or "truth estimation" [1]. The goal of this inquiry is to explore what is gained and what is lost through defining the results of education in terms of outcomes. In engineering education in the US and other countries discussion of educational outcomes has been strongly affected by ABET, the organization that accredits engineering degree programs. ABET has adopted and defined educational outcomes as one of the eight criteria [2] used to assess programs, and mandated periodic assessment of these outcomes in another criteria. While discussion of educational outcomes in engineering education often centers on ABET, the idea that an educational process should be able to state what it accomplishes and measure that in some way goes beyond just that context. Such a common-sense idea, that it is worth defining what should be done and then determining it if was, seems at one level pointless to critique. However, at another level often good ideas are often poorly implemented and the systemic effects of well-intentioned policies are often not as universally beneficial as desired.

It is perhaps not surprising that outcomes have been widely adopted in engineering education since they align well with engineering epistemologies [3]. Problem decomposition is a widely taught and highly effective strategy for addressing complicated problems. If the engineer can effectively divide a complicated design into smaller subsystems whose function can be more clearly defined then, if necessary, further subdivide these subsystems into simple problems with known solutions, the system can be designed modularly. These modules can then be assembled to perform the overall function needed – hence this technique is widely known as functional decomposition. It is worth noting that this technique is not universally applicable. When systems become complex—which can occur through a large number of interconnections, lack of understanding, unpredictable behaviors, uncertain requirements, or a large number of degrees of freedom—then the method of functional decomposition breaks down. Thus in defining educational outcomes it is important to understand what elements of education can be broken off from the whole and developed independently and which cannot. That is what parts of education benefit from a holistic approach?

Educational outcomes also need to be defined to be implemented, and their definition depends on knowing what the desired ends of education are. There is, however, not universal agreement on what the aims of education should be. An example of such differences comes from the area of curriculum theory [4], which identifies four broad ideologies which vary in importance over time on a decadal scale. Each of us has greater or lesser affinity with one or more of these four ideologies:

- The scholar academic ideology prioritizes disciplinary knowledge and the purpose of education is to develop and enculturate students into an academic discipline.
- The social efficiency ideology promotes educational development that promotes individuals becoming productive members of society, and it is important to understand societal needs for effective education.

- The learn centered ideology prioritizes the learning needs of individual students, who come from unique backgrounds that determine their educational needs. Individual growth is prioritized.
- The social reconstruction ideology posits that education is an effective method for righting societal wrongs, particularly those related to inequalities.

If education affects the whole person, and substantial evidence indicates it does [5], there are very many possible outcomes that can be measured. Which outcomes a program chooses to develop depend on which aims of education are viewed as important. Thus any definition of educational outcomes implies they have been based on a system of beliefs, whether or not those beliefs are stated explicitly.

Engineering, like other disciplines, has underlying belief systems which are shared to a greater or lesser extent by those who teach engineering. Compared with many other disciplines the underlying belief systems are in engineering education are more explicit [3], [6] due to regular, high-level reports; these have been reviewed elsewhere [7]. The first of those reports in the US which laid the foundation for many engineering degree programs was the Mann report [8] which was released in 1918 to contrast how the aims of engineering education developed with a rapidly increasing need for engineers in industry. While the majority of the Mann report focuses on how degree programs are to teach engineering, it defines improving industrial production as the essential purpose of engineering: "*Engineering schools are so obviously a result of the needs of industrial production that the conceptions on which they are founded are necessarily much the same for all.*" (p. 9) and "…*that their ultimate aim was increased industrial production, and that their special contribution to this end was systematic instruction in applied science*." (p. 11). To accomplish this goal three key elements were necessary to establish within engineering degree programs: *"...they all have a common core made up of three distinct parts, namely, science (mathematics, chemistry, physics, and mechanics), mechanic arts (drawing and shop), and humanities (English and foreign languages).*" (p. 89). Application of science was particularly emphasized since that was what was needed by industry.

Despite its focus on establishing programs to meet the needs of industry (i.e. the social efficiency ideology) the Mann report also provided ontological insights, that is how engineers should act and what they should become. These are tied to conceptions of larger social good: "*There fore, one of the most important contributions that the school can make toward the education of the engineer is to guide him in developing an attitude toward life and a philosophy of living that will enable him to judge rightly as to the things humanity considers most worth while.*" (p. 111). However character development was framed through a utilitarian lens since there was a need for graduates who would fill needed roles in industry. While application of science was emphasized, engineers clearly worked in the human realm and needed to manage both human and material resources: "…*the modern conception of the professional engineer, not as a conglomerate of classical scholar ship and mechanical skill, but as the creator of machines and the interpreter of their human significance, well qualified to increase the material rewards of human labor and to organize industry for the more intelligent development of men*."

It is worth noting that many aspects of the definition of an engineer at a time when many degree programs were founded would equally fit a management major today. As the scientific revolution affected more and more aspects of life, the view of engineering as the application of science expanded and was codified in engineering education by later reports, such as one released in 1955 which was colloquially known as the Grinter Report [9]. This led to a "swing of the pendulum" in engineering education towards engineering science. This and other shifts in the focus of engineering education over the last century have been documented by Smith, Froyd, and Wankat [10]. These shifts include: a shift away from practical knowledge and skills to engineering science, a shift towards outcomes-based education, a growing emphasis on engineering design, the recognition of engineering education as a practical and theoretical field of inquiry, and the increasing role technology plays in engineering education. It is notable that the shift to outcomes-based education was identified as a significant change. This change was not just in process, but also in academic culture and led to the broad (if often grudging) acceptance of assessment as a valid educational activity that faculty should perform.

Later reports such as *The Engineer of 2020* [11] emphasized the interconnected nature of engineering with society at large: "*Engineering is a profoundly creative process. A most elegant description is that engineering is about design under constraint. The engineer designs devices, components, subsystems, and systems and, to create a successful design, in the sense that it leads directly or indirectly to an improvement in our quality of life, must work within the constraints provided by technical, economic, business, political, social, and ethical issues*." (p. 7). In some ways this echoes the language of the Mann report but acknowledges that as Technology has increasingly become integrated into all infrastructures that a systemic, rather than industry-focused, perspective is necessary. The systemic focus is noteworthy since systems need to be understood either through functional decomposition—the basis of outcome development—or holistically as they become more complex.

As has been pointed out by others [12] engineering education adapts to the times; it must by definition do so since the role of engineers has been to serve the technological needs of society. In this way educational outcomes, and the development thereof, can be seen as a means to align the practice of engineering education with the needs of society. The fact that outcomes support such feedback mechanisms and are integral to processes of continual quality improvement are the basis of ABET's change to EC-2000 criteria about three decades ago, a system which despite some relatively minor adjustments—and the tensions caused thereby [13]—are still in place today.

The View Through Philosophy

From the more distant perspective of engineering education philosophy, things are not as simple as aligning outcomes with societal needs then assessing progress on them. Such an approach works for certain outcomes that are valued in engineering. For example, aspects of engineering education like canonical exam problems and specific skills that build from positivism such as rationalism and empiricism are more straightforward to assess. Such assessment is aided by the ease of identifying knowledge and skills needed by engineers and such activities more readily lend themselves to creating and measuring learning outcomes. For example, the ABET outcome (1)—formulating, identifying, and solving engineering problems—aligns more closely with much engineering coursework than other outcomes such as using appropriate learning strategies. It relatively straightforward for most degree programs to assess such outcomes; technology has been considered teachable since ancient times [14].

Yet not all outcomes are as easily defined or measured. Often desired program outcomes are based on changes in student attitudes or mindsets. Even for outcomes that are relatively easily defined there is somewhat of an educational "Heisenberg Uncertainty Principle" that can make it difficult to devise satisfactory outcomes. The uncertainty principle states that measurements of certain pairs of states of a system such as position and momentum or time and frequency have some finite limit of accuracy. The more accurately one element of the pair is measured, the more uncertain the other becomes. The uncertainty relationship analogy for educational outcome assessment might be defined as between the pair of desired traits that assessment is both specific and broadly informative. Ideally outcomes are widely informative, that is performing an assessment gives you actionable information about characteristics of graduates. The goal is to learn as much from as few measures as possible – having to measure many outcomes for all possible situations a student could encounter is not practical. However achieving broad applicability means that outcomes have to be defined in a way that is not specific, and thus the precision of measurements suffers. The way around this is to assume that a fairly narrowly defined outcome that produces accurate results over time is a valid proxy for some widely applicable characteristic of students. Such proxies have limitations. There is thus a tension between desired characteristics of assessments being both specific and informative that those who seek to define and measure learning outcomes must navigate.

Another issue as pointed out earlier, is that methods of functional decomposition are implicit in outcome assessment. As the role of engineers expands as described in the *Engineer of 2020,* more importance is placed on being able to act within extended systems. However human-socio-technical systems are rarely amenable to methods of functional decomposition. There has thus been increasing emphasis on what are termed "transferrable skills" to better develop engineers' abilities to frame their work within larger systems. However, as the nature of work becomes more systemic, the uncertainty principle means that defining outcomes becomes more difficult. Look, for example, at ABET's reframing of educational outcomes from (a)-(k) to (1)-(7). While a principle of post EC-2000 accreditation has been to allow universities to interpret outcomes, (1)-(7) leave out elements that were difficult to assess while framing desired characteristic of graduates in a more agglomerated manner. In essence there has been a shift away from a set of narrowly focused "specifications" to cataloging broad characteristics of graduates. While not stated explicitly, this shift in essence seems to be moving from clearly defined abilities to a set of broader, more holistic characteristics. Alternatively this might be thought of as demonstrating that graduates have developed a broad set of transferrable skills they can use as heuristics in their future practice of engineering [15]. Developing such heuristics is highly valuable in working with more complex socio-technical systems [16]. However, heuristics differ from learning outcomes as typically defined in engineering education. Heuristics guide action, and can be thought of as habitual ways of acting that emerge by development within a community [17]. Demonstrating some proficiency when asked to do so is not the same as comporting oneself as an engineer. This might be termed a tension between product—understanding what graduates can know and do—and process—how the values embedded in the educational culture influence student modes of being in the world. Competence or capability approaches which are summarized in Heywood [18] (ch. 5) often seek to address this tension explicitly.

A third tension arises through the common view of engineering as an applied science. Although most of the reports referenced earlier defined the application of science as a central characteristic of engineering education, Goldman [19] points out that engineering differs from science in fundamental ways. In particular truth in engineering practice is often contingent on context and circumstance while in science it is universal and rational. In actuality engineering navigates both perspectives through what has been termed a vector of abstraction [20]. However, the rational aspects can be considered secondary since they serve as means to contingent ends. From an epistemological point of view engineers must value both contingent and rational, or necessary, knowledge. This duality of knowledge creates tensions for outcome development and measurement in several ways. One is that contingent knowledge is generally less valued in academic cultures, where math and physics often are the yardsticks by which disciplines measure themselves. Thus necessity often gets preference when outcomes are defined and measured. Another is that assessing outcomes based on necessity is relatively simple, but the nature of contingency makes such outcomes more problematic to assess. This was part of ABET's shift from (a)-(k) to (1)-(7). However it is the ability to apply contingent reasoning that is valued in the practice of engineering [21]. Outcome assessment in engineering seeks to navigate this tension by focusing on design, which is defined (at least by ABET) as bringing necessity to bear on a contingent activity.

Finally, a tension arises from the confusion between outcomes and objectives. These are words that ABET uses in rather specific ways that related to graduates' educational timelines. Outcomes are what students can do by graduation while objectives are their capabilities several years following graduation. Ideally objectives, which are developed with the constituents of a program, inform outcomes. A simpler way to look at the relationship is that objectives are what you wish to achieve, and outcomes are what you do achieve. The tension inherent in such definitions is that an outcome is by definition measurable – what can't be measured isn't classified as an outcome. An objective need not be measurable and thus can be aspirational. However, the process of linking objectives to outcomes drives programs to focus on what can be measured, and may unnecessarily limit the goals and aspirations they seek to achieve. If education is to be aspirational, or in Bruner's words [22] create new cultures rather than replicate existing cultures, the mandate to define then assess outcomes may limits the scope of vision. Although it certainly is possible to define aspirations for a degree program that are not related to outcomes, the practice of outcomes-based education generally discourages setting goals that are not measurable.

In summary the shift to outcomes-based education has confronted faculty, degree programs, and colleges of engineering with four tensions:

1) The tension between defining an outcome so that it is specific and actionable compared to the extent the outcome broadly informs you about things you actually care about.
2) The tension between the need to define graduates' capabilities by outcomes defined in ways that can be measured and achieved while supporting a process and environment that influences students to develop ways of being in the world which are complex and emergent and thus cannot be captured by pre-defined outcomes.
3) The tension between necessity and contingency. The assumptions of defining measurable outcomes is based more on necessary than contingent reasoning, although in engineering design is used to address this tension.
4) The tension between needing to measure results while wishing to achieve goals that can't be immediately measured. This tension practically can put a damper on the aspirations of programs and limit the possibilities inherent in education.

It is important to note that a tension is different than a fault. Tensions exist and simply highlight potential conflicts. None of these tensions are insurmountable, and it is not necessary to resolve them in order to improve or understand an engineering degree program. Rather exploration of tensions can yield "creative chances" [23] which themselves can serve to improve programs. There is more than one way for degree programs to adapt and change.

The Challenge – Beyond Outcomes-Based Assessment

Given that tensions are not problems [24] that need to be solved but rather places to gather thoughts around, it is worth looking briefly at where similar tensions exist. Generally, all degree programs are subject to the first and fourth tensions when they are asked to perform outcome assessment. The key tensions that distinguish engineering programs are the second and third – product vs. process and necessity vs. contingency. Engineering is not the only education program that seeks to create an environment where learning heuristics to guide practice are important and which must balance necessity and contingency; the same challenges arise in other professional programs. Thus looking to the other professions—medicine, law, and the clergy—can inform an inquiry into the systemic impact of widespread adoption of outcomes-based processes. These professions are different from engineering, however, since in engineering the undergraduate degree is terminal; although it can be followed by an apprenticeship and examination if one seeks to be professionally certified. Both medicine and law require postgraduate study, with further mentored practice in medicine. Clerical practices differ widely across religions, but generally require some form of ordination into the mysteries.

Beyond the professions, other degree programs to a greater or lesser extent ask graduates to balance forms of knowing and types of knowledge. One such can be identified by going back to the Mann report. At the time many engineering programs were founded there was a clear emphasis on managing labor, an aspect of work that was much more important at the start of the 20^{th} century near the end of the industrial, but before the information, revolution. As engineering focused increasingly on application of science, the management function may have shifted to business schools; the first business school in the US was the Wharton School at the University of Pennsylvania which opened in 1881. West Point, the first engineering school in the US opened in 1802, and Rensselaer Polytechnic Institute, the second, in 1824. Thus management programs are worth looking at since these share much in common with engineering, particularly in terms of job functions following graduation [21] such as project management; in both degree programs graduates are trained to work with contingent problems. Two other degree programs are worth mentioning in terms of their need to deal with contingent problems and in which practitioners often operate on heuristics rather than rules: teaching and nursing. Until fairly recently these were considered primarily occupations that women went into which associated them with lower status than engineering or management given historical belief systems. However, the ways contingent knowledge is used to manage highly contextualized problems is similar.

An in-depth comparison of the educational methods used by these degree programs is beyond the scope of this paper, however there are significant commonalities between the educational practices they typically adopt and engineering [25]–[27]. While there are significant differences in subject matter and how material is presented, these areas often utilize, or at least recognize, a set of common active learning pedagogies. One of these is the use of cases in business, medicine and law to have students gain experience with real-world (i.e. contingent) problems. Cases are also used in engineering [28]. Another common methodology is problem based learning (PBL) [29] originally developed at McMaster University [30]—or the sister techniques of project or problem based learning—which are becoming increasing common in engineering programs, particularly cornerstone or capstone courses [31]. Problem based learning is also used in medical and nursing programs to help develop clinical reasoning [32] as well as being adopted in business programs. Another similarity is the use of simulation in both medical and engineering degree programs. Teacher preparation programs also incorporate significant practice, such as serving as student teachers, to move beyond information about teaching and learn tacit methods. These are similar to the prevalence of internships in engineering and formal appointment as an intern in medical education. Such practices are not, of course, universal. Each school or degree program has its idiosyncrasies and the variations between programs may be greater than the commonalities, but the use of PBL, cases, simulations or other ways to bring in contingency-based forms of knowledge is fairly common. Techniques like PBL are likely not the most effective methods for acquiring knowledge based in necessity. Furthermore, acting correctly requires knowledge so that necessity and contingency go hand-in-hand.

There is a long literature on PBL and similar techniques which outlines the rationale for using them [29], [33]. One reason is to teach students to actually use knowledge they possess. It also provides students skills in problem definition, which is important in fields relying on contingent knowledge. PBL, if it frames contingent knowledge in a way that is relevant to students, can also address issues related to motivation. Because of the contingent nature of problems and the variability of ways to address them PBL, or variants thereof, also provides a way to address transferable skills such as teamwork, lifelong learning, and communication which are important across many careers.

Another reason these methods may also be widely used is that they help to promote forms of learning which transfer. Transfer is the ability to take what in learned in one setting and continue to use it effectively in other settings [34]. Similarity aids transfer between different settings so that framing problems in a setting similar to what students may face following graduation helps them utilize that knowledge. It should be noted that far transfer, where knowledge is used in very different contexts, does not generally occur. The disciplines that need to deal with contingent knowledge seem to have adopted methods which allow contingent knowledge to occur. Methods such as cases and PBL are more often than not implemented cooperatively. This cooperation not only serves to let students practice transferable skills, but creates a learning environment where by working together students are able to refine heuristics and develop the habitual reactions that are required of professionals and others who work with highly contingent problems.

While widespread, it is worth noting that the methods listed above are not always implemented well. Transfer is supported by scaffolding and having students develop schemas which are necessary for PBL to be effective. Simply giving students a problem to solve in a group does not automatically confer benefits. Transfer is also aided by reflection, which is often incorporated into problem-based learning. In brief it is worth considering that in disciplines like engineering where addressing contingencies in practice is important knowledge matters, but experience may matter more. Ultimately, we become what we do so techniques such as cases, simulations, and PBL allow students to gain experiences with applying contingent knowledge. If designed effectively these learning experiences can transfer to practice.

Another area that most of these degree programs have in common are some form of comprehensive examination before an individual is licensed for practice. Teachers often take praxis examinations. Exams are needed for licensure in engineering if a student seeks the Professional Engineer qualification. Nursing, medicine, and law have licensing examinations with further boards for medical specializations. The exception here is management, although certain sub-areas such as project management offer certification examinations. Such licensure examinations typically serve to regulate entry into a profession, acting as a filter to ensure those entering the field have sufficient knowledge and experience. In this sense they act as to balance necessity, which typically can be tested using examination, with the contingent knowledge required in these fields.

Letting the Tail Wag the Dog

The rise of outcomes-based processes in engineering education over the last decades has allowed new accreditation models and shifted the practice of faculty [35] who have become better at assessing outcomes in courses. As discussed previously the development of outcomes aligns with the functional decomposition processes much used in engineering as well as the problem-focused bent of engineering faculty [36]. However, this shift in engineering education has not come without costs nor is it likely the endpoint of the ongoing evolution of engineering education. The historical view of engineering education shows continual adaptations as societal needs change. It is thus worth looking critically at engineering education's shift towards outcomes with an eye both toward what we are doing now and what we might do in the future.

The shift towards outcomes-based accreditation has brought benefits to engineering education in the US that by now are fairly widely accepted. First, to some extents the shift addressed the concerns of major employers who saw graduates entering their organizations who lacked the skills and abilities to thrive. In particular more emphasis is placed on transferrable skills. The shift also meant that the previous content- and hours-driven assessment, which many termed as bean-counting, was replaced with a system that offered more freedom for programs. A comprehensive study [37] conducted soon after implementation of EC-2000 showed that both faculty and chairs saw changing practices in their department. Most faculty were engaged to some degree in assessment and supported the goals of systematic improvement, assessment, and data-based decision making. Student experiences incorporated more transferable skills such as ethics, communication, life-long learning, and understanding the larger context of engineering. However at the time the study was done employers did not report the changes had a significant impact on the preparation of graduates to join the engineering workforce.

Nothing is ever one-sided, and as outcomes have become part of the larger culture of engineering education there are some side effects. One common complaint about outcomes-based assessment is the time needed to assess and evaluate outcomes. This effort is not always shared equally between faculty in a program. Furthermore, it has become clear over time that outcomes of equal importance are not always equally assessable. For example, one of the major reasons ABET changed criterion 3 from eleven to seven outcomes was to eliminate or integrate outcomes that the volunteers who ran the evaluation process found difficult to assess and programs found difficult to implement. While from a pragmatic perspective this was likely the right course of action, over time such decisions in aggregate have the effect of transforming the overall system of engineering education from focusing on what it should aspire towards to what can be assessed. It is worth having a wider discussion of whether what an engineer should become be limited by what can be measured? In terms of the tensions framed above this is an example of the first and fourth tensions in play; how do programs balance inspirational goals that may not be achieved if they are focused on outcomes assessment? While certainly there is room in a curriculum to have courses that are not assessed, the financial pressures on institutions along with the prevalence of an assessment focused mindset may limit programs ability to innovate.

Another critique of outcomes-based education is that unless a program is careful to bound their use, outcomes can become surrogates for a course or a curriculum. Or as better put by Ogden Nash, "*Progress might have been alright once, but it has gone on too long*." Outcomes focus our attention, they force faculty and programs to recognize which of the many things a university education does should be primary. However, it is widely recognized that an education is emergent, that is more than the sum of its components. This was perhaps best stated by John Henry Newman [38]: "*A university training is the great ordinary means to a great but ordinary* *end; it aims at raising the intellectual tone of society…It is the education which gives a man a clear conscious view of his own opinions and judgments, a truth in developing them, an eloquence in expressing them and a force in urging them*." Imagine a student coming to university for the first time with one simple question, "who should I become?" The answer is obvious – "you should become a good person." Learning outcomes as defined in engineering do little to address this question. Furthermore, who I should become is a different question than "what should I do when I grow up?" or "how do I become an engineer?" Outcomes can indirectly help students answer the what question since by defining the characteristics of an engineer students can decide for themselves whether or not they have an affinity for engineering. Outcomes are still better at answering the how question by pointing to specific learning goals, but they are not a substitute for deeper thinking about the aims of education and how to achieve those when they are not related to engineering. In summary there is a danger that outcomes limit and detract from the more emergent roles of courses and curricula; this is captured by the second tension.

Finally, it is worth commenting in more depth on the relationships between learning outcomes and the tension between the necessary and the contingent; to the authors this relationship seems increasingly like a lynch pin which secures the axle around which many other debates in higher education turn. From one perspective outcomes are necessary, they define the current consensus on what all graduates should achieve, thus setting a minimum standard for engineering education. There is wide support for accreditation activities that set standards and ensure calibration between programs. From the perspective of necessity, the goal is to increase the utility of outcomes by making them more accurate and better aligned with the needs of society for engineers; this echoes the social efficiency ideology of curriculum theory. The closer outcomes align with objective needs as they exist in society today, the better since outcomes are tied causally to the potential for achievement later in life.

The contingent approach, on the other hand, looks at education outcomes more as guidelines that need to be interpreted based on other, more local factors and considerations. Outcomes may be useful to ensure a program is not straying too far from what it should be doing, but other factors such as individual student needs and the systemic effects of injustices also need consideration. In the contingent view the identity and capabilities of an engineer are not determined by defined outcomes as much as by what an individual's end goals are, their engagement with a wider set of experiences, and the way these contribute to the overall process of becoming. The contingent approach has some similarities with bricolage [39] or process of creating meaning through the resources available at hand. Levi-Strauss contrasted the bricoleur against the engineer who develops new tools and organizes resources according to a well thought through plan with a defined end. While the engineer's work is precise with elements of permanence, the bricoleur combines elements that already exist in ways they were not intended for.

Another way to frame these two approaches is that methods based on necessity are causal while those based in contingency are teleological. The focus on ends in the contingent domain allows active learning methods like case studies and problem-based learning to be readily adopted since they serve to help students address contingent challenges. The uncertainty and variety of possible outcomes which would be problematic in necessity offer needed flexibility to address contingent learning outcomes. It is likely that this flexibility underlies the adoption of these techniques in programs which prepare students for professions or in which students will confront contingent problems when they graduate. It may thus be worth looking further at PBL and similar methods through the necessary – contingent lens to understand how they may be more effectively implemented.

Summary

In summary, this paper has looked critically at outcome-based assessment, which has been identified as one of the major changes in engineering education over the last century [35]. Early in its history engineering education in the US adopted a social efficiency stance which supports developing societally valuable outcomes it should seek to achieve. As this philosophy become widespread in engineering education following the adoption of EC-2000, the ideas which underlie outcomes assessment became more prevalent within degree programs. This initial analysis identified four tensions serve as a lens to explore the larger, systemic effects the widespread use of outcomes may cause. Several arguments for and against outcomes-based accreditation were presented.

It was found that one reason outcomes were widely accepted in that they derived from methods of problem decomposition which are widely used in engineering. Functional decomposition, however, only is a viable approach once functions have been identified. It is for this reason that design education has highlighted the importance of problem definition. Succinctly this is the difference between efficiency and effectiveness: doing things right is efficiency while doing the right thing is effectiveness [40]. If outcomes-based assessment is to be effective it is important to have identified the right outcomes. As pointed out earlier, one of the challenges with developing learning outcomes is that they shift attention away from the questions that led to development of the outcomes in the first place. This it is worth asking for more transparency and debate on how outcomes are determined. Another challenge is to utilize outcomes in a way that is not ideological or dogmatic, but flexible. Here the tension between necessity-based and contingent-based approaches can be used as a lens to frame such conversations.

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