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Defining Sustainability in Meaningful Ways for Educators

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Abstract: Though many post-secondary institutions are moving to incorporate sustainability education into their courses and programs, some faculty have not felt able or comfortable in this endeavor. Part of this may be rooted in the fact that a quantifiable definition of sustainability that is accessible across disciplines is largely absent in the literature. This work reviews a multitude of definitions of sustainability and frameworks for sustainability across multiple disciplines and synthesizes them into the cohesive Quantifiable Definition of Sustainability. The Quantifiable Definition of Sustainability seeks to eliminate barriers faculty across all disciplines may face to meaningful engagement with sustainability education.

Keywords: Definition, framework, sustainability, educators, practitioners.

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As we continue to understand the impact of human activity on global environments, both human and natural, our world perspectives change in order to accommodate our new understandings. The understandings of the negative environmental effects we faced in the 1970's paved the way for new political and societal views (Dunlap, Van Liere, Mertig, & Jones, 2000). From that time, Erdogan (2010) accounts for the evolution that Americans have experienced as we are now beginning to focus on environmental issues through the lens of sustainability. It seems that evolution has caused some confusion in the topic, however. Sustainability is often mistakenly thought to be mostly an environmental concept (Lemonick, 2009). While the environmental domain is essential when addressing sustainability, the topic encompasses much more than just the environment (Lemonick, 2009; McDonough & Braungart, 2002), including complex social and economic factors (Bencze, Sperling, & Carter, 2011; Erdogan, 2010; Sekulic, 2011; Wainwright, 2010).

The fact that many post-secondary institutions are creating programs, departments, or even entire colleges devoted to sustainability is an extension of the importance of sustainability into post-secondary education. However, Thomas (2004) has noted that faculty sometimes resist sustainability education efforts. Two of the common reasons given were because sustainability requires knowledge in disciplines outside faculty member expertise and faculty did not know how to gather appropriate information (Thomas, 2004). While it is true that sustainability is a transdisciplinary field (Meadows, 2008; Wainwright, 2010), this should not be a "gatekeeper" to participating in sustainability. Moreover, there are multiple definitions of sustainability across the literature (Djordjevic & Cotton, 2011; Johnston, Everard, Santillo, & Robèrt, 2007; Sekulic, 2011), which can prohibit meaningful interaction of faculty members with sustainability and sustainability education. This work offers a definition of sustainability that can be used in post-secondary environments to help faculty across the disciplines acquaint themselves with the past perceptions of sustainability and to see how it has evolved across the disciplines. It is my hope that this work will allow faculty to pursue interdisciplinary or transdisciplinary efforts in sustainability more readily while simultaneously providing a structured definition that sufficiently quantifies sustainability for disciplines that measure aspects of sustainability.

The Journey to a Definition for Sustainability

Sustainability seeks to address many issues on a global scale. In truth, no one human being could understand sustainability in all its facets, as the issue and its subjects are much too vast. This and other factors contribute to sustainability being a transdisciplinary field. Moreover, the generalized concept of sustainability is a large and pervasive issue that currently defies definition (Djordjevic & Cotton, 2011; Sekulic, 2011). The breadth and pervasiveness sustainability makes the issue hard to focus and understand for most audiences. Moreover, since a common, quantifiable definition of sustainability has yet to be identified (Djordjevic & Cotton, 2011; Sekulic, 2011), some authors have instead focused on providing sustainability frameworks instead of definitions, advocating that this perspective of sustainability will be much more practical and effective given the nature of sustainability (Gagnon, Leduc, & Savard, 2009; National Research Council, 1999; Quental, Lourenço, & da Silva, 2011; Talbot & Venkataraman, 2011). Some of these frameworks are also considered since they imply indirectly a definition of sustainability, though extraction of such a definition from the frameworks is sometimes not clear.

First presented is a sampling of various definitions of sustainability, namely from business (addressed through organizational/corporate needs), agriculture, and engineering; these

were selected as they represent some of the largest key players in the sustainability movement. Following these discipline specific definitions, consideration is given for more transdisciplinary thoughts that unify multiple fields to form a framework for sustainability; these frameworks are the Daly Rules (see Smith, 2010), very weak/weak/strong sustainability (see Hediger, 2006, Munier, 2005), the Triple Bottom Line framework (see Kiewiet & Vos, 2007), the Natural Step (see Nattrass & Altomare, 1999), and the Six R's (see Practical Action, n.d.).

The Base Definition of Sustainability. Following the many attempts of the United Nations to address the environmental concerns of the 1960's and 1970's, a new initiative began in the early 1980's. The United Nations formed the World Commission on Environment and Development (WCED) with Gro Harlem Brundtland chosen as its chairwoman. The WCED's (1987) report, "Our Common Future", defined sustainability through the concept of a sustainable development, and asserted that a sustainability development is a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Chapter 2, para. 1). "Our Common Future" became referred to as the Brundtland Report; the definition of sustainability that the Brundtland Report gave became commonly referred to as the Brundtland definition of sustainability. While not just offering a loose definition of sustainability, the WCED (1987) also advocated for the equitable sharing and use of resources so as to stimulate the economies of all peoples and nations. Care should be given so as to not interpret this as saying that social factors are precedent to economic factors. Moreover, the WCED offered no precedent over what aspects of sustainability were most important but did offer a host of aspects of sustainability that were of great importance which can be delineated as environmental, economic, and social aspects.

While the WCED's definition of sustainability is often one of the most cited resources, if not the most (Ameer & Othman, 2012; Bell & Morse, 2008; Borghesi & Vercelli, 2008; Gagnon, Leduc, & Savard, 2009; Quental, Lourenço, & da Silva, 2011; Ruttan, 1994), this definition suffers greatly from ambiguity and subjectivity, clearly making the process of operationalizing of sustainability very difficult. However, there is something that is captured in this definition that does indeed define what our goals should be, albeit vaguely. Moreover, though this definition presents difficulty in understanding firmly what sustainability is, several other fields have modified and adopted versions of this definition for study and research of sustainability within their lines of work. Caution should be utilized, however, since it is estimated that over 300 definitions of sustainability already exist in the environmental realm alone (Johnston, Everard, Santillo, & Robèrt, 2007).

Corporate Sustainability. Dyllick and Hockerts (2002) offered that corporate sustainability was defined as "meeting the needs of a firm's direct and indirect stakeholders (such as shareholders, employees, clients, pressure groups, communities etc), without compromising its ability to meet the needs of future stakeholders as well" (p. 131). Fairbrass and Zueva-Owens (2012) resound a similar indirect definition of corporate sustainability. Clearly, this definition shifts emphasis to corporate interests instead of the generalized interests expressed in the Brundtland definition. In fact, Kiewiet and Vos (2007) have advocated for abandoning the pursuit of a generalized definition of sustainability and instead opting for situational definitions of sustainability; they claim that since a generalized definition of sustainability has yet to be reached, the more microscopic approach can lend itself to results in specific fields. However, the various definitions of sustainability across various fields have lead to a use of the term in ways

that benefit certain interests or groups, causing inconsistency and competition between stakeholders in terms of practice and goals (Ruttan, 1994). As such, it is recommended here that a core definition of sustainability be pursued, but perhaps emphasized in different ways or contexts across disciplines.

Definitions of business sustainability seem rare in the literature (Dyllick & Hockerts, 2002), but frameworks are more commonly offered. Frameworks specifically geared towards business sustainability that will be presented are the very weak sustainability (see Hediger, 2006), weak sustainability (see Hediger, 2006; Munier, 2005), the Triple Bottom Line (see Marshall & Toffel, 2004), and the Six R's (see Practical Action, n.d.). While the Natural Step (Nattrass & Altomare, 1999) framework does not address business sustainability directly, Nattrass and Altomare's (1999) work outlines how businesses can incorporate the Natural Step in their practices.

Sustainable Engineering. Definitions of sustainability within engineering contexts were elusive in this literature review. One definition offered by Gagnon, Leduc, and Savard (2009) was that a development is sustainable if "it allows every people globally to at least meet their basic needs, if it provides individuals in a given society equal opportunities to increase their quality of life, and if it provides future generations increasing opportunities" (p. 1467). Once again, we see that a discipline specific definition of sustainability borrows greatly from the Brundtland definition. It should be noted that Gagnon, Leduc, and Savard (2009) frame their definition within the context of an interdisciplinary group project setting where engineers work with members of other disciplines to fulfill the needs of clients.

Seliger, Khraisheh, and Jawahir (2011) offer that sustainable manufacturing is dedicated to sustainable products and processes, and that "these conserve energy and natural resources, have minimal impact upon the natural environment and society, and adhere to the core principle of considering the needs of the present without compromising the ability of future generations to meet their own needs" (p. v). Once again, there is a clear similarity between this definition of sustainable engineering and the Brundtland definition.

Just as with business sustainability definitions, sustainability frameworks geared toward engineering are more common. In particular, the Six R's framework (see Practical Action, n.d.) that will be discussed later will apply specifically to manufacturing engineering.

Agricultural Sustainability. In contrast to the areas of business and engineering sustainability, agricultural researchers offer many definitions of agricultural sustainability, though it should be noted that many of these definitions date back between 1989 and 1995. It is likely that this field became invigorated by the World Commission on Environment and Development (1987) definition of sustainability and sought to address the topic within their field early in the development of the field, especially since ending world hunger was a high priority of the sustainability initiative outlined in the Brundtland Report.

Allen, Van Dusen, Lundy, and Gliessman offer that agricultural sustainability "equitably balances concerns of environmental soundness, economic viability and social justice among all sectors of society" (as cited in Bell & Morse, 2008, p. 9). This definition of sustainability echoes various elements of the Brundtland Report, namely the focusing on sustainability through environmental, economic and social lenses. While both definitions vary and are similar in certain ways, this definition still suffers from issues of operationalization; how might one

recognize or even measure sustainability in the agriculture sector? Table 1 provides a synopsis of other definitions and perspectives on agricultural sustainability.

Table 1
Agricultural Sustainability Definitions and Perspectives

Definition 1 – From Ainsworth, "what is sustainable agriculture after all? The only sustainable agriculture is profitable agriculture. Short and sweet" (as cited in Bell & Morse, 2008, p. 9).
Definition 2 – From Avery, "one of the key charges of the environmental activists is the claim that high-yield farming is 'unsustainable'. This has resonated with the public, probably because it implies a lurking, hidden threat. Actually…high-yield farming is more sustainable than organic farming… We also have strong evidence that high-yield farming can continue producing higher and higher yields on into the future" (as cited in Bell & Morse, 2008, p. 9).
Definition 3 – From Schaller, "'sustainable' means the capability to continue producing food and fibre indefinitely and profitably without damaging the natural resources and environmental quality on which all of us depend" (as cited in Bell & Morse, 2008, p. 9).
Definition 4 - "Sustainable agriculture consists of agricultural processes – that is, processes involving biological activities of growth or reproduction intended to produce crops – which do not undermine our future capacity to successfully practice agriculture" (Lehman, Weise, & Clark, 1993, p. 139)

Bell and Morse (2008) characterize that these definitions fall into one of two categories; those who see sustainable agriculture as equivalent to current high-yield farming (definitions 1 and 2) and those who do not see sustainable agriculture as equivalent to current high-yield farming (definitions 3 and 4). Both Ainsworth's (as cited in Bell & Morse, 2008) and Avery's (as cited in Bell & Morse, 2008) definitions fall short on the Brundtland definition of sustainability since both do not consider the long-term effects of soil degradation that current human land use creates (see Barrow, 1994; Chisholm & Dumsday, 1987), including the negative impacts of conventional high-yield farming on agricultural and environmental sustainability (Qiao, Yang, Yan, Xue, & Zhao, 2012; Zhao, Zhou, Min, Wang, Shi, & Xing, 2012). For this reason, Ainsworth's (as cited in Bell & Morse, 2008) and Avery's (as cited in Bell & Morse, 2008) definitions are not considered for the remainder of this work. Schaller's (1989) and Lehman, Weise, and Clark's (1993) definitions are in line with the Brundtland definition of sustainability, but this is simply due to the fact that these definitions are effectively interpretations of the Brundtland definition in agricultural terms. These definitions will thus suffer the same problems that plague the Brundtland definition then. Lewandowski, Kaltschmitt, and Hardtlein offer another agricultural sustainability definition (as cited in Van Cauwenbergh et al., 2007, Introduction, para. 1):

> "the management and utilization of the agricultural ecosystem in a way that maintains its biological diversity, productivity, regeneration capacity, vitality, and ability to function, so that it can fulfill – today and in the future – significant ecological, economic and social functions at the local, national and global levels and does not harm other ecosystems."

This definition of agricultural sustainability is much more operationalizable than previous incarnations because it gives us specific measurable entities to look for to quantify sustainability. However, there are still three problematic aspects of this definition: (1) while the quantities to be measured are specified, the target values of these quantities are not specified; it may be necessary

for ecologists and agriculturalists to supply target quantities for the biotic factors and social scientists to supply target quantities for social factors (including economics), but such values for any of these quantities has yet to be specified in agriculture to the author's knowledge; (2) the temporal aspect of the "future" needs to be specified explicitly or expanded to "indefinitely into the future"; this is necessary to encapsulate the intergenerational equity that sustainability seeks to ensure; (3) this definition presents the expectation that these are the only components for us to evaluate to ensure sustainability; however, such an expectation may not be realistic given the extremely complicated nature of ecological, agricultural, economic and social systems, which implies that this definition may change to incorporate new knowledge in these realms. This definition of agricultural sustainability does provide some solid ground for progress. It should be noted that it varies from the Brundtland definition of sustainability only in the aspect of specifying specific quantities that would/might ensure sustainability.

The Daly Rules. The Daly Rules (see Smith, 2010) are a set of guidelines that define sustainable practices developed by Professor of Public Policy and economist Herman E. Daly, thus giving an indirect definition to sustainability. The Daly Rules are given in three parts: (1) "renewable resources such as fish, soil, and groundwater must be used no faster than the rate at which they regenerate" (Smith, 2010, p. 1); (2) "nonrenewable resources such as minerals and fossil fuels must be used no faster than renewable substitutes for them can be put into place" (Smith, 2010, p. 1); (3) "pollution and wastes must be emitted no faster than natural systems can absorb them, recycle them, or render them harmless" (Smith, 2010, p. 1). These ideas have a large basis in thermodynamics, which means that quantifying sustainability through this conceptualization is tenable. It also relegates economic and social concerns to the aggregate of "rate of consumption" while focusing on the environmental aspect through the "rate of renewal". This has further implications of what sustainability would look like, which Smith (2004) further summarized by comparing the various situations that are possible between rates of consumption and rates of renewal (see Table 2 below).

Table 2
Definition of sustainability through rates of consumption and renewal (Smith, 2010)

Consumption of renewable resources	State of Environment	Sustainability
More than nature's ability to replenish	Environmental degradation	Not sustainable
Equal to nature's ability to replenish	Environmental equilibrium	Steady-state sustainability
Less than nature's ability to replenish	Environmental renewal	Sustainable development

Thus, through logical reduction, there are only two sustainable options; steady-state sustainability and sustainable development. Both steady-state sustainability and sustainable development correlate with specific states of the environment but theoretically do not correlate with specific social and economic states. Other theorists had considered the economic perspective and offered contrasting frameworks.

Very Weak, Weak, and Strong Sustainability Frameworks. Hediger (2006) outlines very weak sustainability, weak sustainability, and strong sustainability and their evolutions through the literature. Moreover, Hediger (2006) offers that the resulting framework differences are often rooted in the discipline that has most prominently shaped each framework. For example, Solow defines very weak sustainability seeks to achieve sustainability by requiring "that the generalized production capacity of an economy is maintained intact, such as to enable constant consumption per capita through time" (as cited in Hediger, 2006, p. 362). In terms of the Brundtland definition, this form of sustainability only seeks to sustain the social and economic domains of sustainability and permits the possible complete degradation of the environmental domain, thus why this is commonly referred to as very weak sustainability. This reflects the paradigm shift from environmental limits on economic growth that was prominent in the Daly Rules to exploitation of the environment to sustain economic and social domains.

In contrast, weak sustainability "requires that the welfare potential of the overall capital base remains intact" (Hediger, 2006, p. 362). In essence, this is a step above very weak sustainability because it allows for the value of non-consumptive items (such as the environment, wildlife, etc.) to be included in the value of the overall capital. That is to say weak sustainability provides an indirect measure (or optional measure depending on user application of weak sustainability) of (1) economic protection to the environment and (2) social protection for society, but only so-much as environmental and social value is conducive or productive for the overall capital base, which is subjective. Both very weak and weak sustainability offer perspectives that are slanted more towards the economic domain, reflecting the more economic basis that these perspectives have in their history.

Strong sustainability breaks from this perspective; it focuses more on environmental concerns. Essentially, strong sustainability implies:

> "a physical principle which is founded upon the laws of thermodynamics and processes of biological growth. As a basic principle of resource management, it has a long tradition in forestry and has logically been extended to other domains of natural resource management. For instance, minimum criteria of "strong" sustainability are generally expressed in physical terms, saying that certain properties of the physical environment must be sustained. However, it is not clearly defined in the literature what it is that should be sustained (Hediger, 2006, p. 362).

It seems that strong sustainability is extremely similar to the Daly Rules. In fact, considering what Hediger (2006) is contending with respect to the Daly Rules, there is a strong parallel in the precedent of both concepts but not in their antecedents and implications. If instead we do not require certain things specifically be sustained and instead quantify sustainability through the rates of renewal and rates of consumption, why can strong sustainability not be realized through the Daly Rules? Moreover, the Daly Rules make explicit what should be sustained; that the rate of renewal is greater than the rate of consumption. It may indeed be that comparison of the rates of consumption and rates of renewal inherently gives rise to the simultaneous sustaining of all three domains (environmental, social, and economic) of the sustainability endeavor.

Consider one last comparison between very weak and strong sustainability. Munier (2005) offers that very weak sustainability has the trait of anthropocentricity, the belief that physical resources or nature are commodities to be utilized for human interests. Both weak and

strong sustainability, on the other hand, allows physical resources and nature to retain an intrinsic value (Munier, 2005). It should be noted that this intrinsic value may indeed become non-intrinsic and instead quantified in strong sustainability depending upon the user of the strong sustainability framework. These distinctions between very weak, weak, and strong sustainability elicit differences in the various paradigms that form the basis for each framework.

The Triple Bottom Line Framework. The Triple Bottom Line framework views sustainability as three distinct domains (environmental, economic, and social) and seeks to balance them all separately. "From this perspective, an organisation is considered sustainable if a certain minimum level of performance is attained [in each domain of sustainability]" (Kiewiet & Vos, 2007, p. 4). Moreover, it is expected that organizations utilizing this approach make decisions based not only on one domain, but all three; namely, profits should be considered in light of (1) environmental impacts that attaining those profits will cause and (2) social justice issues that may arise from such activities (Marshall & Toffel, 2004). It may seem that this is just the Brundtland definition in another form, but the major difference is that the Triple Bottom Line gives specific structure to sustainability that is absent in the Brundtland definition; this structure is the clear delineation between the economic, environmental, and social domains.

While this is often the predominant framework utilized in business/organizational sustainability (Kiewiet & Vos, 2007), there remains the unanswered question of how to balance the concerns of the three different areas of environment, economy and society within the Triple Bottom Line framework (Kiewiet & Vos, 2007; Norman & MacDonald, 2004; Smith & Sharicz, 2011).

The Natural Step Framework. The next framework to consider is the Natural Step from Nattrass and Altomare (1999). The Natural Step claims that:

> in the sustainable society, nature is not subject to systematically increasing (1) concentrations of substances extracted from the Earth's crust; (2) concentrations of substances produced by society; or (3) degradation by physical means; and in that society (4) human needs are met worldwide (Nattrass & Altomare, 1999, p. 23).

This framework focuses much more extensively on the environmental and social domains, leaving economic concerns unmentioned; however, Nattrass and Altomare's (1999) work explains how such practices can be integrated into the economy. This means that while Nattrass and Altomare (1999) do offer suggestions for integrating this framework into the economic domain, the framework itself is geared much more strongly towards the environmental and social domains of sustainability. Moreover, this framework essentially defines several current human activities in the world would be considered unsustainable with respect to this framework, activities such as the burning of fossil fuels, circulation of bioaccumulative chemicals, and land/forest degradation (Marshall & Toffel, 2004).

The Six R's. The Six R's (see Practical Action, n.d.) is a framework for design and sustainable manufacturing that analyzes many steps of the design and production processes. The framework requires that we consider the following:

- Recycle – can a material or product be reprocessed to make something else?

- Reuse – can a product be made into something else with all or some of the parts?
- Reduce – can the manufacturing phase cut down on the amount of material and/or energy used?
- Rethink – can we design in a way that considers all domains of sustainability?; are too many products being made?
- Repair – can a product be designed to be fixed when it breaks down or doesn't work properly?; can we use resources in such a way that does not harm the environment or even restores it?
- Refuse – can we find substitutes for materials or products that are bad for the environment and/or people?; can we find mutual respect from all domains of sustainability when considering a product?

Essentially, this framework does not provide any tools for quantifying how sustainability might be achieved, but rather it forms a framework for reflection upon the design and manufacturing processes; it allows designers, manufactures, and users to evaluate a product's proximity to sustainability. Certainly, however, this framework does not quantify specifically what must be done to achieve sustainability in any domains (environmental, economic, or social), but does attempt to approximately sustainability indirectly in all three domains.

The Quantifiable Definition of Sustainability

This section will offer a quantifiable definition of sustainability, referred to as the Quantifiable Definition of Sustainability (QDS), which is a combination of the strongest aspects of all definitions and frameworks presented so far. It should be noted that the QDS functions both in terms of a definition for sustainability and as a framework for identifying sustainability; while it is obvious that standard definitions provide this function, it is imperative that extra care should be taken here to remind ourselves of that in this case given the long history and debate between definitions and frameworks in sustainability literature. A summary of the comparisons of the various definitions and frameworks is presented in Appendix A.

While the Brundtland definition of sustainability does not specify sustainability in specific terms, it has obviously been a driving force in the evolution of the field. From the perspective of this research, however, the definitions and frameworks presented here are only useful in so much as they offer a way to quantify and understand sustainability or, at least, the path to sustainability. As such, the comparison of these definitions and frameworks of sustainability are framed with that in mind, and will seek to identify which definitions or frameworks best provides a quantifiable approach to the three main domains of sustainability; the environmental, economic, and social domains.

Consider first the Triple Bottom Line framework; it offers a support of the Brundtland definition by considering the three domains of environmental, social and economic as core to achieving sustainability. Also recall that the Triple Bottom Line framework is very common in business sustainability literature, and that a criticism of the Triple Bottom Line is that when some businesses apply the framework to their practices the Triple Bottom Line turns out to be the "good old-fashioned single bottom line plus vague commitments to social and environmental concerns" (Norman & MacDonald, 2004, p. 256). This was echoed by Smith and Sharicz (2011). This perception dominated agriculture as well; agricultural and resource economists had thought at one time that sustainability was being achieved in agriculture since market prices of agricultural commodities had seen a steady and long-term decrease (Ruttan, 1994). This is

exemplary of the misuse of economic indicators to judge progress towards sustainability. Thus, if the Triple Bottom Line framework is to be useful across all practitioners of sustainability, then it must be established in such a way that the resultant framework quantifies explicitly the commitments for each domain of sustainability. Such a framework is possible, but will serve as the definition of sustainability for the purposes of this work.

Recall that Kiewiet and Voss (2007) defined sustainability as achieved in the Triple Bottom Line framework if "a certain minimum level of performance is attained [in each realm of sustainability]" (Kiewiet & Vos, 2007, p. 4). So, using the Triple Bottom Line framework as a skeleton framework for the QDS, we consider each of the definitions and frameworks offered above, judging them individually for each domain of sustainability (environmental, social, and economic) on two criteria; (1) does the definition or framework represent the domain of sustainability strongly?; and (2) does the definition or framework offer a clear, quantifiable method for identifying sustainability?

For environmental concerns, the only definitions or frameworks that satisfy both criteria are the Daly Rules (see Smith, 2010), strong sustainability (see Hediger, 2006), and the Natural Step (see Nattrass & Altomare, 1999). However, the Daly Rules offer the most accessible, specified, and quantifiable measures for this "minimum level of performance." That is to say that for sustainability to be achieved in the environmental domain we must ensure that (1) "renewable resources such as fish, soil, and groundwater must be used no faster than the rate at which they regenerate" (Smith, 2010, p. 1); (2) "nonrenewable resources such as minerals and fossil fuels must be used no faster than renewable substitutes for them can be put into place" (Smith, 2010, p. 1); (3) "pollution and wastes must be emitted no faster than natural systems can absorb them, recycle them, or render them harmless" (Smith, 2010, p. 1). Moreover, the minimum level of performance of the system in the environmental domain is the steady-state sustainability (Smith, 2010).

For economic concerns, the only definitions or frameworks that satisfy both criteria are very weak sustainability. Recall that Solow contends that very weak sustainability requires "that the generalized production capacity of an economy is maintained intact, such as to enable constant consumption per capita through time" (as cited in Hediger, 2006, p. 362). This framework left the environmental domain of sustainability unaddressed and potentially left the environmental domain open for degradation in its current form, thus the framework's title. However, if we do not consider this portion of the QDS alone and consider it in conjunction with the Daly Rules from above, that issue is addressed and this portion would no longer neglect the environmental domain of sustainability. While it has been argued in business if sustainability will weaken the economy by placing such restrictions on how we interact with the environment (Ameer & Othman, 2012; Anderson, 2009), there is growing literature to show sustainability can be profitable (Ameer & Othman, 2012; Anderson, 2009). In truth, it is not that the Daly Rules and very weak sustainability are irrevocably contradictory to each other; it is that to be complementary to one another, we must change the way we do business, which is advocated for in various ways in the literature (see Ameer & Othman, 2012; Anderson, 2009; Dyllick & Hockerts, 2002; Fairbrass & Zueva-Owens, 2012; Johnston, Everard, Santillo, & Robèrt, 2007; Norman & MacDonald, 2004). For example, instead of consuming materials, what if a business model was instead focused on the consuming of services? Such business models have been shown to be profitable and more sustainable (Anderson, 2009).

Finally, let us consider definitions or frameworks that satisfied both criteria in the social domain of sustainability. The only candidate in this portion of the framework is the Natural Step

(see Nattrass & Altomare, 1999). In fact, there is only one aspect of the Natural Step's framework that is specific to the social domain of sustainability; that "human needs are met worldwide" (Nattrass & Altomare, 1999, p. 23). Human needs are defined here as clean water for consumption and use, food, shelter, clothing, healthcare, and education. Since cultures and peoples vary greatly in terms of how they live, it would be outside reasonable expectation that anything beyond this requirement be considered in the social domain of sustainability to be applied globally; that is to say while this may be the only global social domain of sustainability, there certainly are other social aspects to consider at non-global levels. Moreover, while education is generally not considered a human need, it will have to be considered as such for sustainability. The argument here is simple; if our population keeps growing and outgrows the limits of the planet to support us (see Attenborough, 2011; Franck, von Bloh, Müller, Bondeau, & Sakschewski, 2011), we cannot ever hope to be sustainable since our physical environment limits our population. Hence, education must be employed to insure that all global communities understand this. While it is expected that the great global dialogue will continue about this topic, it should also be noted that there will inevitably be discussion of whether or not it is ethical to stop at ensuring clean water for consumption and use, food, shelter, clothing, and education; is it ethical to ensure only the basic survival of all humans and forget the other various realms of societies and not insure that social justice is met in all regards? While such a short-sighted view of social justice is not at all the intended scope of sustainability, there is the issue that the very definition of social justice evolves with humanity and varies across cultures. It becomes a question of faith in humanity at this point: do we trust that we, as a species, are progressing towards the ultimate truth concerning social justice and will be able to treat all humans fairly in the future? I do not know the answer to this, but I certainly hope we are moving in that direction.

There will inevitably be a great global dialogue that will take place to discuss the implications of such practices, but that is beyond the scope of this research. The following is the finalized definition for the QDS. It is as follows:

> A development is sustainable if it meets the minimum level of performances in each of the areas of concern:
> (1) Environmental Domain:
> a. renewable resources such as fish, soil, and groundwater must be used no faster than the rate at which they regenerate (Smith, 2010, p. 1)
> b. nonrenewable resources such as minerals and fossil fuels must be used no faster than renewable substitutes for them can be put into place (Smith, 2010, p. 1)
> c. pollution and wastes must be emitted no faster than natural systems can absorb them, recycle them, or render them harmless (Smith, 2010, p. 1)
> (2) Economic Domain: that the generalized production capacity of an economy is maintained intact, such as to enable at least constant consumption per capita through time (inspired by Solow, as cited in Hediger, 2006)
> (3) Social Domain: at least basic human needs (clean water for consumption and use, food, shelter, clothing, healthcare, and education) are met worldwide (inspired by Nattrass & Altomare, 1999, p. 23)

While this definition of sustainability makes each domain of sustainability quantifiable, it certainly cannot be expected to be representative of sustainability at all levels. There will

undoubtedly be additional considerations to be made at the local level for additional requirements, which echoes the sentiment that situational additions must be considered (see Kiewiet & Vos, 2007).

Moreover, care must be given to not interpret the dimensions of the QDS as unrelated or orthogonal to one another. There is interdependence between these dimensions that is not currently fully understood; part of the mission of sustainability is to understand the interdependence of these dimensions with one another, and how they collectively form the concept of sustainability.

Limitations of the Quantifiable Definition of Sustainability

The presented collection of sustainability definitions and frameworks offer a diverse look at this expansive topic. While the Brundtland definition of sustainability is indeed dominant in the literature and there are some sustainability frameworks to help guide us towards sustainability, it is certainly reasonable that this still leaves plenty of room for disagreement in the field. However, though a continuing discussion on the definition of sustainability should be pursued in the field, Trzyna (1995) offers that "sustainability is not a precise goal but a criterion for attitudes and practices" (p. 16). Munro (1995) echoed this idea, claiming that sustainability is a "continuous and iterative process, through and throughout which experience in managing complex systems is accumulated, assessed, and applied" (p. 34). Much like the large systems that sustainability grapples with, we will likely come to know sustainability as an organic amalgam of so many disciplines that will necessarily require us to be extremely open-minded as the field grows, evolves, and continues to bloom. As such, it is expected that the Quantifiable Definition of Sustainability (QDS) will not be sufficient for the needs or goals of all researchers or educators in sustainability; the QDS is simply a definition of sustainability that allows for all beginning researchers or educators to access the complex ideas of sustainability.

The largest macroscopic limitation of the QDS from a long-term perspective is that it delineates the concerns of sustainability into three seemingly separate domains (economic, environmental, and social). This view of sustainability is limited and misconstrues the true essence of sustainability. Sustainability relies on the integration of the economic, environmental, and social domains into one cohesive system of knowledge (Meadows, 2008). However, such a cohesive system of knowledge has not been concretely defined in the literature. This is where the QDS exhibits strength for beginning practitioners of sustainability education since it offers a succinct perspective of sustainability that is comprehensible across multiple disciplines.

Further Considerations and Conclusion

While the QDS offers a starting point for beginning researchers and educators in sustainability, restricting ourselves to a rigid definition of a concept that is still being understood could severely limit the development and growth of discourse in the field. In this sense, the QDS should not be considered as a "catch all" for considering sustainability. When working with the QDS to learn about, teach, or research sustainability, users must be willing to look beyond rigid definitions and question what aspects of real-world problems the QDS adequately covers and aspects that it does not.

Bell and Morse (2008) offer that "the very holistic and anthropocentric essence of sustainability continues to elude attempts at objective analysis and assessment" (p. xvii). This thought has been prevalent in the literature (Gibbon, Lake, & Stocking, 1996; Izac & Swift, 1994; Kidd, 1992; Robinson, 2004; Schaller, 1989). Some have concluded that this must mean

that sustainability is a futile effort (Morris, 2012). Given the global imperativeness of sustainable initiatives, I would hardly classify the entire sustainability movement as futile, however. Our greatest milestones as a species have often come at the precedent of great and overwhelming odds against us. That does not mean we give up because we find difficulty in even understanding our world. It means we try new approaches and come together with our different perspectives to understand the exact nature of the problem we face. The QDS can offer one common perspective for multiple disciplines to converse so that we may come together and face sustainability issues in meaningful discourse.

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Appendix A

Table A1
Summary of Definitions of and Frameworks for Sustainability

	Concept	Reference	Brundtland Criteria			Quantifiable	Notes
			Environment	Economic	Social		
Definitions	Corporate Sustainability	(Dyllick & Hockerts, 2002)	Indirectly	Yes	Indirectly	No	Presented from a transdisciplinary frame of reference
	Engineering Sustainability	(Gagnon, Leduc, & Savard, 2009)	No	Yes	Yes	No	Focused on firm's work, very business oriented
	Agricultural Sustainability	(Schaller, 1989)	Yes	Yes	Yes	Some	Only agricultural constructs quantified
	Agricultural Sustainability	(Lehman, Weise, & Clark, 1993)	Indirectly	No	Yes	No	
	Agricultural Sustainability	(Lewandowski, Kaltschmitt, & Hardtlein, 1999)	Yes	Yes	Yes	Some	Strong breadth of scope and depth of specifying quantifiable constructs
Frameworks	The Daly Rules	(Smith, 2010)	Yes	Indirectly	Indirectly	Yes	Strong quantifiable environmental framework
	Very Weak Sustainability	(Hediger, 2006)	No	Yes	Indirectly	Yes	Strong quantifiable economic framework
	Weak Sustainability	(Hediger, 2006; Munier, 2005)	Indirectly	Yes	Yes	Some	
	Strong Sustainability	(Hediger, 2006; Munier, 2005)	Yes	Indirectly	Indirectly	Yes	Very similar if not interchangeable to the Daly Rules
	Triple Bottom Line	(Marshall & Toffel, 2004)	Yes	Yes	Yes	Some	
	The Natural Step	(Nattrass & Altomare, 1999)	Yes	Indirectly	Yes	Yes	
	The 6 R's	(Practical Action, n.d.)	Indirectly	Indirectly	Indirectly	Yes	

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