An Energy Model for Viewing Embodied Human Capital Theory

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Human capital development is one of the emerging areas of study with regard to social science theory, practice, and research. A relatively new concept, human capital is described in terms of individual knowledge skills and experience. It is currently expressed as a function of education as well as a measure of economic activity. Little theory exists to establish models of individual or group human capital. By drawing upon existing physical science constructs such as embodied energy, this article applies a framework for articulating an approach to human capital development and interaction. Our proposition is that human capital consists of active and passive capacity, which parallels the theoretic dimensions of potential and kinetic energy. A conceptual binary phase diagram of a human capital system is presented along with examples for applying the model to practice. Utilizing an economic model of resource flows; a model of embodied human capital is developed as a vehicle for sustainable human capital theory.

Within organizations reside the knowledge, skills, and experience that encompass a discrete set of human capital, which when appropriately activated and focused, allows for the achievement of strategically orientated outcomes (Geroy & Venneberg, 2003). Case studies from business, politics and the social sciences portray images of what is now identified as the learning organization which advance knowledge management is critical to overall success (Senge, Ross, Smith, Roberts, & Kleiner, 1994; Ellinger, Ellinger, Yang, & Howton, 2002). However, there is minimal discussion advanced regarding the understanding of sustainable human capital development investment as a critical element in these cohesive organizational systems (Langelett, 2002).

At an applied level, the means of determining return on investment in human capital as an economic indicator of best choice of program intervention was initially explored and developed by Geroy and Swanson in the mid 1980s. But beyond the articulation of any given contemporary human capital development strategy, a theory base that explains and guides fiscally and socially responsible choices for such decisions is lacking (Ellinger et al., 2002; Geroy & Penna, 1995; Geroy & Swanson, 1984; Holton & Baldwin, 2000; Kupritz, 2002).

The mechanisms of human capital growth reside in the complex fabric of organizational culture and environment. Geroy and Venneberg (2003) advance the notion that investing resources in human capital, with the express purpose of establishing a positive return on such investment, must embrace the short and long horizon objectives of the individual, the group and the organization. Their notion of human capital investment as a strategic acquisition of capacity building extends to the concepts of knowledge management as an element of human capital traditionally viewed as a non-economic variable (Sanders, Hopkins, & Geroy, 2003; Senge et al., 1994; Ulrich, 1996).

At the macro-economic level, the globalization of market, enterprise, and workforces dictate that the capital strength of a nation, once measured in theoretical raw resource, goods, and service models such as Leontief's input/output model, must also be measured in terms of human capital (Bell, 1999; Geroy & Venneburg, 2003). As definitions of individual, organizational, and national economic performance evolve and change, new models and concepts—interdisciplinary in nature—are useful to economists, human resource professionals, and social scientists to construct human capital development investment decisions. Arguably the concept of human capital is not currently structured theoretically to view such investment models (Becker & Murphy, 2000).

Utilizing a sustainable development perspective this paper presents a model of embodied human capital as a mechanism for viewing human capital investment. Using energy theory as a proxy for human capital, a model for mapping human capital variability, along with examples, is suggested. Our intent is not to create an applied methodology, but to address the ongoing call of the field to develop a theory base in which to view human capital metrics. To that end this paper presents a model for viewing energy theory as one paradigm, which may contribute to the future development of an embodied human capital theory.

Our proposition is that human capital consists of active and passive capacity (Geroy & Venneburg, 2003), which parallels the theoretic dimensions of potential and kinetic energy. Furthermore, by adding to either of these human capital dimensions, as with energy, the creation of synergy through teaming will create a "compound" which is greater than the sum of its parts.

The Human Capital Dilemma

When considering human capital as a type of functional capital we find a simple categorization strategy utilized by Langelett (2002) that distinguishes between human and physical capital. These are satisfactory when considering economic investment in, and return on, investment from these two sources of capital. However, difficulty is encountered when we recognize that physical capital such as land and equipment is measured in terms of monetary value (appreciating or depreciating) as reflected on a financial balance sheet. Proclamations of human resources as our most important assets have not resulted in the inclusion of human capital as equivalent in measure to physical capital. Nor do we find any representations of human capital assets present in organizational financial statements.

Tracey (1998) contrasts human capital with financial or equipment capital and emphasizes human capital as "the assets or wealth of an organization embodied in or represented by the hands, minds, and talents of its employees" (p. 243). While these notions are readily understood conceptually, they lack any real sense of representation with regard to an index or coefficient of human capital.

Attempts at representing human capital in terms of its embodied content (as opposed to return on investment) were noted by Langelett (2002). Citing the work of Minkiw, Romer, and Weil in 1992, an augmented model of

Robert Solow's neoclassical growth model attributes most of the variability in international economic growth to components of human capital that include savings, education, and population growth. Here we find education, represented in years of formal schooling, to be the closest expression of human capital as a quantifiable construct.

The call for human capital metrics has only recently been expressed in the academic literature. Geroy and Venneburg (2003) operationalized human capital metrics by including within human capital "performance capacities variables that are both active and passive" (p. 89). This notion is an important one as it recognizes that in any given situation an individual is not compelled to operationalize their entire performance capacity set, only the active capacity is necessary to perform the required task(s).

By framing the concept of human capital in terms of economic investment in skill and knowledge for performance improvement, it is imperative that the individual and the organization be able to measure the acquisition of such skill and knowledge. Return on this form of capital investment now becomes an outcome measure of an overall investment strategy. This is clearly separate from associating human capital as a distinct economic entity. As such, human capital as a discrete measure of the capital embodied within an individual or group remains a measure without units.

We believe that any strategy for investment and development in human capital must consider the long term, intergenerational objectives of human capital development.

Social capital, a form of human capital, refers to the connections, or social networks, among individuals. These networks give rise to norms of behaviors and attitudes, such as reciprocity and trustworthiness (Robins, 2005). Special interest groups such as trade organizations or political action committees may draw upon years of accumulated social capital to promulgate standards or influence legislation seeking to improve their socio-economic status. Significant energy inputs in the form of human and non-human capital are required to accumulate and sustain viable social capital. The current work anticipates social capital as a study in "meta-human" capital systems. While we leave this topic for future investigation, we refer the reader to the works of Becker and Murphy (2000), Becker and Becker (1997), Putzel (1997), and Rubio (1997) for an in-depth view of social capital theory.

For the purpose of clarity with regard to distinguishing between different approaches to capital we propose a taxonomy that recognizes two forms of capital: human and non-human. While human capital is thought to depreciate over time in a manner similar to physical capital it is also believed that, unlike physical capital, human capital cannot exceed the life span of the individual that possesses it (Langelett, 2002). We believe that any strategy for investment and development in human capital must consider the long term, intergenerational objectives of human capital development. Therefore, it is imperative that models for human capital be formulated in a manner consistent with the theory and practice of sustainable economic development.

A Lens for Viewing Sustainability and Human Capital

The Economics of Sustainability

The concepts and contexts of sustainability in terms of economic, environmental, social, political, and futurity objectives are expressed in the writings of Birkeland (2002), Hawken, Lovins, and Lovins (1999), Langston and Ding (2001), and Sarkis (2001). Sustainability has become operationalized in the popular lexicon as embodying strategies and objectives toward environmental preservation, energy efficiency, and economic and social welfare. Regarding development, a popular and satisfactory definition of sustainability is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Langston & Ding, 2001, p. xiii).

Only recently has our understanding of the interconnections between environment, economy, and social well-being led people to consider how to assess and interpret the information we are gathering (Birkeland, 2002). According to Sarkis (2001), as a myriad of descriptors, factors, and metrics exist for the reporting of data to support the concepts of sustainable development. From an operations perspective, the stability and vibrancy of socio-economic systems, coupled with environmental considerations, are relevant to any assessment of sustainable practices.

The matrix of factors that describes and defines sustainability as a strategic outcome includes the notions of environmental friendliness, energy efficiency, and socio-economic equity and futurity issues. Like the concept of human capital, the concept of sustainability is lacking in the development of models that allow for a more thorough and integrated picture of what truly defines a sustainable physical or human capital system. From an economic perspective, an analysis of flows—in the form of an input, process, and output of resource utilization—with particular emphasis on energy utilization may be helpful to empirically assess sustainable practices (Daly, 2002).

The study and assessment of sustainability is the fundamental premise underlying the field of ecological economics (Martinez-Alier, Munda & O'Neill, 2001). Utilizing a systemic approach to environmental issues, three systems (economic, human, and natural) are considered in terms of their relationships. Attempts at measuring each system with a single denominator may prove elusive as the complexity of interrelationships suggest multiple denominator evaluation.

The implication of the concept of sustainable development underscores the need for actions and strategies that achieve improvements to the human condition for the long run, instead of unsustainable short-term gains. Munasinghe (2001) suggests that a balanced consideration of social, economic, and environmental issues is required when attempting to implement strategies for sustainable development. Utilizing this perspective, considerations for maintaining flows of capital systems, whether physical or human, should emphasize "preserving the resilience and dynamic ability of such systems to adapt to change, rather than the conservation of some 'ideal' static state" (Munasinghe, 2001, p. 136).

Christensen (2001) argues that neoclassical economic theory, with its reliance on individuals seeking maximization independent of others, is inadequate in light of the recognition that microeconomic production functions were conceived without any consideration of the materials and energy required to do work. A reformulation of economic thinking based upon biophysical and ecological approaches to economic production activities is therefore required.

Moreover, "it would be inappropriate to base production theory and environmental economics on concepts which are incompatible with the operations of the physical and biological world" (Christensen, 2001, p. 16). It is here we find the most compelling evidence that economic behavior may be viewed from a perspective of material and energy flows, with particular emphasis placed on the laws of thermodynamics.

In many ways human behavior can be seen as a reflection, and a representation, of mechanisms more often associated with the natural sciences (Christensen, 2001; Knight, 1973). Certain phenomena such as energy transfer, catalysis, and friction, which represent aspects of theory within the areas of chemistry and physics, can provide useful tools for social scientists. Knight (1973) recognized "the parallelism of economic theory with the science of mechanics, where the abstraction and unrealism are greater, but their necessity and usefulness are not questioned" (p. 61). Whether by direct association or through analogy and metaphor, our natural world offers a powerful source of insight and understanding into human perception and understanding.

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Embodied Energy

Embodied energy is the term used to describe the amount of energy utilized in the production, transportation, and operational use of materials or systems (Atkinson, Hobbs, West, & Edwards, 1996; Lippiatt, 1999; Ludwig, 1997; Pierquet, Bowyer, & Huelman, 1998). The unit of energy is the Joule, which is both discrete and quantifiable. A working definition of embodied energy from Knight (1982) is "the total energy flow of a system, including the energy expended to produce a component or to maintain an interaction, which may serve as a measure of the economic entity involved" (p. 1).

The theories underlying the concept of embodied energy are rooted in the laws of thermodynamics. Energy is considered a fundamental property of matter; it can be neither created nor destroyed, only transformed or transferred in the form of work or heat. The popular notion of energy consumption can therefore be reduced to an analysis of energy flows. For example, fuel is not "consumed" by an automobile; its chemical energy is transformed through combustion into heat and transferred to the mechanical components of the drive-train for propulsion. Any statements or propositions regarding the energy modeling of systems are fundamentally predicated on these laws (Annamalai & Puri, 2002; Carrington, 1994; Jones & Dugan, 1996; Whalley, 1992). Knight (1982) was one of the first to consider that embodied energy may be predictive of the "natural selective process [which] will eliminate items that use more energy than they stimulate" (p. 2).

In essence, embodied within all human or material capital systems are discrete energy inputs necessary to access, extract, manipulate, process, develop, transport, and sustain them. Subsequently, systems may be analyzed in terms of the sum of their energy inputs as well as in terms of the economic costs incurred as a result of these inputs (Birkeland, 2002; Christensen, 2001; Kaufman, 2003).

Entire systems, including man-made or natural environments, such as manufacturing plants or forest ecosystems, may be described in terms of their energy utilizations or transfers. Specifically, the energy associated with a piece of dimensional lumber, a wall, or a building may be described as an embodiment of the sum of its energy inputs. Our model of articulating knowledge, skill and ability may be represented as a function that draws upon appropriate combinations of passive and active capacity. In this sense, it parallels embodied system energy that includes both potential and kinetic components.

A Model of Embodied Human Capital

An emergent theory of embodied human capital would encompass the human capital capacity sets of individuals as well as the interaction effects of combining specific individual capacity sets in search of optimal outcomes. Using energy as a proxy for human capital suggests that, as with all energy inputs versus outputs, human capital's ability to build and sustain both active and passive capacity will have its own outcome measure. While individual capacity could be discretely measured using such a methodology, the combining of individual capacities into groups or teams is of particular interest when considering such an approach. Therefore, when viewed through this lens, the ability to perform work as output is reliant upon human capital capacity sets. As such this will correspond to the energy input-output model.

This notion can be applied at the individual or team level. Working alone, an individual may be expected to complete a project in a specific period of time to a degree of quality that reflects their unique capacity sets. Working together, each individual worker contributes some percentage of the total active capacity necessary to complete the project. When teaming, their combined efforts, carefully orchestrated, will provide for one of two possible positive productivity outcomes: more work will be performed for the same energy input, or less energy will be required for the necessary work to be performed, relative to individual performance (Antoszkiewicz, 2000).

By viewing an emergent embodied human capital theory in this manner suggests there is a continuum dimension where the possible combinations of the active capacity contributions of two or more individuals lead to a desired output. Consequently, there exists an optimal contribution ratio that represents the synergistic partnership among them to successfully complete work. To illustrate this notion, an example of a human capital phase diagram is presented in Figure 1. Notably it embodies the notions associated with modeling the energy inputs of material systems. (Norton, 1949; Putnis, 1992).

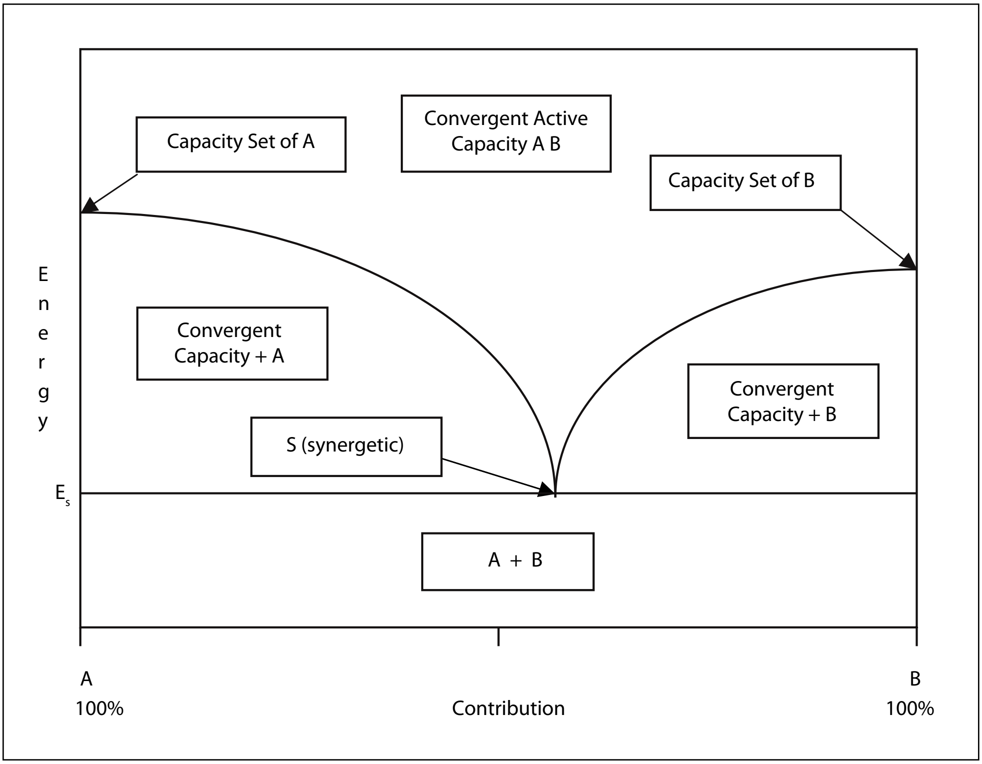
A Human Capital Phase Diagram

Drawing upon energy theory and the specific notion that individuals bring a certain quantity of energy and/or human capital to specific work requirements, individuals can be conceptualized as single elements, or as ingredients in a composition or mix of people (e.g., team) needed to perform a given task or operation. Figure 1 shows a conceptual phase diagram for a human capital system with individual members A and B.

Each individual can be conceived in terms of their capacity set with a discrete amount of knowledge and ability represented by proxy in terms of energy. Moving along the X-axis, a capacity set with the synergetic composition S optimizes A+B simultaneously at the human capital embodied energy E_s.

The synergetic composition S shows the least amount of combined or "convergent" energy/capacity required to successfully complete the task or activity. This represents the most efficient utilization of the combined

FIGURE 1. Conceptual binary phase diagram of a human capital system with individual end members A and B. A capacity set with the synergetic composition S optimizes A+B for a specified task simultaneously at the human capital embodied energy $E_{s.}$



capacity sets of A and B. Similar to the energy flows inherent in the heating and cooling processes required for creating complex materials, capacity sets, represented as energy inputs, are necessary for individuals A and B to combine—or fuse—to form the AB team. Total system energy requirements are therefore maximized at E_s, which is consistent with the idea that individuals working together can achieve far more (per individual) than each could working separately (Antoszkiewicz, 2000; Cox & Spencer, 1998).

As an example, we can apply our model to an automobile industry design team. Provided the task of developing the next generation hybrid automobile, an individual design engineer specializing in power-train efficiency would draw upon her capacity set to design a high energy-efficient vehicle. Working alone, we would anticipate the engineer to utilize all relevant active capacity, and perhaps some passive capacity from prior professional or life experience, to complete a new design. The result may well be a highly efficient vehicle. However, automobile sales rely on a host of other factors, of which energy efficiency is only one.

Here we glimpse the potential for capacity set mapping, manipulation and development to effectively result in individual, team and organizational gains.

By adding a second design engineer that specializes in ergonomics and aesthetics, we would expect the design team to achieve the desired work outcome (a stylish, driver-friendly, energy-efficient and salable hybrid vehicle) by effectively combining their capacity sets. Of course, the degree and amount of each engineer's contribution to the design effort may vary based upon situational factors. However, our model suggests that an ideal combination of the team's capacity set would result in the desired work outcome at a minimum input of effort (energy). Furthermore, these efficiency points, or low energy "wells" could be identified through experimentation.

The consequences for teaming efficiencies extend well beyond the example presented above. Individuals or small groups with insufficient or poorly matched capacity sets would be expected to require significant amounts of supervision to effectively achieve work outcomes. However, teams that are comprised of individuals with carefully matched capacity sets, including knowledge, skills, abilities and other factors, could leverage inter-team efficiencies while performing work in a more self-directed manner, thus freeing manager and supervisor time (high capacity/capital) for reinvestment. Here we glimpse the potential for capacity set mapping, manipulation, and development to effectively result in individual, team, and organizational gains.

The implications of such an approach include the ability to develop a practical model to map the effects of combining individual human capacity sets for problem solving and productivity improvement. As exemplified in the physical sciences, the selection of individual constituents coupled with environmental considerations may lead to a number of possible outcomes. Fundamental to these outcomes, as well as to the processes that produce them, are unique patterns of energy transfers and transformations. By carefully selecting the constituents and contributions of team members we may maximize output at a minimum of input. (Antoszkiewicz, 2000).

Discussion

Non-human capital, such as buildings, equipment, and precious materials, transcends traditional environmental and cultural views. While valuation may vary somewhat due to situational factors in the economy (such as inflation, etc.), their position within complex capital systems remains relatively fixed in terms of utilization. Human capital is highly contextual and has the potential for innumerable applications. Individual and group capacity sets may be applied to a myriad of problems, tasks, and activities. While this may render the modeling of human capital systems a complex and challenging endeavor this does not mean we should not attempt to do so.

Our current ability to model human capital is, at best, a reflection of indirect processes such as education, training, and experiences from which we piece together notions of increasing individual sets of active and passive capacity. We may suggest alternative strategies for human capital development and utilization, and measure effectiveness in terms of ROI analysis; however, human capital as a quantifiable measure, much like the concept of sustainability, remains without satisfactory metrics.

A theory of embodied human capital is useful for matching individual capacity to complex economic systems. The challenges inherent in such an approach go far beyond individual human capacity to the social aspects of individual interactions within groups. As our ability to map and interpret the interactive effects of learning interventions on individuals improves, embodied human capital theory can provide a mechanism for integrating individual human capital sets into notions of individual, group and organizational performance.

By drawing upon the fundamental measurement techniques and processes of the physical sciences, ideas of human capital metrics may be further developed for social science research. By exploring the boundaries and limitations of our current theories, new directions can be found in the theory and practice of other disciplines. Somewhere between a comparison and a conversion lies the true synergy in interdisciplinary synthesis.

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