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**The Fourth Industrial Revolution's Wave Crashes Upon the
Shores of Accounting: The Value Metric for the Fourth Industrial
Revolution**

February 10, 2022

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Acquisition Research Program

Naval Postgraduate School

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Prepared for the Naval Postgraduate School, Monterey, CA 93943.



The research presented in this report was supported by the Acquisition Research Program at the Naval Postgraduate School.

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Abstract

Almost 30 years ago, Elliott (1992) shared several critical insights about the inadequacies of the field of accounting to account for radical changes in the ways businesses develop and execute strategy based on the fundamental opportunities that had come about due to information age technology. Accounting has remained virtually unchanged for over 500 years. Society has now entered what Schwab (2015) referred to as the “Fourth Industrial Revolution,” where technology advancements that follow an exponential growth curve introduce a reality that combines technology across the physical, digital, and biological domains. The Fourth Industrial Revolution has the potential to change both public and private sector organizations, and society itself. However, accounting practices are not positioned to take advantage of these changes.

With this phenomenon in mind, this study seeks to address a gap in the literature, which indicates that the current accounting practices are insufficient to meet the challenges of the Fourth Industrial Revolution. . They do not provide a raw, nonmonetized common unit of value that can measure productivity on a ratio scale for nonprofit organizations or at the subcorporate level in for-profit organizations. Through a discussion guided by the literature, this study seeks to generate a scholastic dialogue on how to address this problem.

List of Key Words: Accounting, Fourth Industrial Revolution, Measurement Theory, Measurement Scales, Allocation Problem, Criteria for Value, Nonprofits, For-Profits



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Disclaimer: The views represented in this report are those of the authors and do not reflect the official policy position of the Navy, the Department of Defense, or the federal government.



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Introduction: Motivating Phenomenon

Nearly three decades ago, Robert K. Elliott (1992) shared several critical insights about the inadequacies of the field of accounting to account for radical changes in the ways businesses develop and execute strategy based on the fundamental opportunities that had come about due to information age technology. His insights were summarized in his *Accounting Horizons* seminal article the “Third Wave [i.e., information age] Breaks on the Shores of Accounting.” Elliott’s (1992) premise was that the “Third Wave” (i.e., the transition of the predominant source of wealth creation) had shifted from the industrial era to the information era, due to the rapid growth of opportunities provided by information technology. This shift in the engine of wealth creation also shifted the general rules for ensuring a successful business organization. This shift required a major adaptation in accounting to provide more useful information in the information age that had not been provided via standard accounting practices (e.g., generally accepted accounting practices, or GAAP). As Elliott (1992) stated, “If the purpose of accounting information is to support business decision-making, and management’s decision types are changing, then it is natural to expect accounting to change” (p. 61).

This call for reform and innovation in accounting is well supported by the fact that the accounting system in use today was developed by Franciscan Friar Luca Pacioli in 1494 and has remained fundamentally unchanged for 527 years (Sangster & Scataglinibelghitar, 2010; Stoner, 2011). The relentless progress, fostered by the incredible increases in productivity and new opportunities for value creation, due to innovative uses of information technology in the 30 years since Elliott (1992) made the case for modernizing and reforming accounting, appears to have done little to foster innovations in standard accounting practices. At the fundamental level, modern-day accounting remains unchanged with no significant research proposing reforms to the field (Hopwood, 2007). To make the need for accounting to change more urgent, society has now entered the “Fourth Industrial Revolution” where technology advancements follow an exponential growth curve (Lee, 2013; Salawu & Moloji, 2020; Schwab, 2015, 2017).



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Problem Statement

The comprehensive research of Cluskey et al. (2007) into the curriculum and programs at top accounting institutions found that within the field of accounting there is a lack of theory to challenge current practices contained in GAAP documentation as well as in the International Financial Reporting Standards (IFRS). This has caused a stagnation in accounting theory because academics have primarily become methodologists rather than scholars seeking to advance the body of knowledge via innovation in accounting theory. Therefore, while society has advanced into, and is passing beyond, the Third Wave and is well into the Fourth Industrial Revolution—an era dominated by technological advancements—accounting has largely remained in the past, still using the basic double entry cost accounting techniques developed by Friar Pacioli.

That said, one of the major reasons that accounting has sustained its usefulness is that it provides a commonly agreed upon means to historically measure cost and sales revenue at the whole corporate level. The GAAP procedures and policies have been largely successful in preventing fraud due to transparent accounting auditing procedures. Such sustained success over the hundreds of years since its first invention makes accountants very reluctant to change this successful system of business performance measurement.

The challenges posed to current accounting practice from the businesses participating in the Fourth Industrial Revolution reflect the need for new accounting theory. In fact, these accounting challenges are even more significant in nonprofit and governmental sector organizations that have no sales revenue (to generate performance measurements such as return on investment [ROI] estimates) to assess their productivity performance (Jarvinen, 2016; Steccolini, 2019). This is a problem because in the nonprofit organizations (e.g., in defense departments) there is no raw, nonmonetized common unit of value that is measured using a ratio scale that would enable use of a productivity ratio.



A similar problem exists in for-profit organizations because sales revenue does not get allocated at the subcorporate level. In fact, the for-profit organizations only measure value (i.e., sales revenue) at the whole corporate level, since value is accounted for outside the corporate boundaries. In these organizations, sale revenue is not allocated to subcorporate functions or core processes. Only costs are allocated at the subcorporate level in both for-profits and nonprofits.

This value allocation problem is exacerbated because even with the powerful technological tools (e.g., artificial intelligence [AI]) available in the Fourth Industrial Revolution, executives do not have access to basic economic subcorporate productivity information. Without a common unit of value, in addition to the cost to produce the unit of value, forecasting future economic value performance at the subcorporate level is not possible. A value metric, measured in common units, is required to take advantage of these powerful analytic tools that then could be used to help predict the impact of technology (or other) subcorporate investments on organizational productivity in terms of their value adding corporate performance.

Further, these powerful productivity forecasting tools would be useless, without a ratio scale common unit value metric, in nonprofit and public sector organizations because leadership would not be able to assess the relative impact of various investments, for example in infrastructure, safety, defense, and national parks. In both types of organizations, executive leadership must manage the suborganizational, corporate functions as a portfolio of investments with the expectation that such investments will offer the best returns given a certain tolerance for risk.

Purpose Statement and Research Approach

The purpose of this study is to identify the inadequacies in current accounting practice for measuring the productivity and value creation performance of modern nonprofit and public sector organizations as well as in for-profit organizations. While nonprofit organizations diverge from for-profit organizations in how they operate, the differences are typically at the whole organizational strategic level that focus on whole organizational values and goals (Hall & Millo, 2018). It follows that at the subcorporate level, nonprofit and for-profit organizations are essentially the same in that they are both



“nonprofits” because sales revenue is not allocated, and nonprofits have no sales revenue. Performance information in both types of organizations would be quite useful because such performance information would enable forecasting future performance of the whole organization that is subject to the performance of the suborganizational units or core processes. Further, this kind of comparative value adding performance information would lead to identification of best functional or core process practices both within and among other organizations and their suborganizational units, core processes. Such new value accounting methods would be generalizable across all organizations at the subcorporate level. The foregoing possibilities form the overriding goal of this paper: Issuing a challenge, and a plea for help, to the academic accounting community to develop a theoretical framework that will result in a methodology that will pose a new common unit of value that would make all public sector outputs comparable. The result will be a means to measure, and account for, the relative productivity of various public sector organizations and their suborganizational components.

A byproduct of solving this problem would be a new accounting method to peer inside the corporate “black box” to assess the relative performance of the for-profit sector’s suborganizational units, core processes. With this new method to allocate sales revenue to the subcorporate level, it will be possible to provide analysts with a new source of comparative value to cost performance information. It would follow that such new performance information would allow more precise forecasts of future performance. After all, when the productivity of a corporation is not well aligned with the stock price of the corporation, equity bubbles result due to the lack of transparency, as seen in the early heady days of internet-based businesses in the late 1990s and early 2000s.

This study explores how the existing body of accounting theory and research fails to adequately address the problem of there being no agreed upon ratio scale common unit of value developed to account for value creation and productivity in the public sector as well as at the subcorporate level in for-profit companies. To make the case for this gap in accounting theory, this study poses the value problem in a way that indirectly demonstrates the inadequacies of previous similar attempts to address this general problem (for example, using economic utility units or “utils” [McGee, 1997] and human resource accounting [Flamholtz et al., 2002]). The attempts to deal with the



value problem have been based primarily on derivative measures (i.e., not positing common ratio scale units of value) and have not led to substantial agreement as to what constitutes a ratio scale measure of common units of value. The current study is designed to pose this problem, with the hopes that it will encourage debate that motivates accounting theoreticians to propose solutions that might lead to an agreed upon metric for a common unit of value for nonprofit organizations and for the subcorporate level in for-profit organizations.

Fourth Industrial Revolution: Hidden Value

The Fourth Industrial Revolution presents some particularly challenging problems for standard accounting policy and practice. As more and more processes become the venue for optimization by intelligent agents or automation (e.g., using AI), and these agents evolve independent of their human creators, they can begin to make decisions independently. This is particularly problematic for defense operations but, also, applies to service companies (e.g., Facebook). If accounting is charged with monitoring the productivity of any set of functional areas or core processes, then accountants must be able to follow the cost of production and should also be responsible for following the resulting value created by that production. When management leadership focuses their operations optimization strategies on cost reduction, it follows that the evolving intelligent agents will also focus optimization on cost rather than value. The optimizing efforts of independently acting intelligent agents will become increasingly difficult to monitor. The extreme risk that results will be the risk that such agents will attempt to optimize away all costs, creating the cost cutting death spiral.

If, on the other hand, management focuses operational optimization strategies on increasing value, it is likely that these evolving agents will follow suit. The problem is that there is currently no way for GAAP-based policies and procedures to allocate revenue inside the corporate wall or to provide a common unit of value that does not require monetization for nonprofit, governmental organizations, such as the Department of Defense in the United States. So, the Fourth Industrial Revolution is bound to crash on current accounting practice, just as Robert Elliott (1992) predicted that the Third Wave would do more than 20 years ago. Accounting theory must provide a better way



to track the production of value as well as cost and provide systems that can track the behavior of evolving intelligent agents in terms of their value and cost producing behaviors.

To fully understand the implications of the current movement toward the Fourth Industrial Revolution, it is useful to review the current research and thinking about how this movement will impact many aspects of organizational processes and future strategies. The prior research and commentary provide implications for the value focus of the current paper. The World Economic Forum notes the following:

The Fourth Industrial Revolution represents a fundamental change in the way we live, work and relate to one another. It is a new chapter in human development, enabled by extraordinary technology advances commensurate with those of the first, second and third industrial revolutions. These advances are merging the physical, digital and biological worlds in ways that create both huge promise and potential peril. The speed, breadth and depth of this revolution is forcing us to rethink how countries develop, how organisations create value and even what it means to be human. The Fourth Industrial Revolution is about more than just technology-driven change; it is an opportunity to help everyone, including leaders, policy-makers and people from all income groups and nations, to harness converging technologies in order to create an inclusive, human-centred future. The real opportunity is to look beyond technology, and find ways to give the greatest number of people the ability to positively impact their families, organisations and communities. (Cox et al., n.d., n.p.)

With this emergence of the new reality that connects technology across the three primary domains (i.e., physical, digital, and biological), the implications from this revolution ties directly to the value problem that is driving the current study. The Fourth Industrial Revolution is forcing leaders and policy-makers to rethink the concept of “how organizations create value” (Cox et al., n.d.). The implication is that the current system of value, based on the traditional monetization of value, will likely not work well in the emerging era precipitated by the Fourth Industrial Revolution.

Budryte et al. (2020) noted that the role of the state and society will likely change as a result of the behavior of intelligent technologies in the Fourth Industrial Revolution, which will cause “the development of digital economy” and “a change in the value orientations of society” (p. 89). This move toward a predominant digital economy requires the support of an accounting system that can track the value and cost creating



work characterized by digits (i.e., information bits) instead of money alone. The problem remains for accountants to track the conversion of digital inputs into digital outputs from organizations, whether for-profit or nonprofit. But without theoretical accounting concepts and operationalizations to guide accounting practitioners, it will be problematic to provide management with basic accounting information required to make portfolio optimizations based on value as well as cost.

Brondoni (2019) noted that this new Fourth Industrial Revolution economy may spell the end to the multinational, gigantic corporations that have dominated the economic landscape in the past. If the resulting economy becomes fragmented into smaller units of production and that production is intelligent automation, following the inevitability of evolutionary pressures, then accounting must provide the raw data (i.e., cost and value) necessary for optimization strategies. As companies are created, expand, and contract, it becomes incumbent on the accounting community to adapt to the rapidly changing contours of this emerging economy. New companies likely have no revenue streams that accurately reflect the value they are creating. For example, Facebook had no revenue streams in its early life, yet it appears obvious that the members of this company were creating nonmonetized value. Despite its heavy inertia, governmental organizations also evolve, but the question remains as to how these evolutionary changes affect the value such organizations create if their leadership's optimizing strategies are not focused on value.

Chovancova et al. (2018) noted how the previous industrial revolutions not only impacted the growth of productivity and capabilities, but also structurally impacted the macroeconomics at the gross domestic product (GDP) level. Thus, the implications may be that the Fourth Industrial Revolution will also structurally change the economy based on AI powering a robotic workforce. As noted, "At the high level of robotization, it is possible to assume that ... the financial service sector, which is particularly demanding for human capital, will in the near future show a decreasing trend" (Chovancova et al., 2018, p. 413). This does not bode well for the accounting community, which must provide the investment finance community with meaningful raw data to feed their forecasting methodologies, resulting in suboptimized portfolio allocations.



At the individual level, the digitization of the economy also changes the dynamics of how individuals relate to their work and society. Lord (2020) noted how

the global workforce has undergone intense periods of upheaval and change over the past few decades. Technological developments, economic rises and falls and political ideological shifts have reconfigured the working world and challenged traditional employment structures on a global scale. (p. 407)

These changes were exacerbated in 2020 through the impact of the COVID-19 global pandemic that pushed towards a dispersed workforce that relied upon technology to bridge the social distancing that was necessary to slow the spread of the coronavirus. However, during this time, the pandemic also became a motivating factor for senior management to automate more of the functions that were traditionally performed by humans as well as to introduce more human–robot teams.

Lord (2020) noted that blending of robots with the human workforce had mixed results in a case study in South Africa by noting that “the relationship between automatons and mixed production of human workers and robots” was a concern due to the fact that “the rise of the latter fundamentally threatens the former” (p. 413). This reluctance to accept the increasingly robotic workforce by the robots’ human counterparts relates to a threatening subset phenomenon for employees fueled by the Fourth Industrial Revolution (i.e., “Will a robot take my job?”). This question is one of the most frequently searched Internet phrases and has driven the conversation across education and work-preparedness to a new toxic work environment between humans and their robot/AI counterparts (Coldwell, 2019; Teng et al., 2019). One of the most cited studies that investigated this phenomenon was the Oxford study by Frey and Osborne (2017), which analyzed more than 700 occupational areas and then “examine[d] expected impacts of future computerisation on US labour market outcomes, with the primary objective of analysing the number of jobs at risk and the relationship between an occupation’s probability of computerisation, wages and educational attainment” (p. 254). In fact, Frey and Osborne’s (2017) study and analysis became the basis for the website, *Will Robots Take My Job?* Within that website, among the occupations that scored the highest were “accountants and auditors,” which had, at the date of this article, a 94% risk of being automated by AI out of their career fields (Will



Robots Take My Job?, n.d.). In fact, many professional accounting journals are calling for their community to change and adapt to this current era. This research begs the question of how much value intelligent robotic automation is providing within the subcorporate realm or in nonprofit organizations. If it is simply a matter of replacing human operators with robotic operators, then no new value has been created; only costs have been reduced.

As stated by Coovadia (2019), in this Fourth Industrial Revolution it is essential for accountants to “embrace this technology age and follows a path of lifelong learning to add new value within their specific roles” (p. 44). One group of accountants, the Maryland Association of Certified Public Accountants (MACPA), have followed this advice when they provided a framework for learning events specifically tailored to understanding the emerging role of the accountant in the Fourth Industrial Revolution (Maryland Association of Certified Public Accountants, n.d.). However, it appears that the MACPA is an exception and not the rule for education in the accounting profession. The accounting and management literature are full of examples of how accountants are slow to adapt to change, as many are still struggling to use basic automation tools in their field, and very few (except for the European accounting academic and professional communities) have attempted to include the role of intangibles on the balance sheets (Hunter et al., 2012; Mikayilov, et al., 2020; Ndlovu, 2021; Sultana, 2015).

Despite the field of accounting not being adequately prepared for the changes in their field caused by the Fourth Industrial Revolution, these changes are inevitable, and the literature recommends using strategic adoption and innovation for fields, such as accounting, to prepare for the upcoming intelligent technology age (Bagnoli et al., 2019; Ndlovu, 2021; Páez-Avilés et al., 2018; Polivka & Dvorakova, 2021). One of the reasons the accounting field is unprepared for, and vulnerable to, the Fourth Industrial Revolution is that it is based on simple elegant calculations that are ripe for replacement by automation. In fact, other professionals are examining the implications of emerging intelligent automation in terms of the impacts in taking some, or all, of their job functions. According to McGahan et al. (2021), as a result of new technological developments in AI, it may not be long before AI replaces most of middle management. This ties to our research problem as an issue because the AI optimization algorithms



used to replace middle management are focused on cost savings. Thus, if intelligent evolving AI only has cost as the primary subcorporate economic parameter, it will optimize without prejudice all the core processes to eliminate costs and thus lead an organization to enter into a cost-cutting “death spiral” because the evolving AI does not have the tools to optimize based on value. There is an argument that the AI can optimize based on productivity; however, how will it optimize on value when all core process outputs are different and not monetized?

Finally, Baer et al. (2019) presented several questions concerning the impact of AI on value parameters (e.g., in the productivity ratio). A critical issue in this study was the recognition that there is a need for a new value parameter that is not monetized so that future process automation can be optimized on value and not solely on cost reduction. The study also posited that a cost parameter would be enough in and of itself if all processes were perfectly optimized. However, no such perfectly optimized organization currently exists, making the sole focus on cost optimization a “fool’s errand.”

The remainder of the current study explores the requirements for the development of a new common unit of value in accounting and the requirements for its inclusion in accounting theory and practice.



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Problems in Accounting

This section briefly discusses the history of accounting and how it survived since its inception through the agrarian age through the four previous industrial revolutions to remain largely intact today. However, in the light of the changes from the Fourth Industrial Revolution with the growth of technology and the combining physical, digital, and biological domains, the inherent challenges of the value allocation problem may be likely to grow as well.

Successful History of Accounting

Since Fra Pacioli, a 15th century scholar, invented present day accounting (see Mari, et al 2020; Sangster & Scataglinibelghitar, 2010; Stoner, 2011), it has survived largely intact with few and minor modifications. In fact, it has survived beyond the agrarian, industrial, and information ages because

- it protects investors from fraud;
- it provides a subcorporate, objective method to allocate costs;
- it provides the raw data for financial analysis; and
- it works well for nonprofit, governmental organizations.

Given its history of success, why try to change or modify its fundamental tenets? The real question for current accounting practice is in the Fourth Industrial Revolution: What critical performance information is missing? The answer, we believe, is that it does not provide a “common unit” metric for suborganizational *value allocation* in corporations or for nonmonetized value allocation in nonprofit organizations. This is the heart of the research problem, which we conceptually define in this paper as the “Value Allocation Problem.”

Value Allocation Problem

The first issue is whether there is a need for a new value parameter. In other words, “Why try to do this when accounting has been so successful? After all, after over 500 years of following the same accounting theory, why try to modify it?”



Even in the nonprofit world, why try to modify basic accounting theory? The adaptation of generally accepted accounting practices in the nonprofit world has, among other benefits, provided a means to identify fraudulent uses of taxpayer investments. Unfortunately, it has not provided these taxpaying investors with a way to assess the relative productivity performance of various nonprofit, governmental functions or core processes. The taxpayer is left to assess the relative performance of their tax dollar investments in terms of the services they actually receive. This is a less-than-precise way for them to judge the relative performance of their investments across nonprofit, governmental sectors.

A common unit of value metric would allow these investors a way to assess the relative return on their investments in terms of value produced for tax dollar invested. Such performance information might motivate representatives of these nonprofit, governmental entities to press for more investments in some sectors and reduced investments in other sectors based on a more precise understanding of their relative productivity due to use of a new common unit of value-based estimate. This kind of knowledge would lead to a pressure for greater efficiency and likely would also lead to greater effectiveness. Representatives of these sectors would be able to make more defensible economic arguments for investments or reductions of investments.

The same rationale would apply to for-profit corporations for measuring productivity at the subcorporate level. Investors would be able to see how efficiently their investment dollars were being used to produce value throughout a corporation. If, for example, corporate leadership deems that it should receive large increases in compensation, they would have to demonstrate how such investments would result in increased productivity within the corporation. Additionally, management would have a basis for comparing investments in various information technology options in terms of how these would increase value-based productivity among subcorporate units, core processes. Analysts would also have the opportunity to keep track of such investments in information technology options via the common referent point use of value to cost productivity ratios using standard financial analysis techniques such as portfolio optimization of all investment options. Further, they would be able to track such



performance over time using standard methods to assess volatility (i.e., risk) that would feed standard forecasting, back casting regression modeling.

While there are possible advantages of allocating sales revenue to subcorporate units or core processes, no accounting methodology currently exists to make this possible. Accounting theory simply does not allow allocation of sales revenue to the subcorporate level because accounting theory provides no objective way to do so. Historical cost accounting theory provides a deterministic-objective method to allocate costs because the costs are historical and can be allocated to the subcorporate units or core processes that incurred those costs at a given point in time. In the case of allocating sales revenue to the subcorporate level, using the same kind of deterministic historical method has not been possible because no objective way to allocate value (i.e., sales revenue in for-profit corporations) has been identified. However, it stands to reason that the historical sales revenue (i.e., value) actually came from the functions--core processes of the black box corporate entity, just as the historical costs were incurred by the same black box and its subcorporate units or core processes. This issue is even more acute for nonprofit, governmental organizations that have no sales revenue to allocate, even if accounting theory could provide a means to do so.

There are several nonprofit, governmental examples of where such a value metric might provide useful to decision-makers in allocating taxpayer investments. There has been a big push for investments in national infrastructure in the United States. Taxpayers can readily see the advantages of repairing aging bridges, filling in potholes in the highways, improving the quality of drinking water, and providing more public transportation options—largely because they can see the immediate benefits in their daily lives. The rationale for investing in less tangible potential beneficial options, such as improving library services and addressing income equality or global warming are less immediately clear and therefore harder to justify in the minds of many taxpayers. If such a range of investments could be quantified from a common point of view in terms of their potential value to cost, using objective metrics for both parameters, the taxpaying public could be provided a more objective means to assess the value they would receive from the cost of using their taxpayer investments.



Another, more concrete example comes from the U.S. Navy's ship maintenance investments, which are quite substantial. A proposal has been put forward to increase the productivity of these maintenance processes using various technologies such as product life cycle management, three-dimensional laser scanning technology, and additive manufacturing (Housel et al., 2015). The challenges for the executive decision-makers include whether to invest in all three technologies immediately, over time, or not at all. The Navy executives' common focus is on cost savings for all operations, including ship maintenance. With this as the single optimization strategy, it would be best to fire all maintenance personnel and sell the ships, resulting in no costs for maintenance. As this is not possible, it must be acknowledged that the ship maintenance activities provide some value. The problem is how to quantify that value in other than purely cost savings terms. Using an ambiguous, subjective value rationale would not be ideal as the results of such analysis would not provide comparable estimates of the value to cost problem. However, with a common units of value parameter, the cost to value estimates would be comparable and provide a more defensible rationale for allocating scarce ship maintenance investment dollars.

A very serious question for venture capitalists (VCs) is how to assess the potential ROIs in start-up companies that have virtually no sales revenue. For example, imagine that you are a typical VC or a naïve angel investor trying to decide whether to invest in MySpace or Facebook in the year 2005. At that point in time, Facebook had virtually no revenues and MySpace was producing modest revenues, and their business models appeared to be very similar. Standard financial analysis would probably lead to greater investments in MySpace, given its history of sales revenue to investment costs due to the availability of equity price volatility or simple ROI volatility. However, it was clearly the case, in hindsight, that Facebook was creating value. But this value simply could not be objectively monetized and, therefore, verified—unlike in the MySpace corporation. In the Facebook case, there was no objective, ratio scale value parameter supplied by accountants. If accounting theory could have provided an objective historical estimate of value production over time for Facebook, the VC investor would have been provided another source of information to make their investment decisions. This kind of problem may become the dominant challenge for investors living in the age



of the Fourth Industrial Revolution, which is typified by start-up companies that are producing “truly new” products or services for which there are no market comparables (using that standard appraisal methodology). A new ratio scale value parameter would provide insights into the historical value production of such new companies, which is one reason accounting theory should be expanded to incorporate the rationale for such a parameter.

To summarize the rationale for expanding accounting theory to include a new ratio scale value parameter for nonprofit and for-profit organizations, we offer the following potential advantages of having such a new parameter. It would

- measure the productivity of all suborganizational components, processes, and functions from a common value to cost reference point;
- be useful to financial analysts and investors as it allows more precise forecasting of future organizational performance;
- be useful to the taxpaying public: providing a way to understand how much value they receive per the tax dollar invested; and
- allow executives to manage their organizations as a portfolio of suborganizational assets from a common referent, value to cost, point.

Several potential benefits resulting for incorporation of this new value parameter in accounting theory would include some rather provocative but potentially very useful options for investors as well as accounting professionals. Auditors could expand their services to include a common way to compare the productivity of various units, functional areas, or core processes. This group of accounting professionals is perfectly placed to provide such a new service because they are already collecting performance data (quite often to determine whether there have been nefarious activities in an organization). They would need new training on how to collect the value parameter data and how to incorporate it in their analyses.

Another possibility that would require substantial change would be the creation of a subcorporate equities market. To use an example of the outcome of such a move for investors, the result would be the opportunity to invest in subcorporate units, functional areas, or core processes. It would be rare, if not impossible, to find a corporation that is perfectly optimized throughout all its units, functional areas, or core processes.



Therefore, the implicit assumption is that to improve subcorporate productivity all that is needed is to reduce costs—as a means to optimizing the organization—and this would have no harm to value production because all operations would then be perfectly optimized. Thus, there are discontinuities in the relative productivity of subcorporate units, functional areas, and core processes. In given market sectors, some subcorporate units are more productive than others. If a corporation were virtually separated into, for example, functional areas, investors would be more motivated to invest in those that provided better returns to risks (i.e., using the Sharpe ratio) based on historical performance.

This kind of subcorporate equities market would also provide greater transparency of how well management was using investors' dollars throughout the corporation. The added benefit of this kind of transparency would be that capital flows to transparency because it reduces risks. The data from this kind of market would provide financial analysts with a new source of information to assess the potential of given investment options, as well as assessing the productivity of the corporation holistically. Such new information would tend to drive capitalism to a lower level, forcing corporate executives to divest poorly performing units or to force greater productivity from the poorly performing units. This kind of information would also lead to less requirement for executive management, as the force of capital would optimize corporations simply by providing more precise performance feedback for subcorporate units. The investor would also benefit from having an order of magnitude more equities (e.g., from approximately 3,000 New York Stock Exchange equities to 30,000 subcorporate equities) to choose from to optimize their portfolios. Ultimately, the concept is that the more information investors have about the performance of organizations, the better able they are to make sound investment decisions.



New Value Metric Requirements and Measurement Theory in Accounting

Ultimately, accounting is basically a measurement system that provides information about the use of investments (i.e., costs) to fund the activities of an organization. As such, it allows for the tracking of the use of investments and the value such investments produce.

Accounting is the science of measurement. It is treated as an enterprise information system, which primary task is the measurement and valuation. Measurement precedes valuation and is associated with the process of collecting the various figures and descriptive information in the process of accounting. (Sadowska & Lulek, 2016, p. 247)

A critical question for those accounting researchers who are attempting to address the problem or opportunity to develop a common unit of value metric is, “What criteria or constraints are required to make this new common unit of value acceptable to nonprofit and for-profit accounting theoreticians?” In what follows, we outline what we believe to be required for such a common value unit to be deemed a valid and reliable metric. A brief review of some general measurement theory postulates precede the enumeration of the required criteria for such a new metric.

Measurement theory discussions that are relevant to the current article focused on four basic measurement scales that can be used for various accounting problems. The hierarchy of these scales is as follows and is summarized in Table 1.

Ratio Scales

A ratio scale is defined by Godfrey et al. (2010) as a “type of scale where the rank order is known, intervals are equal, and the scale has a unique origin or natural zero point. Under a ratio scale we can compare the relative performance of firms and legitimately use accounting numbers as ratios” (p. 510). These scales measure phenomena of interest in terms of common units and assume that such units are continuous and have a true zero point (Bhandari, 2021). Bhandari (2021) describes ratio scales in detail as follows:



A ratio scale is a quantitative scale where there is a true zero and equal intervals between neighboring points. Unlike on an interval scale, a zero on a ratio scale means there is a total absence of the variable you are measuring. Length, area, and population are examples of ratio scales. ...At the ratio level, values can be categorized, ordered, have equal intervals and take on a true zero. ... On a ratio scale, a zero means there's a total absence of the variable of interest. (Bhandari, 2021, n.p.)

Mature science typically employs ratio scales for measurement. Accounting uses ratio scales based on the common monetary units. At the subcorporate level, in for-profits and in nonprofits, cost is measured in monetary units. There are basically no sales revenue comparable common units of value in nonprofit organizations, such as the DoD (excluding foreign military sales). In for-profit corporations, value is measured at the whole corporate level in terms of sales revenue that occurs outside the corporation.

There are no common units of monetized value in for-profits at the subcorporate level. Ultimately, however, a new common unit of value metric must be based on ratio scaling to be acceptable in accounting theory and practice. Ratio scales are predominantly used in "mature" (Kuhn, 2012) sciences because they permit the application of the reductionist epistemic assumption. As sciences follow the reductionist move toward greater clarity of the phenomena under study, they continuously apply ratio scaling. In the search for a new common unit of value, accounting theory would be applying a reductionist logic to establish a measure that was more precise than monetization because it would be agnostic to monetization and would provide a more fundamental unit of economic activity, leading to a more profound and a more precise understanding (i.e., accounting for) of the performance of an organization because it would be equally applicable in a for-profit or a nonprofit organization. The absolute reliance on monetization in accounting has prevented the normal movement toward a more mature science of accounting based on the inevitable need to move toward a more granular unit of economic activity.

Table 1 demonstrates how the arithmetic application of the ratio scale allows the accountant to make determinations of equality (i.e., that "a" does not equal "b"), the rank



order (that “a” is greater than or less than “b”), the determinations of equality of intervals (that the difference that “a” is greater than or less than “b” is consistent with the distance that “c” is greater than or less than “d”), and the determinations of equality of ratios (that the ratios between “a” and “b” are consistent with the ratios of “c” and “d”) .

Interval Scales

An interval scale is defined by Godfrey et al. (2010) as “a scale that uses numbers which have rank order and equal appearing intervals ... but uses an arbitrary point of reference” (p. 508). These scales typically assume that human judgement concerning given research problems can be assessed on an integer-based scale that can run from 1–5, 1–7, 1–10, 1–100, and so on. Interval scales essentially attempt to mimic ratio scales when the use of ratio scales is problematic. For example, it does not make sense to suggest that individuals being surveyed have a zero level of attitude about a given subject, such as the death penalty or the value of a given new corporate logo or brand. Another example is the thermometry, when one uses the Celsius or Fahrenheit scales for temperature, the values for each degree are equally spaced (Abdel-Magid, 1979; Chambers, 1965; Larson, 1967). However, one cannot say that 30 degrees Celsius is twice as hot as 15 degrees Celsius. Also, for those scales, the “zero” is an arbitrary term.

The advantage of interval scales over ordinal and nominal scales is that interval scales provide a form of distance information, which makes possible the use of advanced statistical methods. Mattessich (1964) noted that “standard cost accounting” (p. 71) is an instance in which accounting consistently utilizes the interval scale. This is because, as Mattessich (1964) noted in standard costing, the “standard” is based on an arbitrary scale (i.e., an average cost, or planned cost) so the variances are based off that “standard” rather than a true zero. However, interval scales that show only the relative difference in value of a given subcorporate for-profit corporations or a respective DoD organization’s functions would ultimately not be acceptable in accounting theory or practice. This is because such judgements are not auditable or objectively defensible in accounting for value.



Ordinal Scales

An ordinal scale is defined by Godfrey et al. (2010) as a scale that uses “numbers to rank or order between alternatives” (p. 509). An example of how accountants use ordinal scales is the “chart of accounts” that are listed in rank order. Vickrey (1970) described this as “numerals assigned to the classes on a typical chart of accounts” these charts of accounts “constitute a place-value system similar to the decimal system, ordinal scales for determining classes and subclasses are established” (p. 737). Another example of ordinal scales in the nonprofit sector is the U.S. Department of Defense ordering military programs by their military value. The operational term that they use to describe this ordering is a “rack and stack” process for military decision-makers to order programs by their priority in meeting their organization’s military mission in the case of budget cuts. Godfrey et al. (2010) noted that accountants undergo a similar process in the private sector by ranking firms according to their profitability. While the ordinal scale provides utility, its major weakness is that it does not provide any information about the distance between the numbers on the ranking.

Nominal Scales

A nominal scale is defined by Godfrey et al. (2010) as one that uses “numbers as labels” (p. 508). Lim (1966) noted that the “nominal scale is significant in the accounting measurement process in that the nominal scale permits the universe of events of an entity to be grouped into property sets” (p. 643). Vickrey (1970) stated that the “single nominal scales” are not as useful to the field of accounting “because of the requirement that scales used to measure classificatory systems partition the elements of the systems into mutually exclusive classes” (p. 736). Thus, the purpose of the nominal scale in accounting is to categorize items on the balance sheet into groups. While Godfrey et al. (2010) noted that because of the limited utility of the nominal scale, many theorists do not even consider nominal as a measurement scale. However, it is the nominal scale that facilitates double entry accounting by allowing the accountant to compare each category on the balance, and thereby is fundamental to accounting.



Table 1. Summary of Measurement Scales Based on Their Arithmetic Applications

Uses and Applications	Nominal	Ordinal	Interval	Ratio	
Determination of Equality	X	X	X	X	
Determination of Rank Order		X	X	X	
Determination of Equality of Intervals			X	X	X
Determination of Equality of Ratios				X	

Note. This table is an adaptation of Vickrey's (1970) "Familiar Scale Types" (p. 733).

To conclude this discussion on measurement scales, Vickrey (1970) noted that "various authors have claimed that nominal, ordinal, interval, and ratio scales are being used extensively in accounting" (p. 735). However, the utility of each kind of scale and the extent of the use of each kind of scale is not equal among the scales. As demonstrated in Table 1, the ratio scale provides the most utility and use to the accounting profession, whereas the interval, ordinal, and nominal scales provide more limited information about an organization's economic activity.

Necessary Criteria for a New Unit of Value

There are several required criteria that are necessary for any new common unit of value for nonprofits and for-profits (at the subcorporate level). This is simply a preliminary list of criteria; others may follow with more research on this topic. It follows that accounting researchers may increase, decrease, or disallow some of the following criteria. The purpose of the current article is to stimulate research and debate concerning the nature and form of a new common unit of value in accounting.

The first, and perhaps most important, criterion is that any new accounting metric of any kind that will help provide precise information about the organization's economic activity must be measurable using a ratio scale. That is, the metric must be measurable in common units of value just as cost is measurable in common units of money. Otherwise, it will be virtually impossible to precisely account for the value generated



within an organization, while cost can be precisely accounted for in traditional accounting theory.

It is difficult to imagine how a practicing accountant would account for value, objectively, using the judgements of executives or lower-level managers based on an interval or ordinal scale for example. How would an auditor precisely and objectively account for the value produced by a given unit, function, or core process in anything other than a ratio scale? The complexity of attempting to interpret value judgements, based on anything except a “common units,” ratio scale-based parameter, in a way that would make such subjective judgements of value comparable across an organization, would mitigate against using anything but a ratio scale for the new value metric. One of the reasons that accounting has last for hundreds of years is that it is deterministically objective and simple to apply practically. As such, it has provided defensible, historically precise statements concerning a given organization’s use of investment dollars.

Any proposed common unit of value must *not* be derivative of cost. For example, if it is proposed that the new value unit simply be a cost saving based unit, then the ultimate logic would be to fire all employees and sell all inventory and equipment, offices, and so on. The resulting cost savings would be the largest possible if cost savings equals value units. This approach would also tend to entice executives and managers to optimize processes or functions based on cost rather than a unique measure of value. Focusing optimization on value, instead of purely on cost savings, would help organizations, for-profit and nonprofit alike, to avoid the well documented “Cost Reduction Roller Coaster” (Shields & Young, 1993, p. 18), which is a “typically a distress tactic targeted at all employees. It is triggered in reaction to an immediate threat, such as poor performance, loss of contracts, or price reductions” (p. 27). Shields and Young’s (1993) “Cost Cutting Roller Coaster” is often referenced in the more recent “Cost Cutting Death Spiral” (Oliva & Sterman, 2010; Rust et al., 2002).

Such approaches assume that it is possible to cut costs without destroying value. Of course, the possibility that cost cutting that does not destroy value is a wonderful idea but begs the question of whether value has also been cut because there is no unique metric for tracking value in such an approach. It follows that if all the



performance information is contained in the denominator (i.e., cost) of the productivity ratio—that is, output (i.e., value)/input (i.e., cost, investment)—then there is no need for a new value metric. Such “cost savings equals value” approaches implicitly assume that the organization has perfectly optimized processes, allowing for reductions in the denominator (e.g., using intelligent automation) without a reduction in the numerator. Perhaps such perfectly optimized organizations exist but, to date, none have been identified.

The opposite would also be true for such organizations using a new common units value parameter to gauge the relative productivity of their functional areas or core processes, because more investments in organizational processes would result in more value produced. Again, if such organizations exist, they are well hidden from public view—due, in part, to their lack of value producing transparency.

A new value unit must be agnostic to monetization, or it will not be useful to nonprofit organizations that produce no sales revenue. This requirement challenges the reliance on the monetization of value. As accounting does not allow, or perhaps even consider, the allocation of sales revenue to the subcorporate level in for-profit organizations, monetization cannot be the sole basis for a new common unit of value metric. This is not to say that the current value operationalization, based on sales revenue, would be changed with the introduction of a new monetization agnostic unit of value.

Such a new unit of value would simply provide a way to make the productivity of all subcorporate processes comparable, providing executive leadership and general management a means for comparing core process or functional area performance across an organization from a common objective value perspective. It would also allow a comparable performance index across industries in terms of core processes or functional areas. In addition, for-profit subcorporate process or functional area performance could be compared to similar functional areas or core processes in nonprofits. For example, in the U. S. Navy ship maintenance core processes, the for-profit shipyards and Navy shipyards perform essentially the same tasks. The resulting core processes are highly comparable, and performance analysis within and across the



two types of shipyards could be compared to determine best practices and the effects of new technologies to support ship maintenance processes.

A new value metric cannot be based purely on a market comparables (i.e., market comps) approach. Market comps can be useful when the valued entity is truly comparable to the non-valued entity, such as when realtors estimate the value of a given property on the market comps of real estate that have recently sold in the same area. They use a price per square foot (or meter) to estimate the potential market value of a new home that will be placed on the residential real estate market shortly.

One problem with this approach when applied to a subcorporate component, process, or function is that it is very difficult to find a comparable component that has generated revenue that would allow the generation of a sales price per value unit. It is highly unlikely that defensible market comps could be generated for all organizational functions, processes, and components that when summed would then equal the sales revenue of a given corporation at a given point in time. While market comparables are a useful valuation technique at the whole corporation level, it is inadequate at the subcorporate level. For some of the same reasons, it is inadequate for nonprofits because their suborganizational components would not have a common reference point for their market comp valuation.

A new value unit must be empirically observable just as the generation of costs is empirically observable on an organization's general ledger. It follows that when a unit of value is produced, it should be objectively empirically observable. In the case of the use of intellectual capital to generate units of value, such implicit units of value produced would have to be made explicit to be accounted for. For example, when the output of a process or function is a decision, the production of the decision would have to be made explicit to be empirically observed. It follows that even implicit production of value units via the use of intellectual capital resources would have to be accounted for in the same way as empirically observable production of value in explicitly defined processes and/or functions. This is critical because auditors of value to cost ratios would need to identify the amount of value produced for a given cost within a given organizational component.



General measurement theory requires that any measurement deemed to be acceptable must also be reliably generated. One reason for the success of traditional cost accounting is that its general principles can be applied reliably in any organizational setting. Any approach that uses a new common unit of value must also be reliable or it will surely fail over time. For example, no audit would be deemed acceptable if different auditors applied general accounting principles and derived different costs for the same components and/or functions.

It would be acceptable when trialing a new value metric to have some limited variances in accounting for value. However, when the principles, upon which rest the credibility of the new value metric, produce widely different estimates of value, then the approach will be doomed to failure. Elements of the principles that are highly subjective will severely limit the reliability of the new value unit metric.¹

One of the reasons that basic accounting has been so successful over the centuries since it was invented is that it is relatively easy to understand and use. It follows that any approach to understanding and using a new value metric should be relatively easy to understand and use. If an approach to understanding and flexibly using a new value metric can be taught to undergraduate accounting students, then the approach will be more likely to succeed.

If the rationale for the new metric and the ways it can be used in accounting are overly burdensome and difficult to apply, it will be unlikely to attract adherents in the highly pragmatic accounting community. It will also be difficult to include in standard accounting information systems if it does not adhere to the general historical deterministic logic of cost accounting. Such practical issues must be addressed and resolved, or the new value metric approach will never reach wide adoption by the practitioner accounting community.

¹ One model suggested for use in evaluating the value of defense/military is the insurance model. While it stands to reason that a defense organization should provide insurance against attack from enemies, using an insurance model is very problematic. Such a model would require extensive actuarial tables that currently do not exist due to the relatively few actual kinetic attacks on the United States. It also fails to provide a means to differentiate the relative insurance value of all the components of an integrated military. As such it does not meet most of the criteria reviewed for a successful approach to assigning relative value, in common units, to the various components of the military.



A final criterion for any new value methodology would be that it must eventually be validated by empirical research that is acceptable to the academic accounting community. As such, it would have to be subjected to peer reviewed, credible academic accounting or management journals. This is the standard criteria for any new scientific approach.



Conclusion

A successful introduction of a new theory of value accounting must pass the test of the foregoing criteria to reach wide adoption. The sole focus of the current study is to attempt to place the issue of the need for a new value accounting methodology, and resulting ratio-based value parameter, that reaches into the insides of a for-profit as well as providing a new way to track value to cost performance in nonprofits. If the accounting community takes up this challenge and succeeds, it will lead to important new insights that only accounting models and practices can bring. If the conversation among executives and managers for process optimization can be changed from an obsession with cost to an obsession with value, the future of capitalism and the Fourth Industrial Revolution will be bright. Accountants, armed with a new value metric, can help drive organizations, for-profits and nonprofits, toward greater value production, leading to numerous benefits to organizations and society in general. Failing to find a way to focus on value will relegate accounting to a very small place at the table of executive leaders.



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Future Research

There are a series of questions that must be addressed in a new value metric initiative before it can succeed. The answer to these questions will build the scaffolding for a new theory of value at the subcorporate level in for-profits and across the components of nonprofits.

Here are some research questions to inform the approach of this new value metric research agenda:

- What are the constraints in the accounting field that inhibit making changes to GAAP and IFRS to adapt the new value metric for the Fourth Industrial Revolution?
- How does the accounting field currently address deficiencies in practice for public sector organizations, and how would a new value metric help in this task?
- What are constructs and premises for a new theory of value that could be applied in the public sector?
- What are the general boundaries and constraints for development of a new theory of value for the public sector?
- What are the requirements from organizational leaders and managers that would make a new theory of value useful for them?
- What are the significant gaps/differences between the identified requirements for a new theory of value and current accounting metrics?
- How would a new theory of value metric meet the criteria for acceptance as a raw, historical, common unit of measurement?



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References

- Abdel-Magid, M. (1979). Toward a better understanding of the role of measurement in accounting. *The Accounting Review*, 54(2), 346–357.
- Akhter, A., & Sultana, R. (2018). Sustainability of accounting profession at the age of Fourth Industrial Revolution. *International Journal of Accounting and Financial Reporting*, 8(4), 139–158.
- Aleksandrov, E. (2019). Actors' reflexivity and engagement in the formation of new accounting tools during university hybridization. *Qualitative Research in Accounting and Management*, 17(1), 51–81.
- Baer, W., Housel, T., & Jones, R. (2019, July 11–12). *Challenge for acquisition of AI: An econophysics approach* [Presentation]. IC15: World Conference on Intellectual Capital for Communities in the Knowledge Economy, UNESCO, Paris, France.
- Bagnoli, C., Dal Mas, F., & Massaro, M. (2019). The 4th Industrial Revolution: Business models and evidence from the field. *International Journal of e-Services and Mobile Applications*, 11(3), 34–47.
- Bhandari, P. (2021, September 16). *What is a ratio scale of measurement?* Scribbr. <https://www.scribbr.com/statistics/ratio-data/>
- Bickle, J. (2008). Real reduction in real neuroscience: Metascience, not philosophy of science (and certainly not metaphysics!). In J. Hohwy and J. Kallestrup (Eds.), *Being Reduced* (pp. 34–51). Oxford University Press.
- Bierman, H. (1963). Measurement and accounting. *The Accounting Review*, 38(3), 501–507.
- Brondoni, S. (2019). 4.0 IR, oversize economy and the extinction of mammoth companies. *Symphonya: Emerging Issues in Management*, 2, 8–24.
- Budryte, P., Chala, N. D., & Poplavska, O. M. (2020). Transforming the relations between state and society in the context of the 4th Industrial Revolution: Ukraine's experience. *Public Policy and Administration*, 19(1), 89–98.
- Burritt, R., & Christ, K. (2016). Industry 4.0 and environmental accounting: A new revolution? *Asian Journal of Sustainability and Social Responsibility*, 2016(7), 1–16.
- Chambers, R. (1965). Measurement in accounting. *Journal of Accounting Research*, 3(1), 32–62.
- Chambers, R. (1968). Measures and values: A reply to Professor Staubus. *The Accounting Review*, 43(2), 239–247.



- Chambers, R. J. (1964). Measurement and objectivity in accounting. *The Accounting Review*, 39(2), 264–274.
- Chambers, R. J. (1991). Metrical and empirical laws in accounting. *Accounting Horizons*, 5(4), 1–15.
- Cho, C. H. (2020). CSR accounting ‘new wave’ researchers: ‘Step up to the plate’ ... or ‘stay out of the game’. *Accounting and Management Information Systems*, 19(4), 626–650.
- Chovancova, B., Dorocakova, M., & Malacka, V. (2018). Changes in the industrial structure of GDP and stock indices also with regard to industry 4.0. *Business and Economic Horizons*, 14(2), 402–414.
- Cluskey, G. R., Ehlen, C. R., & Rivers, R. (2007). Accounting theory: Missing in action? *Management Accounting Quarterly*, 8(2), 24–31.
- Coldwell, D. A. L. (2019). Negative influences of the 4th Industrial Revolution on the workplace: Towards a theoretical model of entropic citizen behavior in toxic organizations. *International Journal of Environmental Research and Public Health*, 16(15), 2670+.
- Coovadia, H. (2019). Chartered accountants in the 4th Industrial Revolution. *Accountancy SA*, 44.
- Cox, K., Hawkins, T., Yiming, L., & Ratan, R. (n.d.). *Fourth industrial revolution*. World Economic Forum. Retrieved January 25, 2022, from <https://www.weforum.org/focus/fourth-industrial-revolution>.
- Elliott, R. K. (1992). The third wave breaks on the shores of accounting. *Accounting Horizons*, 6(2), 61–85.
- Flamholtz, E. G., Bullen, M. L., & Hua, W. (2002). Human resource accounting: A historical perspective and future implications. *Management Decision*, 40(10), 947–954.
- Frey, C. B., & Osborne, M. A. (2017, January). The future of employment: How susceptible are jobs to computerisation? *Technological Forecasting & Social Change*, 114, 254–280.
- Godfrey, J. M., Hodgson, A., Tarca, A., Hamilton, J., & Holmes, S. (2010). *Accounting theory*. John Wiley.
- Guliyev, V., & Hajiyev, N. (2020). *New approach to the nature and accounting of amortization of assets*. Varazdin Development and Entrepreneurship Agency.



- Hall, M., & Millo, Y. (2018). Choosing an accounting method to explain public policy: Social return on investment and UK non-profit sector policy. *European Accounting Review*, 27(2), 339–361.
- Hopwood, A. G. (2007). Whither accounting research? *The Accounting Review*, 82(5), 1365–1374.
- Housel, T., Ford, D., Mun, J., & Hom, S. (2015). *Benchmarking naval shipbuilding with 3D laser scanning, additive manufacturing, and collaborative product lifecycle management* (Report No. NPS-AM-15-126). Naval Postgraduate School. <https://dair.nps.edu/handle/123456789/2650>
- Hunter, L., Webster, E., & Wyatt, A. (2012). Accounting for expenditure on intangibles. *Abacus (Sydney)*, 48(1), 104–145. Ijiri, Y., & Jaedicke, R. (1966). Reliability and objectivity of accounting measurements. *The Accounting Review*, 41(3), 474–483.
- Jarvinen, J. (2016). Role of management accounting in applying new institutional logics: A comparative case study in the non-profit sector. *Accounting, Auditing, & Accountability*, 29(5), 861–886.
- Kovalchuk, J., & Stepnov, I. (2017). *About the new industrial production management concept as the company strategy in the fourth industrial revolution*. EDP Sciences.
- Kuhn, T. S. (2012). *The structure of scientific revolutions, 50th anniversary edition*. University of Chicago Press.
- Larson, K. (1967). Descriptive validity of accounting calculations. *The Accounting Review*, 42(3), 480–488.
- Larson, K. D. (1969). Implications of measurement theory on accounting concept formulation. *The Accounting Review*, 44(1), 38–47.
- Lee, J. (2013). Industry 4.0 in big data environment. *German Harting Magazine, Technology Newsletter*, 26.
- Li, Q., & Shen, B. (2016). Sustainable design operations in the supply chain: Non-profit manufacturer vs. for-profit manufacturer. *Sustainability*, 8(7), 639.
- Lim, R. (1966). The mathematical propriety of accounting measurements and calculations. *The Accounting Review*, 41(4), 642–651.
- Lord, P. (2020). Changing world, changing work. *Contemporary Social Science*, 15(4), 407–415.



- Makino, M., Polygalov, D., Bolaños, F., Benucci, A., & McHugh, T. J. (2019). Physiological signature of memory age in the prefrontal-hippocampal circuit. *Cell Reports*, 29(12), 3835–3846.
- Mari, L.M., Picciaia, F., & Sangster, A. (2020). Manzoni’s sixteenth-century “Quaderno Doppio”: The evolution of accounting education towards modern times. *Accounting History*, 25(4), 580–601.
- Maryland Association of Certified Public Accountants. (n.d.). *#FutureReady learning framework*. Maryland Association of CPAs. Retrieved January 25, 2022, from <https://www.macpa.org/future-learning-framework/#0>
- Mattessich, R. (1964). *Accounting and analytical methods*. Irwin.
- Mikayilov, F., Mammadova, S., Ibishov, E., Rzayev, R., & Huseynov, R. (2020). Evaluation of national wealth approaches and problems. *Economic and Social Development: Book of Proceedings*, 3, 344–349.
- McGahan, A. M., Bogers, M. L. A. M., Chesbrough, H., & Holgersson, M. (2021). Tackling societal challenges with open innovation. *California Management Review*, 63(2), 49–61.
- McGee, R. W. (1997). The fatal flaw in the methodology of law & economics. *Commentaries on Law & Economics*, 1(1), 209–223.
- Ndlovu, L. (2021). Enhancing the value of patents as corporate assets in South Africa: How can Artificial Intelligence (AI) assist? *Potchefstroom Electronic Law Journal*, 24, 1–38.
- Oliva, R., & Sterman, J. (2010). Death spirals and virtuous cycles: Human resource dynamics in knowledge-based services. In P. P. Maglio, C. A. Kieliszewski, and J. C. Spohrer (Eds.), *Handbook of Service Science* (pp. 321–358). Springer.
- Páez-Avilés, C., van Rijnsoever, F. J., Juanola-Feliu, E., & Samitier, J. (2018). Multi-disciplinarity breeds diversity: The influence of innovation project characteristics on diversity creation in nanotechnology. *The Journal of Technology Transfer*, 43(2), 458–481.
- Polivka, M., & Dvorakova, L. (2021). Selection of the ERP system with regard to the global 4th Industrial Revolution. *SHS Web of Conferences*, 92, 04019+.
- Prentice, C. R. (2016). Why so many measures of nonprofit financial performance? Analyzing and improving the use of financial measures in nonprofit research. *Nonprofit and Voluntary Sector Quarterly*, 45(4), 715–740.
- Rust, R. T., Moorman, C., & Dickson, P. R. (2002). Getting return on quality: Revenue expansion, cost reduction or both? *Journal of Marketing*, 66(4), 7–24.



- Sadowska, B., & Lulek, A. (2016) , Measuring and valuation in accounting – theoretical basis and contemporary dilemmas. *World Scientific News* 57, 247-256.
- Salawu, M. K., & Moloi, T. S. (2020). Critical factors for accounting estimation of investment in artificial intelligence: An imperative for accounting standards setters in the Fourth Industrial Revolution Era. *The Journal of Accounting and Management*, 10(1), 39–48.
- Sangster, A., & Scataglinibelghitar, G. (2010). Luca Pacioli: The father of accounting education. *Accounting Education*, 19(4), 423–438.
- Sarkar, S. (1992). Models of reduction and categories of reductionism. *Synthese*, 91, 167–194.
- Scerri, E., & McIntyre, L. (1997). The case for the philosophy of chemistry. *Synthese*, 111, 213–232.
- Schaffner, K. (2006). Reduction: The Cheshire Cat problem and a return to roots. *Synthese*, 151, 377–402.
- Schaffner, K. (2012). Ernest Nagel and reduction. *Journal of Philosophy*, 109, 534–565.
- Schwab, K. (2015, December 12). The Fourth Industrial Revolution: What it means and how to respond. *Foreign Affairs*. <https://www.foreignaffairs.com/articles/2015-12-12/fourth-industrial-revolution>
- Schwab, K. (2017). *The Fourth Industrial Revolution*. Crown Business.
- Shields, M. D., & Young, S. M. (1992). Effective long-term cost reduction: A strategic perspective. *Journal of Cost Management*, 6(1), 16–30.
- Steccolini, I. (2019). Accounting and the post-new public management: Re-considering publicness in accounting research. *Accounting, Auditing, & Accountability*, 32(1), 255–279.
- Stoner, G. (2011). The perseverance of Pacioli's goods inventory accounting system. *Accounting History*, 16(3), 313–329.
- Sultana, N. (2015). Audit committee characteristics and accounting conservatism. *International Journal of Auditing*, 19(2), 88–102.
- Tahmasib, H., Ulkar, M., Elshad, A., Fakhri, N., & Farida, S. (2020). The impact of the transition to electronic audit on accounting behavior. *Economic and Social Development: Book of Proceedings*, 4, 378–384.



Teng, W., Ma, C., Pahlevansharif, S., & Turner, J. J. (2019). Graduate readiness for the employment market of the 4th Industrial Revolution. *Education & Training (London)*, 61(5), 590–604.

Vickrey, D. (1970). Is accounting a measurement discipline? *The Accounting Review*, 45(4), 731–742.

Will Robots Take My Job? (n.d.). *Will “accountants and auditors” be replaced by robots?* Retrieved January 25, 2022, from <https://willrobotstakemyjob.com/accountants-and-auditors>





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