Towards Improving Green Technologies Education: The Role of the ACM/IEEE/AAAI Model Curricula

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***Abstract*—In Spring 2021, the joint work of the ACM, IEEE Computer Society, and AAAI started the effort to revise undergraduate Computer Science curricular guidelines issued once every ten years, currently referred to as CS2023. Significant updates to the new version of the CS curricula have been proposed, particularly the infusion of Society, Ethics, and Professionalism (SEP) into all the 18 knowledge areas (KA) of the curricular recommendation. Additionally, due to new and rapidly emerging computing areas, the number of platforms has increased considerably in Mobile, Web, Game Computing, and Embedded and Industrial Robotics. The Specialized Platform Development (SPD) KA proposes a shift from "elective" to "core" knowledge units. Because of the rapid research development in Green Technologies (GT), we recognize that the pedagogical and the SEP components shall be infused in the design and development of such technologies to foster technological innovation and excellence for the benefit of humanity. In this paper, we recognized several KAs that can influence computing curricula, particularly the ones that reference industrial and GT. Additionally, the authors of this paper recommend the SEP considerations in the development of technologies that will influence the next decade of research and industry implementations.**

***Index Terms*—CS2023, Computer Science, Specialized Platform Development, Society, Ethics, Professionalism, SEP, ACM/IEEE/AAAI. green technologies, education**

I. Introduction

In Spring 2021, the joint work of the ACM, IEEE-Computer Society, and AAAI started the effort to revise undergraduate Computer Science curricular guidelines issued once every ten years, currently referred to as CS2023. The work comprises 18 Knowledge Areas (KA), covering significant concepts in the most influential computer science areas. Because of the collective efforts between professional associations, it is worth discussing the convergence of pedagogical and educational components in the design of Green Technologies (GT). Therefore, this work is an opportunity to incorporate educational recommendations into multidisciplinary areas. Mainly, this work focuses on the following areas of interest:

Specialized Platform Development. Due to the ubiquitous interfacing between software and hardware platforms, the Specialized Platform Development (SPD) KA has reflected the commonality and interactivity in devices among the other KAs. The SPD has included topics such as Mobile Computing, Game Computing, and Industrial Robotics – the latter, along with embedded systems, play an enormous role while designing elements that deal with the transmission of information. Considerations while distributing and storing data from smart grids or any transportation mechanisms. Additionally, it can recognize standards and regulations for items of interest in any technology, particularly:

Society, Ethics, and Professionalism. Developing technologies and curricula in the 18 KAs implies recognizing ethical responsibilities and their societal implications. Therefore, the KA *Society, Ethics, and Professionalism*, often referred to as *SEP*, strongly influences the development of all the 18 KAs, particularly in SPD. Nowadays, emerging technologies must consider SEP and its implications. Therefore, infusing SEP into curricula is a priority in any multidisciplinary study area.

Green Technologies++. Although the majority of the areas of interest of GT focuses on technologies promoting secure and clean energy systems for the 21st century, such as renewable energy/smart grids, energy generation, transmission, distribution and storage, transportation, electrification, codes, standards, regulations, and policies – to mention a few, the pedagogical component in training future generations of engineers and technologists is critical and as professionals are encouraged to apply these curricular recommendations for the benefit of humanity. An immediate example of software development's green implications is the excessive electricity consumption in training and running machine learning models. Also, massively distributed code (such as Gmail or other *free* services) consumes a substantial amount of electricity. By acknowledging common elements like these, students should be taught efficiency differently and answer engineering questions such as "how to get the answer/solution in an acceptable time while being as green as possible." Any software/programmatic efficiencies in these arenas have a significant Green impact. The work presented in this paper intends to relate at least two CS2023 knowledge units as a consideration while designing

future curricula that involve any GT area.

II. ABOUT THE CS2023: SIGNIFICANCE AND RELEVANCE

The ACM/IEEE/AAAI CS2023 document contains 18 KAs that cover most of the CS curriculum typically used in undergraduate institutions. The CS2023 presents 18 KAs: Algorithms and Complexity (AL), Architecture and Organization (AR), Artificial Intelligence (AI), Data Management (DM), Graphics and Interactive Techniques (GIT), Human-Computer Interaction (HCI), Mathematical and Statistical Foundations (MSF), Modeling (MOD), Networking and Communication (NC), Operating Systems (OS), Parallel and Distributed Computing (PDC), Programming Languages (PL), Security (SEC), Society, Ethics, and Professionalism (SEP), Software Development Fundamentals (SDF), Software Engineering (SE), Specialized Platform Development (SPD), and Systems Fundamentals (SF). Despite the curricular guideline in computer science education, specific areas impact hardware and industrial systems, therefore – green technology components. Moreover, a significant addition to the CS2023 is the integration of the SEP Knowledge Unit into the 18 KAs. Because of the constant emergence of technologies, it is critical to consider the SEP responsibilities while designing, developing, and using any technology.

A. The SPECIALIZED PLATFORM DEVELOPMENT KA

The Specialized Platform Development (SPD) KA proposed in the previous version of ACM/IEEE-CS Computer Science curricular guidelines covers topics and concepts that impact emerging computing areas in computer science curricula for the next decade. The SPD KA covers designing and developing applications that reside and interoperate with specific software and hardware platforms.

The SPD may be applied over many computing ecosystems and is complementary to the other KAs in many aspects, for example, by providing a mechanism for students to take their programming and software development skills and apply them to a broader platform widely used in practice. The SPD considerations intersect the fundamental areas of the core of the computing curriculum and, therefore, are advised to incorporate fundamental concepts in this KA. In general, there is a need for a specialized platform development curriculum mainly due to the high demand on computing needs for both software and hardware interactively and the appearance of application areas such as drone platforms, robotics, Internet of Things (IoT), next-generation of wireless networks, and quantum computing, in addition to the traditional ones such as web programming, multimedia development, mobile computing, app development.

Motivation and Current Challenges in Green Technology. Industry and Educational entities partner in different ways. One major challenge is incorporating industry needs into the curriculum so future professionals are guided to work in the specialized areas of interest. Currently, some challenges shall be addressed (or at least recognized) from the undergraduate perspective. For example, pedagogically speaking, technological platforms can successfully demonstrate software development principles using various low-cost and accessible environments, such as Raspberry PIs and Arduinos in Robotics and Drone [1] programming, to demonstrate design and energy consumption. In other cases, concepts and real-world issues such as energy-efficiency-oriented design, i.e., green radio. [2], and the discussion of ecological and economic implications while implementing mobile communications. [3] are challenges needed to be hosted in the academic arena.

Moreover, Mobile and Web Platforms have played an essential role in industry and software engineering for the past decade, especially with emerging computing areas such as intelligence computing (i.e., Data Science, AI/ML), Cloud, and Quantum computing, platforms considerations, and constraints development are considered in this KA. For example, designing and developing green network technologies suggest the chance to build future devices capable of adapting their performance and energy immersion to satisfy operational requirements [4]; or, modern blockchain technology, as a form of a significant increase in energy consumption caused by the Internet of Things (IoT) [5], suggests teaching these challenges and concepts through undergraduate education in computing. The SPD knowledge units proposed are the following:

Introduction: This unit aims to develop core concepts relating to specialized platform development. Students shall recognize different SPD and their corresponding applications, programming languages used for these particular and modern applications, and how to use them effectively. This KU aims to recognize the possible infusion of specialized platforms in modern and futuristic computing areas that permit computer users to interact with such platforms.

Mobile Foundations: This unit aims to develop concepts relating to mobile platform technologies, strengths, and limitations. The topics in this KU include development, mobile platform constraints, access, mobile computing affordances, emerging technologies, testing, and asynchronous computing.

Web Platforms: This unit aims to develop concepts relating to web platforms. Some of the topics in this KU include *programming language features, considerations through web platforms, privacy considerations, architecture, and storage solutions, web programming languages, web platform constraints, software as a Service (SaaS), web standards, computing services, data management, architectures (monoliths vs. microservices), micro-front ends, storage solutions*.

Mobile Platforms: This unit aims to develop concepts relating to specific web platform technologies and their considerations. This KU is separated from the foundations due to the need to satisfy the demand for specific mobile programming courses.

Robot Platforms: The robot platforms knowledge unit aims to consider topics related to deploying software on existing robot platforms and applying these robots to specific problems. Concepts include *robotic platforms, specialized programming languages and tools for robotic development, and the interconnection between physical and simulated systems*.

Embedded Platforms: The knowledge unit recognizes the impact on embedded platforms and their applications. Embedded platforms are an extensive specialized area that spans sensor technology to ubiquitous computing applications and deployment.

Game Platforms: The Knowledge unit aims to recognize concepts related to game platforms and computing technology that make this unit unique. Game design can enhance problem-solving in computer science by using principles of game design to engage the transferability of concepts in problem-solving. The game platform's topics include *simulations, game platform constraints, serious games, and user research*.

Interactive Computing Platforms: Knowledge unit recognizing the impact on interactive computing platforms. Emerging computing areas such as Data Science, Quantum Computing, and various creative disciplines explore this knowledge unit. This unit aims to explore concepts impacting interdisciplinary computing areas, often known as CS+X.

The SPD KA is significant to the computing education community since much of contemporary software and hardware development takes place to a degree of a specialized platform. Additionally, there are best practices to teach computer science fundamentals using a specialized platform, e.g., [6]–[10].Also, it is significant to the GT community since the design and usage of specialized platforms are essential for reducing human impacts on the natural environment and for deploying applications to alternative energy technologies in the manufacturing industry, such as [11]. A vivid example is the embedded platforms, particularly the Internet of Things, applied to these challenges are now called. Internet of Green Things (IoGT) is successfully applied in farms, greenhouses, and others [12] and [13].

B. The Society, Ethics, and Professionalism Knowledge Area

While technical issues are central to the computing curriculum, they do not constitute a complete educational program in the broader context. Students must also be exposed to the larger societal context of computing to develop an understanding of the relevant social, ethical, legal, and professional issues. Computing faculty unfamiliar with the content and pedagogy of applied ethics are urged to take advantage of the considerable resources from ACM, IEEE-CS, SIGCAS (ACM Special Interest Group on Computers and Society), and other organizations. It should be noted that the application of ethical analysis underlies every subsection of this Society, Ethics and Professionalism KA in computing. The ACM Code of Ethics and Professional Conduct, the IEEE Code of Ethics, and the AAAI Code of Ethics and Professional Conduct provide guidelines and case studies that serve as the basis for the conduct of our professional work. The General Moral Imperatives explain our commitment to personal responsibility, professional conduct, and leadership roles. It falls to computing educators to highlight the domain-specific role of these topics for our students. However, programs should certainly be willing to lean heavily on complementary courses from the other humanities and social sciences.

Social Context: Computers and the Internet, perhaps more than any other technology, have transformed society over the past several decades, with dramatic increases in human productivity, an explosion of options for news, entertainment, and communication; and fundamental breakthroughs in almost every branch of science and engineering. Social context provides the foundation for all other SEP knowledge units, especially Professional Ethics.

Tools for Ethical Analysis: Ethical theories and principles are the foundations of ethical analysis because they are the viewpoints from which guidance can be obtained along the pathway to a decision. Each theory emphasizes different assumptions and methods for determining the ethicality of a given action.

Professional Ethics: Computer ethics is a branch of practical philosophy that deals with how computing professionals should make professional and social conduct decisions. There are three primary influences: 1) The individual's ethical code, 2) Any informal or formal code of ethical behavior in the workplace, applicable licensures or certifications, and 3) Exposure to formal codes of ethics.

Intellectual Property: Intellectual property refers to a range of intangible rights of ownership in any product of the human intellect, such as a software program. The law, which varies by country, provides different methods for protecting these ownership rights based on their type. Four intellectual property rights are relevant to software: patents, copyrights, trade secrets, and trademarks. Each affords a different type of legal protection.

Privacy and Civil Liberties: Electronic information sharing highlights the need to balance privacy protections with information access. The ease of digital access to many types of data makes privacy rights and civil liberties more complex, differing among various cultures worldwide.

Professional Communication: Professional communication conveys information to audiences with different goals and needs. Effective professional communication of technical information is rarely an inherited gift but instead needs to be taught in context throughout the undergraduate curriculum. Like most skills, it requires practice.

Sustainability: As computing extends into more and more aspects of human existence, we already see estimates that 10% of global electricity usage is spent on computing, and that percentage seems prone to continue growing. Further, electronics contribute individually to the demand for rare earth elements, mineral extraction, and countless e-waste concerns. Students should be prepared to engage with computing with a background that recognizes these global environmental costs and their long-term effects on the environment and local communities.

History: The history of computing is taught to provide a sense of how the rapid change in computing impacts society globally. It is often taught in context with foundational concepts, such as system fundamentals and software development fundamentals. History is essential because it provides a mechanism for understanding why our computing systems operate the way

they do, the societal contexts in which these approaches arose, and how those continue to echo through the discipline today.
Economies of Computing: The economies of computing are essential to those who develop and provide computing resources and services to others and society in general. They are equally important to users of these resources and services, both professional and non-professional.
Security Policies, Laws and Computer Crimes: While security policies, laws, and computer crimes are essential, they must be viewed with the foundation of other Social and Professional knowledge units, such as Intellectual Property, Privacy, and Civil Liberties, Social Context, and Professional Ethics. Perhaps more than any other technology, computers and the Internet has transformed society over the past 75 years. At the same time, they have contributed to unprecedented threats to privacy; new categories of computer crime and anti-social behavior; significant disruptions to organizations; and the large-scale concentration of risk in information systems.
Justice. Equity, Diversity, and Inclusion: Computer Science has had—since its inception as a field—a diversity problem. Despite being a creative, highly compensated field with myriad job (and other) opportunities, racial and gender, and other inequities in representation are pervasive. Many factors contribute to the lack of diverse identities within computer science, and there is no single, quick fix. Explicitly infusing justice, equity, diversity, and inclusion across the computer science curriculum demonstrates its importance for the department, institution, and field—all of which likely have a JEDI statement and initiative. Enacting systemic change to ensure justice, equity, diversity, and inclusion is paramount. The SEP KA is significant to the computing education community since the advances in computers science education consider society's responsibilities and the ethical implications for the design, development, and implementation of software solutions from fundamental courses such as CS 1 [14], [15] to advance courses. Also, it is significant to the GT community since most green tech literature includes the SEP implications and future work in policy design and how to integrate energy justice principles, such as storage penetration with desired equity outcomes [16].

III. GREEN TECHNOLOGIES++

The focus of Green Technologies is to serve as an umbrella to intersect engineering, research, and academic specialist with industry needs to discuss applications related to the challenges of securing green and clean energy sources. Many areas of interest belong to this umbrella, including renewable energy and smart grids, energy generation, transmission, distribution and storage, transportation, electrification, codes, standards, regulations and policies, and related topics, including engineering education. This section provides an intersection of these areas with the two KAs proposed in CS2023.

A. INTERSECTION OF AREAS

Figure 1 shows the intersection between both CS2023 KAs: Specialized Platform Development (SPD) and Society, Ethics and Professionalism (SEP) with Green Technologies (GT) Education. The objective is to recommend an opportunity to infuse computing curricula while designing educational material for GT, in such way that:

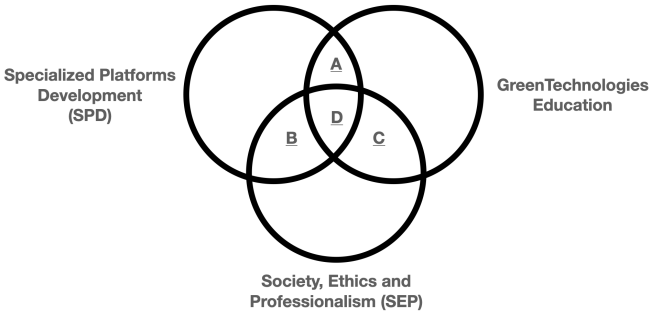

Fig. 1. The A, B, C, and D show the intersection of interest between the CS2023 KAs and GT Education.

A: These concepts relate to any specialized platform used in GT or those platforms with reckonable environmental impact. Concepts and topics related to the interface between software to hardware shall cover in this intersection. For example, learning outcomes that address needs from GT can be achieved by any knowledge unit from SPD. Learning outcomes related to energy generation and optimization, securing green and clean energy sources, and data distribution and storage. Any subject related to machinery related with drones, robots, energy optimization, and sustainability is provided by this intersection; **B**: The Society, Ethics, and Professionalism applied to any layer of SPD. Concepts and topics related to infusing SEP into learning outcomes and topics to the design, implementation, and usage of any specialized platform. The concepts covered in this intersection shall answer the questions, "What are the ethical responsibilities and the implications in society of using specialized platforms?"; **C**: Identifying the SEP implications and responsibilities while using GT. Recognize cases about how important it is to infuse the SEP considerations in the GT curriculum. Topics such as sustainability, economies in computing, privacy, and civil liberties, to mention a few, shall answer a question such as: How can global electricity usage be reduced that in GT? What are the consequences of globalization and nationalism in the computing industry? What are the privacy implications of widespread data collection for transactional databases, data warehouses, surveillance systems, and cloud computing? **D**: The ultimate goal is to recognize real-world GT challenges that consider SEP while designing interfacing between software and hardware. This intersection shall answer questions such as, what are the implications of SPD that can address SEP implications while solving GT?

IV. DISCUSSION AND SUMMARY

This paper introduces the new ACM/IEEE/AAAI CS2023 curricula project. In particular, the paper focuses on two main KAs: the Specialized Platform Development knowledge area, which promises a direct impact on industrial and embedded

systems and applies to green technology areas. The second KA is Society, Ethics, and Professionalism, which now every KA in CS2023 has embedded as part of the knowledge units. The critical need for SEP in curricula has developed the need to infuse the SEP concept in any area of academia and industry. Although this document recommends two specific KAs from CS2023 to infuse into GT, it does not restrict the incorporation of additional ones. For example, additional KAs that can be explored include but are not limited to:

Architecture and Organization (AR): that can be used to recognize specific architectures, such as quantum computing, that could help reduce emissions in agriculture or accelerate improvements in technologies such as solar panels or batteries [17]; **Data Management (DM)**: we discussed integrating future research and policy design for energy justice principles. Moreover, energy storage systems are deployed to support grid reliability, and therefore, concepts from data management shall be considered [16]; **Artificial Intelligence (AI)**: the ubiquitous area of artificial intelligence will only increase in pace in likely every area and concentration in computing. Work has already started to economically evaluate energy efficiency and renewable energy technologies [18]; **Security (SEC)**: nowadays, security, in general, is a concern for any computing area. ACM identifies cybersecurity as one of the six primary computing disciplines, and therefore, the purpose of Cybersecurity Curricula 2017 [19] is to provide interdisciplinary content to the six major computing disciplines. Recognizing security features of the IoT systems across many parts of the IoT protocols is now being studied [20] to improve security. Additionally, improving physical security has impacts on other related GT, such as *Electric Vehicle Supply Equipment (EVSE)* [21], and *smart grid on public networks* [22]. Future work includes: packaging a course in GT that can cover several knowledge units from various KAs, emphasizing GT challenges. Additionally, an objective is to create a best practice of these KAs and discover competencies infused into the GT curriculum.

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