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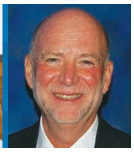

The Importance of Educating Computational Educators

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Technological advances, slow curricula evolution, and other elements contributed to shortfalls in the 21st-century preparation of potential computer science students. It becomes necessary to reevaluate how computer science is treated as a teachable subject.

Teaching has always been a calling. It requires vast specific subject area mastery, pedological and people skills, patience, and increasing degrees of empathy. While some demand that the novice deserves an expert, this is often not the case where teacher salaries are uncompetitive. At the same time, however, technology has flourished, primarily due to the increasing reliance on omnipresent digital devices.

PROFOUND CHANGES IN CURRICULA

Graph algorithms have become the glue of successful corporate integration and interoperability at scale. Google became a search giant primarily via the graph-based PageRank algorithm. Amazon thrives on graph-theoretically managed logistics data. Social media success depends upon natural human interactions, largely captured as exploitable graphs. In recent decades, however, as this unprecedented level of internal corporate interoperability took hold among the leading proprietary Silicon Valley powerhouses, graph theory was initially offered only at the collegiate level. However, this is not to say that graph theory should not be successfully taught as low as the primary school level.[1]

Simultaneously, the trend toward making meaningful sense of "big data," often involving vast semistructured or unstructured sparse data matrices, has matured within

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numerous corporations. These data often span multiple media formats and frequently live among the clouds. Once again, graph databases are beginning to serve as gateway repositories that enable powerful artificial intelligence (AI) and machine learning algorithms to enhance the predictive power of the big data upon which they operate.[2] These powerful algorithms call for a profound appreciation of advanced probability and combinatorics, which, once again, were often seriously addressed only at the collegiate level.

While the proper protection of proprietary algorithms is a legitimate competitive concern in either a free enterprise system or an authoritarian state, the failure to integrate the underlying concepts in elementary, middle, and high school curricula fosters an unacceptable elitism among existing practitioners. This is not to say that corporations or authoritative regimes are or should be omnipotent but rather to underscore the high price of expertise that is quantitatively unavailable in the marketplace of available talent. Critical shortages of skilled computer artisans will likely continue without a suitable educational pipeline. Correspondingly, a dearth of talent leads to an increased risk of mediocre performance, dangerous and too frequently unexplainable algorithms, unnecessary security exposure, failed initiatives, and the furtherance of unchecked unintentional or intended unethical practices. Against this massive influx of technology at scale, primarily driven by graph algorithms and combinatorics, a ready and sufficient talent pool becomes essential to the explainable, secure, and successful deployment of advanced computational capability that genuinely serves humankind.

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This calls for an overhaul of the forms of mathematics offered at primary and secondary levels. It is not to dismiss the importance of algebra, trigonometry, geometry, and calculus but rather to suggest that graph theory, data analytics, and probability combinatorics are equally important modern-day skills that must be appreciated starting at an early age. Moreover, the degree of linear and nonlinear mathematics that come into play in most disciplines suggests that such a balance is necessary. This is particularly true as the Newtonian age of linear Industrial-Age architectures gives way to a networked era, where cyberphysical, cyberbiological, and cybersecure systems operate under different but equally valid nonlinear mathematical constructs.[3] By introducing big data as a legitimate substitute for algebra, some school districts are beginning to lead the way.[4] Studies also exist to show that graph theory is easily absorbed if introduced adequately in the early education pipeline.[1] Thus, there is a beginning of an awakening that dynamic networks and static architectures can and do coexist in the classroom as they do in real life.

FROM STATIC TO DYNAMIC

Living on the Internet, the World Wide Web (WWW) was invented to support human collaboration and information sharing. It has primarily done so but not without simultaneously reinforcing ugly forms of bias that often strengthen utter misperceptions, disinformation, and malevolence. Paradoxically, the WWW indifferently and simultaneously fosters both educationally enhancing and socially dysfunctional behavior. Perhaps more significantly, the WWW also hastened the awareness of networks as thriving dynamic entities. This came to pass almost as an unintended consequence of the WWW's evolution.

Naturally evolving from the complexity theory of the 1990s to today's view of network science, the notion of network dynamics has grown alongside the previously described supportive mathematics. Moreover, such networks were not just attributable to computer science phenomena, such as the Internet; instead, networks began to appear across disciplines. Whatever the field of study or the relationships across other fields or subfields of specialization, thriving nonlinear networks have gained clear focus. While seemingly defying the legitimate reliance on reductionism and determinism prevalent in earlier eras, networks amplify the sum of their parts. They can change or self-destruct with the seemingly slightest provocations. They also tend to be far more sensitive to state change over shorter periods.

At the same time, these dynamic systems coexist with rock-solid static systems. They do so in a fashion that suggests the so-called static systems operate over different time scales, sometimes brought about by network shifts in the shorter lived volatile dynamic networks. This is the case as even solid rocks change state to become magma upon a caldera eruption. This suggests that the hotly debated concept of time comes into play in computer science and across multiple disciplines. Quantum computer science is further illuminating the effects of time.[5] It also suggests that computer science pervades the fields in ways influenced by the underlying principles of the academic disciplines, the associated periodic behaviors, and the dependencies among other related disciplines.

This further indicates that computer science can only stand with a basic threshold as it becomes highly specialized in its permeated employment within specific fields of study. While fundamental systems architecture, algorithms, programming languages and practices, mathematics, and basic security are essential elements, the ultimate deployment often depends upon the degree of special disciplinary or cross-disciplinary requirements. In essence, the network era suggests that computer science, while foundational, is merely a stepping stone toward more profound cross-disciplinary know-how. This may account for the paradox of decreasing interest and enrollment in computer science degree programs at a time of unprecedented demand for computer-savvy professionals. It also suggests that computer science fundamentals, if indeed foundational, need to be introduced and reinforced throughout elementary, middle, and high school education.[6] The same principle applies to the need to instill critical awareness that the Internet, and indeed all digital technology, can either enlighten or do grievous social harm, depending on how it is utilized. This ethical mandate also strongly suggests that the methods of the delivery of computer science education must also be taken into consideration.

ONLINE OR OFFLINE

The COVID epidemic, with its mandates for degrees of isolation, greatly amplified an evident trend toward online education. Already fueled by economic considerations, COVID hastened a rapid transition to online delivery in environments where it was once absent. The results are mixed. Those accustomed to traditional lecture-style delivery were locked into talking-head presentations often augmented by static electronic slides. Those more associated with Socratic interactive exchange were challenged to draw out all their students. A few pioneers harnessed multimedia tools, including the metaverse, to advance their knowledge. More useful delivery tools and significant online course development guidance, however, were often initially hard to implement in haste. Unsurprisingly, many elementary, middle, and high school performance metrics have declined since the onset of COVID, particularly in mathematics.[7]

There are also significant culture gaps at work, driven by the relentless march of technology and acerbated by the shift toward online delivery. The most critical gap has its roots in fundamental economics. Those with the technical means to access a full range of instructional technologies are educational beneficiaries. Those needing more virtual devices and the necessary bandwidth to harness these tools for educational purposes functionally, however, are too frequently left out. The resulting technological chasm in communities still needing to update their technical bases has likely broadened the economic divide fueled by inequitable educational opportunities.

Moreover, accustomed to omnipresent low-cost smartphones, social media, television, and multimedia delivery tools, many students exhibit levels of technological dexterity that bewilder their elders. While possessing superior media manipulative skills, these youngsters often need a fundamental appreciation of the underlying technology, much less how to discriminate between valuable and harmful content. Worse, the allure of generative AI, such as ChatGPT, may further dull students' ability to think critically for themselves.

Because of a constant stream of media and the apparent hastening of time wrought by instantaneous nonstop content, youth can also become lethargic to traditional education techniques. Simply put, materials not delivered at a fast pace can rapidly become dull. These cases illustrate a slightly different cultural gap between generations. While older generations are accustomed to delivery using logical and methodically developed steps, cyber-savvy students natively prefer to absorb information rapidly, often in disjointed sequences. This usually involves multisensory input. Ironically, this is in keeping with incrementally appending nodes and relationships to a graph-based network. Is it also a natural and legitimate form of neural and cognitive development? The Chinese version of TikTok, partially focused on purposeful educational delivery, bears watching.[8]

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A third gap is more subtle. Formal mathematics typically involves formal proofs. Applied mathematics, the stuff of algorithms, involves the practical use of mathematical skills. The levels of abstraction differ significantly between the two approaches. Often, students sense that mathematics is too complicated or has no practical bearing on their lives. The perceived difficulty level leads to anxiety, and the sense of no value leads to indifference. Either way, studies show that youth are frequently averse to learning mathematics.[9] Teachers with formal mathematical backgrounds and rote curricula often contribute to high student frustration with mathematics. This creates a bias that further isolates students from vital computational knowledge.

These three gaps offer the opportunity for enhanced online delivery that directly addresses the relevant issues dealing with ethically applied computational skills. Online delivery is, at its best, interactive. It is, at its best, a process of discovery where the student is a participant, not a recipient, be it artificial or virtual reality or just online. It is, at its best, purposeful but oriented to maturing creativity and profound understanding as it builds upon foundational materials. It is built on a foundation of premeditated questions, activities, and feedback for assessment.[10] It is, at its best, guided, relevant, engaging, and enjoyable.

These lofty goals establish that more groundwork must be laid at all levels of education[11] and that truly transformational best practices must be preserved and replicated across largely independent educational systems. One area of ongoing academic development involves "design thinking." This concept strives to discover creative and collegial solutions to wicked problems. It shows some promise, presuming further research and the adaptation of design thinking principles in education.[12] This is particularly applicable to the aligned notion of algorithmic thinking. With the advent of generative AI, methods to reinforce critical thinking must also be strengthened, perhaps even requiring students to express themselves independently in the classroom absent immediate technological crutches.[13]

However, more than a transformation in the delivery of computationally related education is required. As strongly suggested previously, revamped content must also come into play. This calls for introducing modern fundamentals such as graph theory, combinatorics, data analytics, and algorithmic (procedural) techniques throughout primary education. It suggests that nonlinear and linear processes must coexist in the classroom for a fuller understanding of the emerging science of dynamic networks. It urges the early introduction of cyber ethics and cyber hygiene into existing curricula at all levels. At the higher education level, it suggests that disciplinary studies must emphasize their unique computational and technological underpinnings. It also means that more cross-disciplinary studies are likely indicated.

While most school systems, large or small, operate independently, it is unlikely that any national movement to revamp computational curricula will have an appreciable effect. Instead, it is logical to expect that pockets of excellence will develop worldwide. Hopefully, these enlightened communities can serve as beacons for others to emulate, thus spiriting a grassroots movement to make computational education relevant to the omnipresent technology that continues to permeate the globe. To initiate such a movement, however, it is essential that those who teach computational studies be appropriately enlightened.[6] Thus, the real need is to revamp how teachers are prepared to deliver meaningful and relevant content effectively. This is where independent higher education institutions have the most incredible opportunity to productively advance the societies they support.

Thus, the real need is to revamp how teachers are prepared to deliver meaningful and relevant content effectively.

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