A Bridge to Quantum STEM*

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Abstract

In my talk I would like to focus on the following three topics: (a) our new MS in QIS program, (b) results of a very recent QED-C member survey and (c) alternative ways of teaching Quantum Mechanics (QM) concepts to the CSCI sophomore.

1. The absence of any serious education in QM in a large fraction of traditional US engineering programs, including computer engineering and the closely related computer science and data science programs, presents many BS degree STEM graduates with the daunting problem of how to get trained quickly and efficiently to pursue the new opportunities in quantum information sciences (QIS). Since Fall 2021 Indiana University has an intensive MS program[1] (approved[2] in October 2020 at the state level) that delivers parallel tracks in quantum mechanics/quantum information combined with an intensive research experience in a QIS-related activity supervised closely by faculty in our Quantum Science and Engineering Center (IU QSEc[3]) and sustained with year-round internships with any of the industrial members in our new Center for Quantum Technologies[4] (CQT). Our program is truly inter-disciplinary and aimed at STEM undergraduates that were not majors of Physics. I would like to describe the challenges and opportunities associated with such a unique project.

2. Continuing a process that began over 50 years ago with the publication of Curriculum 68[5] the three major professional societies in computing (ACM, IEEE Computer Society, AAAI) have sponsored five efforts to establish international curricular guidelines for undergraduate programs in computing on a roughly 10–year cycle. The last report came out[6] in 2013 and makes no reference to Quantum Computing (QC) or Quantum Information Science and Technologies (QIST) and perhaps understandably

*Extended abstract of my proposed/invited talk at the Workshop on Quantum Education for Quantum Workforce Development organized Jan 29-31, 2023, in Arlington, VA, by the QLCI Conceptualization Grant team at the University of Florida, as requested by organizers.

[1] https://qis.iu.edu/academics/qis-classes.html

[2] https://news.iu.edu/live/news/26992-6-new-degrees-approved-including-graduate-degrees

[3] https://qsec.sitehost.iu.edu/research/history/

[4] https://news.iu.edu/live/news/28006-3-research-universities-to-collaborate-with

[5] https://dl.acm.org/doi/10.1145/362929.362976

[6] https://ai.stanford.edu/users/sahami/CS2013/final-draft/CS2013-final-report.pdf

so. Early last year (February 2021) the QED-C Workforce Development TAC contacted the ACM/IEEE Boards of Education offering to assist in the proper, accurate inclusion of QC topics and learning outcomes in the CS202X Curricular Guidelines. They responded with interest but also mentioned that, organizationally, they were in flux: there was an outgoing board and a new incoming board and they were in the process of putting together a new steering committee. We shared our plans for the year[7] and then decided to stay in touch. This year (2022) in April the decision was made to reconnect with the ACM/IEEE curricular guidelines task force, let them know what we did in 2021, ask them where they're at, and reiterate our offer to help with the quantum aspects of hardware, computation and networking (and perhaps even sensing[8]).

The ACM SIGCSE (Special Interest Group in Computer Science Education) sponsors an annual, international, technical symposium. SIGCSE 2020 first organized a full-day pre-symposium event[9] entitled "Programming Quantum Computers: Tools and Techniques for Computer Science Undergraduate Faculty." The event was held in Portland, Oregon, on March 11, 2020, in person—with a few speakers giving their talks remotely[10]. Some of the featured speakers at this event: Will Oliver (MIT), James Weaver (IBM), Dan Koch (AFRL), Eric Johnston (PsiQuantum), Mariia Mykhailova (Microsoft Quantum) and Hans Christian von Baeyer (Chancellor Professor of Physics at the College of William and Mary). At the end of that day the (rest of the) conference was canceled along with several remaining quantum-related presentations[11]. In 2021 SIGCSE was entirely online; this year (2022) the conference was in person, in Rhode Island. A BOF (Birds-of-a-Feather) session was organized by the Architecture and Organization (AR) sub-committee of the CS202X Curriculum[12] Task Force with the following topic/title[13]: "Should Quantum Processor Design be Considered a Topic in Computer Architecture Education?" It was then argued that QC is an AR topic because QC is set to exploit the computational aspects of an entirely new hardware platform (qubits) and because the associated (classical) computer architecture and organizational aspects are non-trivial.

In May 2022 I joined[14] the AR sub-committee[15] as a QED-C liaison. This summer we wrote[16] "On the Design and Implementation of a Quantum Architectures Knowledge Unit for a CS Curriculum". It was accepted for presentation to SIGCSE 2023 in Toronto, Canada. It proposes three curricular plans for incorporating QIST topics (via QC) into the CS undergraduate curriculum. In anticipation of the last QED-C plenary of the year, the QED-C Workforce TAC has asked[17] its members to comment

[7] https://legacy.cs.indiana.edu/~dgerman/qed-c/wd-tac/schedule.html
[8] https://www.edx.org/professional-certificate/georgetownx-foundations-of-quantum-sensing
[9] https://legacy.cs.indiana.edu/~dgerman/quantum-computing-for-undergrads/sigcse2020.html
[10] https://legacy.cs.indiana.edu/~dgerman/quantum-computing-for-undergrads/videos.html
[11] https://legacy.cs.indiana.edu/~dgerman/quantum-computing-for-undergrads/tcNickolas.html
[12] https://dl.acm.org/doi/abs/10.1145/3478432.3499036
[13] https://dl.acm.org/doi/10.1145/3478432.3499201
[14] https://legacy.cs.indiana.edu/~dgerman/2022/CSCI202X/Case-for-QED-C-Representation-on-the-Committee.pdf
[15] https://csed.acm.org/architecture-and-organization/
[16] https://legacy.cs.indiana.edu/~dgerman/2022/CSCI202X/sigcse2023.pdf
[17] https://legacy.cs.indiana.edu/~dgerman/2022/CSCI202X/doug-review.pdf

on the topics/illustrative learning outcomes proposed by our paper in an attempt to obtain broad industry review and feedback.

I would like to describe the paper, the process that led to it and to discuss the data collected[18] in a survey we, at QED-C, ran in November (that included a questionnaire for a national quantum technician consortium).

3. This past (6W2) summer session we first offered (on the IU Bloomington campus) a CSCI-C 290 class[19], aimed at sophomores, and entitled "Programming Quantum Computers".

In this context I would like to compare and contrast several alternative ways of introducing essential QM topics to CSCI sophomores such as: traditional (calculus-based), operators-based (no calculus), linear algebra, rewriting systems like the Quantum Abacus[20] or diagrammatic/pictorial style[21] systems like those introduced by Coecke, Abramsky and Kissinger.

Adrian German is a Senior Lecturer in Computer Science with the Luddy School of Informatics, Computing and Engineering at Indiana University in Bloomington. He is also Acting Organizing (and Outreach[22])Manager and Industry Liaison for the Indiana University Quantum Science and Engineering Center. In 2021 he served as Chair of the Workforce Development Technical Advisory Committee (TAC) in the QED-C[23] and was the organizer and co-chair of the Q2E[24] Track at Q2B 2021 in Santa Clara, California. He is currently a member[25] of the AR subcommittee of the CSCI 202X Curricular Guidelines Commitee of ACM, IEEE-CS and AAAI. He remains active in the QED-C Workforce TAC where he continues to be the organizer of the e-Poster Research Sessions[26] and has co-authored[27] "Assessing the Needs of the Quantum Industry" a paper published in the IEEE Transactions on Education earlier this year. The Quantum Economic Development Consortium (QED-C) is a broad international group of stakeholders from industry, academia, national labs and professional organizations that aims to enable and grow the quantum industry and its associated supply chain. QED-C was established with support from NIST as part of the federal strategy for advancing QIST as per the National Quantum Initiative Act in 2018.

[18] https://legacy.cs.indiana.edu/~dgerman/2022/CSCI202X/ar-survey-qc-001.pdf
[19] https://legacy.cs.indiana.edu/classes/c290-quantum/sum2022/syllabus.pdf
[20] https://legacy.cs.indiana.edu/classes/c290-quantum/quantum_abacus.pdf
[21] https://www.amazon.com/Picturing-Quantum-Processes-Diagrammatic-Reasoning/dp/110710422X
[22] https://legacy.cs.indiana.edu/~dgerman/2022/qis-student-journal-club/
[23] https://quantumconsortium.org/members/
[24] https://legacy.cs.indiana.edu/~dgerman/qed-c/wd-tac/q2e-2021.html
[25] https://csed.acm.org/architecture-and-organization/
[26] https://legacy.cs.indiana.edu/~dgerman/qed-c/wd-tac/student-ePosters.html
[27] https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9733176