Quantum computing education in South Africa

Mapping Opportunities & Challenges

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science, technology & innovation
Department:
Science, Technology and Innovation
REPUBLIC OF SOUTH AFRICA

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Opening & Acknowledgments

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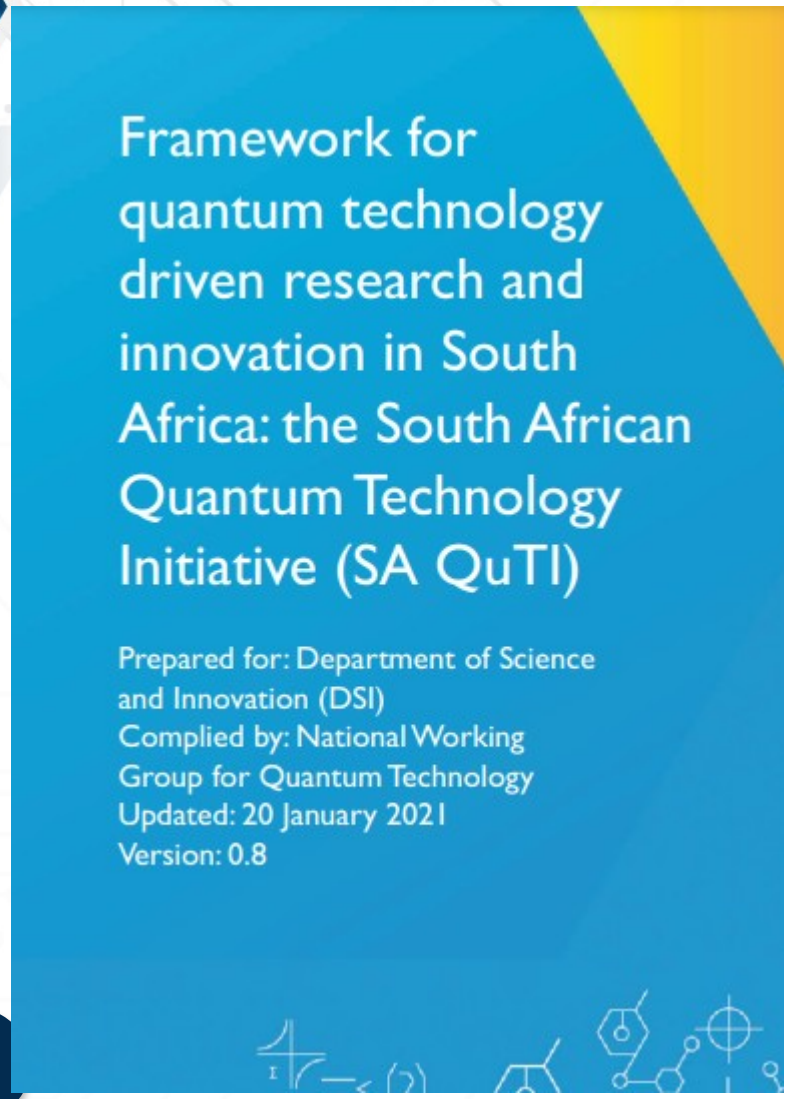
Motivation & Context



South Africa has several strong centres in quantum computing and quantum technology that cover 13 higher-education institutions and several other national research facilities. The growing network of researchers, mostly of young academics, has an excellent track record of publication. Also, postgraduate students are increasingly attracted to the area.

Currently there are no commercial companies that are directly involved in the development and commercialization of quantum information technology in South Africa. However, there is already some evidence from the financial sector. The South African industry is diverse enough to benefit from entering the quantum information technology market.

To create the conditions for a globally competitive research environment in quantum technology and to grow a local quantum technology industry in south Africa, the following recommendations are made:

Recommendation 1: Education and training programmes

Curricula development and deployment at Honours and Masters level in quantum technology.

Recommendation 2: Stakeholder awareness campaign

An active awareness campaign to disseminate information on quantum technologies to key stakeholders, including the public, government and industry. A strong public engagement is necessary to familiarize the citizens and other stakeholders with the foundations and principles of Quantum Technology. Also, it will be crucial to inform the key stakeholders of the opportunities for economic development that Quantum Technology offers.

Recommendation 3: Research chairs

Create critical mass in quantum technology research leadership across the country through senior and emerging research chairs.

SA QuTI South African Quantum Technology Initiative

Motivation & Context

Recommendation 4: Governance and coordination

Establish a governance structure for national coordination, particularly of synergetic activities, and to drive legislative, standardisation and certification activities. The South African Quantum Technology Initiative (SA QuTI) will be a consortium of five Universities, three main centres (SU, UKZN, WITS) and two emerging centres (CPUT and UZulu), and the Centre of High Performance Computing (CHPC), as the provider of the quantum computing infrastructure. The QuTI will exploit synergies with the Converging Technologies Platform for the National System of Integration. Wits University will act as the main contracting site.

Recommendation 5: Flagship programmes

Establish one flagship programme in each of the three focus areas, distributed across national nodes.

Recommendation 6: Establish new emerging centres

Support new participants in quantum technologies with the aim of diversity in demographics, geographics, and in focus.

Recommendation 7: Quantum technology seed fund

Support the establishment of a quantum industry through strategic and financial support for technology development and deployment.

Recommendation 8: Quantum technology legislation and validation

Provide a national context for a quantum enabled future through government interventions in the form of local economic clusters, legislation with respect to the transition to and adoption of quantum technology, and formalise the need for validation.

Recommendation 9: Interface with the Converging Technology Platform

Engage with the Converging Technology platform and become one of the enabling emerging technology pillars.

Method Overview

- Surveyed all 26 public universities for Quantum Computing (QC) content in prospectuses (UG and PG).
- Identified the active SA QuTI nodes with a specialisation in QC.
- Sent emails requesting course/module details to universities with QC groups.

Key Findings: University & Research Landscape

- We could only find 3 universities with dedicated QC coursework, and QC groups with dedicated websites, however their coursework and activities are difficult to find in their online available prospectus documents.
- SUN offers coursework, we are waiting for the detail. They have postgraduate QC students. The course they offer appears to be a full module.
- UKZN offers an honours level course directed at computer science students (COMP718 Contemporary Topics in Computer Science) and the same course directed at physics students (B/PHYS737 Advanced Topics in Quantum Physics). They also have postgraduate QC students.
- At WITs QC is taught as an elective module in the School of Electrical and Information They teach an introductory and more advanced course.

  ELEN4022A — Full Stack Quantum Computing
  ELEN7069A Applied Quantum Computing

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Key Findings: University & Research Landscape

Currently, UKZN offers the following course on Quantum Computing for computer science & physics students at the Hon. Level:
Same course two codes - COMP718 Contemporary Topics in Computer Science B/PHYS737 Advanced Topics in Quantum Physics

Course Content:

This course is divided into two parts:
1. Basic principles of quantum computing and quantum algorithms
2. Quantum algorithms for machine learning

Part 1:

- Postulates of Quantum Computing
- Qubits
- Quantum Gates
- Quantum Circuits
- Universal gate sets and advanced techniques for quantum circuits
- Deustch-Jozza Algorithm
- Quantum Simulation Algorithm
- Quantum Search Algorithm
- Quantum Fourier Transform
- Shor's Algorithm

Part 2:

- Data encoding
- Quantum kernel methods
- Variational quantum classifiers
- HHL and matrix inversion
- Quantum advantage in machine learning

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Key Findings: University & Research Landscape

School of Electrical and Information Engineering
University of the Witwatersrand, Johannesburg
ELEN4022A — Full Stack Quantum Computing

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2 Course Objectives

The main objective of this course is to introduce students to quantum computing and its near term application. The course will expand the students' existing knowledge of quantum mechanics and develop the skills to use quantum systems to achieve computation, apply engineering techniques to quantum computing, and critically analyse the impact of existing quantum hardware on quantum processes. The course will also introduce relevant quantum algorithms, industry recognised tool-chains, and approaches for improving the performance of quantum computation. The course will develop a strong foundation in quantum computing that will benefit the students in both the ever growing quantum industry and research applications.

5 Prior Knowledge Assumed

The following prior knowledge is assumed on the part of students starting this course:

1. Proficiency in programming in a high level language such as C/C++. Experience using Python is beneficial, but not assumed.
2. Working knowledge of good software engineering practices including the use of systems that provide for version control and collaboration, such as GitHub.
3. Basic knowledge of quantum mechanics and linear algebra.

The following table lists the summative assessment elements in the course and their contribution to the final result.

Assessment Contributor	Duration (hours)	Component	Method & Weight	Calculator Type	Permitted Supporting Material
Laboratories	18	No	Rubric - 25%	-	Computing resources
Project	30	No	Rubric - 35%	-	Computing resources
Exam	3	No	Marks - 40%	-	-

Textbooks

- Introduction to Classical and Quantum Computing by Thomas G. Wong, Rooted Grove, Nebraska, 2022 *ISBN: 979-8-9855931-0-5*. PDF version of textbook available for free at www.thomaswong.net
- IBM Quantum Documentation – https://docs.quantum.ibm.com
- Qiskit | IBM Quantum Computing – https://www.ibm.com/quantum/qiskit

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International Inspiration & Local Gaps

- Surveys show that industry interested in QC care more about having trained programmers
- There is more international research on student experiences
- There is a greater effort to cater for non-physics, and even non-technical individuals
- There appears to be greater emphasis on teaching “level appropriate” QC content at high school
- There is active interest in finding alternative ways to teach QC. For example teaching it as primarily a programming course with background in probability as opposed to just linear algebra, or teaching the course without any discussion of entanglement or even superposition.
- Using games and alternative teaching materials is frequently described.

International Inspiration & Local Gaps

Exploring Quantum Reversibility with Young Learners

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Figure 1: Two panes of an 8-pane zine about Reversibility

Game	Description
Cat/Box/Scissors [17]	A quantum version of Paper/rock/scissors. Players control a cat that can be in a superposition of two states and can collapse to one of the possible outcomes when measured.
Quantum Battleships [17]	A quantum version of the classic Battleship game. Instead of traditional "ships," players deploy qubits.
Entanglion [50]	A Board game for two people designed to teach concepts of QC.
qCraft [17]	qCraft is a mod for the popular game Minecraft. The mod uses virtual versions of quantum logic gates and qubits within the Minecraft world.
Quantum Chess [17]	Chess in which pieces can be in superposition and an attack is a measurement.
Quantum Cats [17]	A narrative-driven game designed to teach QC through the adventures of cats that interact with quantum systems.
Quantum Odyssey [38]	A space-themed adventure game that integrates QC principles. Players take on the role of an explorer who uses quantum mechanics to solve puzzles.
Qubit Jump! [18]	A logic puzzle game where players control qubits and use quantum gates to reach a target state using quantum operations.
Quantum Adventures! [18]	A platformer game featuring levels in which players use quantum concepts to solve puzzles and progress through different challenges.

Table 4. A summary of educational games teaching QC concepts.

Reflections & Recommendations

- Local linear algebra courses could add Bra–ket notation (Dirac notation) to the syllabus
- Input of the experiences of students after taking QC course modules could inform where adjustments could be made
- More investigation into alternative methods of teaching based on the student's intended application.

How and Why Computer Science (CS) Became Its Own Subject

- **Pre-1950s**: Computing was taught within mathematics, electrical engineering, or physics departments.
- **1960s–1980s**: As computing gained importance, universities began offering dedicated computer science degrees.
- **Key reason**: Classical subjects (math/physics) didn't address software engineering, algorithms, or system design — which were emerging as crucial fields in their own right.

What does a QC business analyst look like?

Computer Science was formalised to:

- Focus on algorithms, data structures, and theoretical computation.
- Teach practical programming and system design.
- Explore computability and complexity from a more applied lens than traditional math.

Computer science eventually became its own subject, with simplified logic and math courses tailored to what programmers actually needed — not what mathematicians needed.

We may need to do the same for QC: build tracks for developers, analysts, and applied researchers without assuming a background in quantum mechanics.

Simplification of Math and Logic in CS Curricula

CS logic courses avoid full symbolic logic used in philosophy/math. Instead, they:

- Focus on Boolean algebra, propositional logic, and predicate logic.
- Emphasise applications in program verification, and automata theory.
- Teach practical programming and system design.
- “Discrete Mathematics” (sets, functions, graph theory) was created as a tailored math course for CS.
- Linear algebra and probability are introduced practically, often through data structures or algorithms.

Thank you