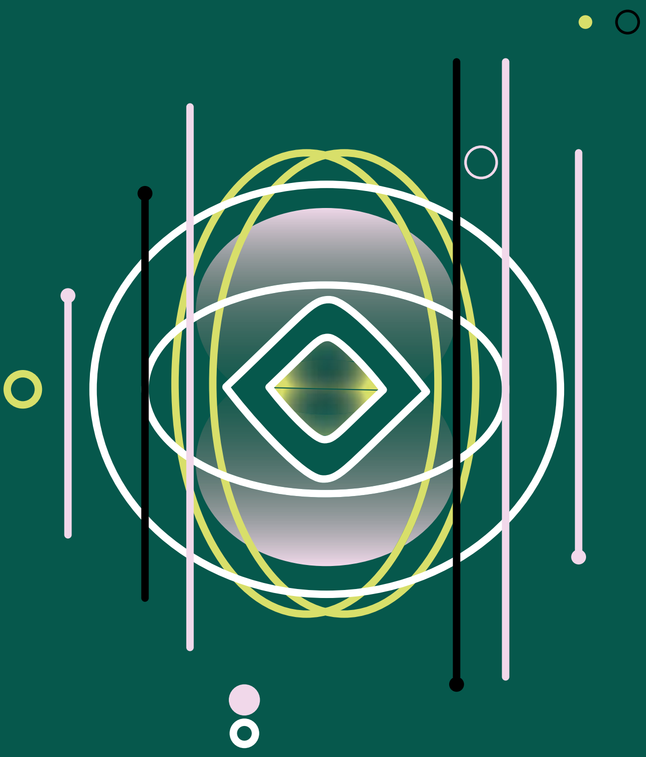
HOW MIGHT CHATGPT IMPROVE THE ACCESSIBILITY OF QUANTUM COMPUTING?



A Design Research on Improving Quantum Computing Accessibility Through AI.

How Might ChatGPT Improve the Accessibility of Quantum Computing?

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Executive summary

In this summary, a series of experiments and research will be explored to address the question: ***"How Might ChatGPT Improve the Accessibility of Quantum Computing?"*** The challenges associated with specialized knowledge in higher education, the concept of accessibility, and the complexities in quantum computing will first be addressed. Additionally, the potential role of ChatGPT in bridging the accessibility gap and simplifying quantum technology will be investigated. Through the presentation of findings from user tests and evaluations, this summary will conclude by discussing the implications of the final design obtained.

Higher education typically imparts **specialized knowledge** in specific subjects, which can make broadening one's knowledge horizons difficult due to the deep expertise gained. However, **modern technologies** have transformed this, **allowing non-experts to explore various fields**, even those unrelated to their expertise. **Accessibility** plays a key role in bridging the gap between knowledge and curiosity. When a subject becomes easily accessible and understandable to all, people can follow their interests, even if they lack prior knowledge in that specific area.

Quantum computers are an intriguing and recent technology that even experts in quantum physics struggle with when it comes to highly complex tasks such as programming. This level of complexity is further highlighted by their **limited accessibility,** which places people like non-experts outside, incapable of satisfying their curiosity.

This is a significant issue since in the coming years, the technology will become more powerful, yet part of the interested people won't be able to use it effectively. **Currently**, non-experts can only observe Quantum Computers from a **distance**, possessing only a basic understanding of what they are and a vague notion of their capabilities. In the desired future interaction, allowing users to ask questions and gain practical experience with the technology could facilitate a better understanding. Given this, it's worth considering: **Are there potential methods to make Quantum Computers more user-friendly and accessible?**

One technology that became widely popular, especially in education, for its ability to fill this gap is **ChatGPT**, a Large-Language Model (LLM) developed by OpenAI. The use of it in **education** has led to a heated discussion. Some see it negatively for making tasks such as essay writing too easy, while others believe it could raise educational standards and help students achieve more challenging objectives.

A tangible example of using ChatGPT with no expertise is using it as a **programming tool for classical computers**, where numerous studies proved it to be effective. Hence, if ChatGPT can serve as a link between people, regardless of their expertise, and Quantum Computers, it could significantly **influence the future of quantum computing**, making it possible for more people to satisfy their curiosity.

The central question ***"How might ChatGPT help make quantum technology more accessible to non-experts?"*** It is based on the assumption that **ChatGPT**, being a publicly accessible tool, has the potential to **achieve this goal**, as evidenced by its history of providing positive results via tailor-made and interesting educational experiences for students.

The investigation employs both qualitative and quantitative methods based on human-centered design principles, in alignment with the theoretical knowledge of quantum computing acquired during the Master's program. The general approach selected for exploring the **hypothesis** is organized around **research questions.**

"Can ChatGPT help anyone engage in quantum programming? What kind of background is necessary?"

In User Test 1 individuals with different backgrounds were recruited; 2 non-experts, 2 coding experts, and 2 quantum experts with the task to code Grover's algorithm in the IBM quantum lab helped by ChatGPT. The findings from this study indicated that **having a basic coding knowledge or understanding of quantum computing is advantageous**, while an in-depth knowledge of quantum mechanics is not essential. As a result, individuals with backgrounds in coding or quantum performed better in the test. Individuals with coding experience demonstrated a strong ability to spot possible syntax issues and anticipated problems. On the other hand, quantum experts had enough theoretical knowledge to assist the GPT in creating accurate code that fulfilled particular requirements or objectives.

"Can ChatGPT assist individuals new to quantum computing and spark their interest in the field?"

Students from the Industrial Design Engineering program were involved in a workshop to **evaluate the engagement and experiences of non-experts** as they delved into quantum coding. The workshop involved individuals with a background in design, challenging them to produce visual outputs with creative coding using classical computing and later quantum computing. The results revealed that the classical computing aspect was highly **enjoyable and enabled participants to connect with ChatGPT**, allowing them to create projects even with minimal expertise. Similarly, for quantum creative coding some participants managed to produce intriguing visual outputs despite not gaining an in-depth understanding of quantum theory. Based on the feedback received through questionnaires after the workshop, **ChatGPT played a significant role in facilitating participants' initial coding efforts**, triggering their interest in the field of quantum computing.

Findings from the background research evolved in the **design process**, revealing a key insight that presents an opportunity: a direct connection of ChatGPT with IBM Quantum Lab through **GPT customization.**

The **design goal** was to create an open online environment that would serve as an **opportunity to make quantum computer programming easy to access for non-experts** with diverse backgrounds. The aim was to empower users to interact with the design, allowing them to generate quantum code, spark curiosity, and encourage a deeper exploration of the world of quantum computers. The design would be considered successful if, by using it, people could create a working code, have a positive and engaging experience, and feel motivated to use the method again in the future.

"Can a custom-built "GPT" outperform standard GPT4 in helping people run functional code?"
Testing the differences and determining whether improvements are present seemed essential to further recommend the best design output, especially referring to the newly **developed custom GPT, Quantum Buddy.** Five quantum experts of different expertise were selected as the target group for the test, as a certain level of understanding of quantum concepts and Qiskit was necessary to differentiate the responses between the two GPT versions. Ultimately, the test revealed that **both versions were apparently highly efficient** in resolving errors and addressing issues, even if **Quantum GPT showed a slight advantage in tailoring solutions to quantum-specific topics.**

"How accurate and useful is ChatGPT for quantum programming?"
As proof of confirmation of the custom GPT's value, an expert was invited to assess six codes from Participants One, Two, and Three from the previous user test. The aim was to **determine the capabilities of the two GPT versions** and what factors contribute to their qualities.
The primary findings highlight the **importance of the reasoning** behind the code, which is essential for evaluating how GPTs approach problem-solving and their efficiency. This investigation delves into what makes code effectively fulfill its intended purpose. The reasoning is crucial in this assessment. If code demonstrates solid reasoning but contains minor syntax errors, the problem is usually not significant and might be attributed to data errors, yet its value is preserved.

The **design output** has resulted in a personalized GPT called **Quantum Buddy 2.0**, which was developed through continuous improvements and modifications, guided by feedback and tests from earlier versions. What sets this GPT apart from the previous versions are the resources it incorporates, designed specifically to bridge the gaps created by the absence of datasets in certain quantum fields.

"Can ChatGPT enable quantum programming beginners to produce quantum computing programs encouraging them to enjoy and continue using the method?"
The final design needed to meet the assessment criteria previously pointed out. The final evaluation test involved six participants with coding backgrounds, who were ultimately identified as one of the two groups that could benefit most from this method. They were asked to provide solutions to a Traveling Salesman Problem and share their experience. The research findings indicate that initially, ChatGPT's solutions for the Traveling Salesman Problem lacked accuracy in syntax, which was worsened by updates to the *Qiskit. optimization* library.

Despite these obstacles, regular updates facilitated progress, leading to a successful resolution by one participant. Overall, participants had a **positive user experience and showed enthusiasm** for further exploration and debugging. Additionally, they **expressed optimism about ChatGPT's potential** in fields such as cryptography and optimization, despite concerns about its accuracy compared to classical computing. However, **challenges persist in creating precise code,** emphasizing the necessity for future improvements, especially in the updating of the dataset.

In conclusion, the main question, ***"How Might ChatGPT Improve the Accessibility of Quantum Computing?"*** was positively addressed. The findings demonstrate that **ChatGPT significantly eases the process** of programming quantum computers, underscoring its role in **making quantum computing (QC) accessible**. It facilitates learning and improves performance across **diverse backgrounds**, enabling beginners to experiment with creative coding, aiding coders in grasping quantum mechanics, and increasing the efficiency of quantum computing experts. It is crucial to recognize that the research represents the **beginning of a broader inquiry**, highlighting opportunities, limitations, and challenges.

Important **limitations** to consider in the design and research include the **rapidly expanding and evolving** capabilities of ChatGPT. This suggests that the demand for specialized versions like ChatGPT-4 may decrease. Additionally, **changes in Qiskit's programming language** could potentially affect the quality of database responses, which is already becoming a noticeable issue.
Therefore, in **future developments,** Quantum Buddy might either become obsolete or serve as a tool, enabling users from diverse backgrounds, even those with advanced knowledge in other areas, to customize their own GPT for their quantum computing needs. It's important to note that to remain a valuable tool, Quantum Buddy needs **ongoing development and updates.**

NOTE: ChatGPT was utilized throughout the project, spanning from user tests to the evaluation of visuals and text.

Terms to know

AI = Artificial Intelligence
LLM = Large Language Model
NL = Natural Language
QC = Quantum Computer
QT(s) = Quantum Technology(es)
GPT = Generative Pre-trained Transformer
NLP = Natural Language Processing
TSP = Travel salesman problem

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CHAPTER 0

INTRODUCTION

Quantum computing is an advanced technology based on quantum mechanics, that offers unique solutions to problems that traditional computers can't tackle (S. Pandey, N. J. Basisth, T. Sachan, N. Kumari, P. Pakray, 2023). However, it faces a significant **challenge** (World Economic Forum, 2022): a wide **knowledge gap** exists between experts in the field and those who are just starting to learn about it. This gap is mainly because quantum computing requires a lot of specialized knowledge to understand fully.
P. Nelson from the EPSRC pointed out in 2017 (P. Nelson - EPSRC, 2017) that beginners often find quantum computing both exciting and overwhelming, mainly due to a lack of information. To really get involved especially with quantum programming, a good amount of knowledge and skills is needed, making it **seem like the technology is not easily accessible** to everyone.

To make quantum computing more **approachable**, it's important to **reduce the knowledge gap** and give people the information they need to use quantum technology with confidence. Two possible approaches to make quantum computing more accessible are through **education** and **usability enhancements**, with a greater emphasis placed on education (P. Vermaas, 2022). By explaining quantum computing concepts in simpler terms and making them more understandable to a wider audience, it's possible to **increase interest** in and knowledge of quantum, leading to more people joining and innovating in the field (World Economic Forum, 2022) [FIG. 01].

Using tools like **ChatGPT**, a Large Language Model (LLM) developed by OpenAI, is a smart way to help bridge the knowledge gap due to a big increase in the development of generative AI (Y. K. Dwivedi, 2023), making technologies like it **available for everyday use**. ChatGPT is a good example [FIG. 02] of how AI can help **simplify complex topics** such as quantum computing, letting users interact by applying everyday language (NL=Natural language), and allowing them to learn about quantum computing without needing a deep understanding of it. As a tool, it can lead to **many benefits**, such as easier access, immediate feedback, customized learning experiences, support in many languages, and clear, practical examples. However, it's also important to recognize some limitations (R. Yilmaz, F. G. K. Yilmaz, 2023), like the unstructured potential learning and the difficulty in using AI tools with other necessary programming software.

By using innovative tools and methods, the **thesis aims to study how to make quantum computing more accessible** and encourage more people to explore and contribute to this field.

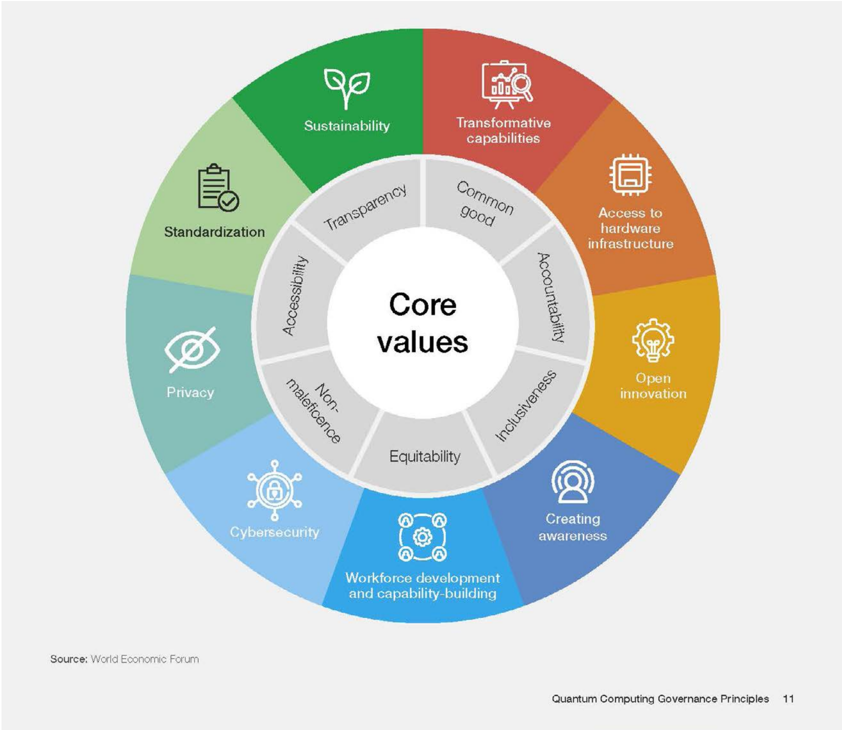
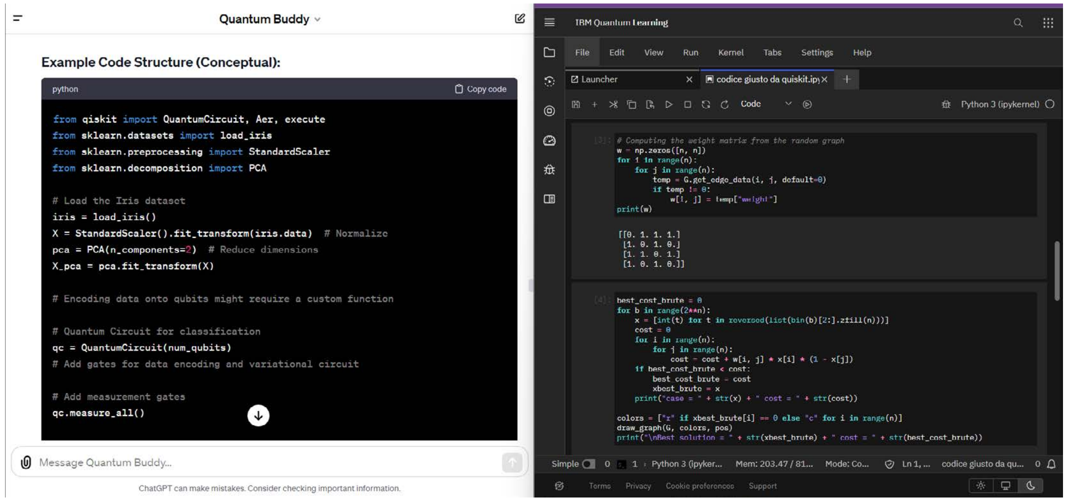


FIG. 01 - The vision of the fundamental Values of the World Economic Forum with accessibility being one of them

FIG. 02 - A screenshot of chatGPT used as a tool for coding quantum.



CHAPTER 1

BACKGROUND ANALYSIS

1.1 Quantum computers

Quantum computing is an exciting and new technology that uses the principles of **quantum mechanics**, setting it apart from traditional computing. Quantum computers rely on **qubits** [1] [FIG. 03], which are more flexible than the standard bits used in classical computing because they can be in a state of 0 and 1 at the same time, thanks to a property known as **superposition** (R. Müller, F. Greinert, 2021). This ability, along with other quantum phenomena like entanglement and interference, **enables QC to solve complex problems** that are too difficult for classical computers (S. Pandey, 2023).

The field of quantum is still in its **early stages**, and it challenges computer scientists to come up with new ways of programming that are suited to the unique capabilities of quantum computers.
Instead of just creating algorithms step by step, programming for quantum computers involves **novel techniques** like adjusting phases and combining amplitudes in different ways to get useful results (E. Rieffel, W. Polak, 2000).
For creating programs on these quantum systems, tools like the **Qiskit library** [FIG. 04] are essential. IBM developed Qiskit (IBM, 2023) as an open platform that enables the development and execution of quantum computing programs, thus highlighting the evolving connection between quantum computing and programming (J. Coles et al., 2018).

[1] Qubit (quantum bit): is the fundamental unit of information in quantum computing, comparable to the classical bit. In quantum mechanics it operates as a two-state system, allowing it to exist simultaneously in two distinct states.

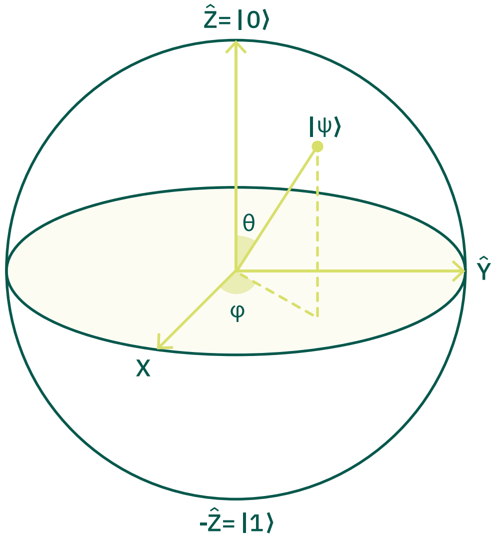


FIG. 03 - A qubit visualization

FIG. 04- A screenshot of the Qiskit Circuit library from IBM.

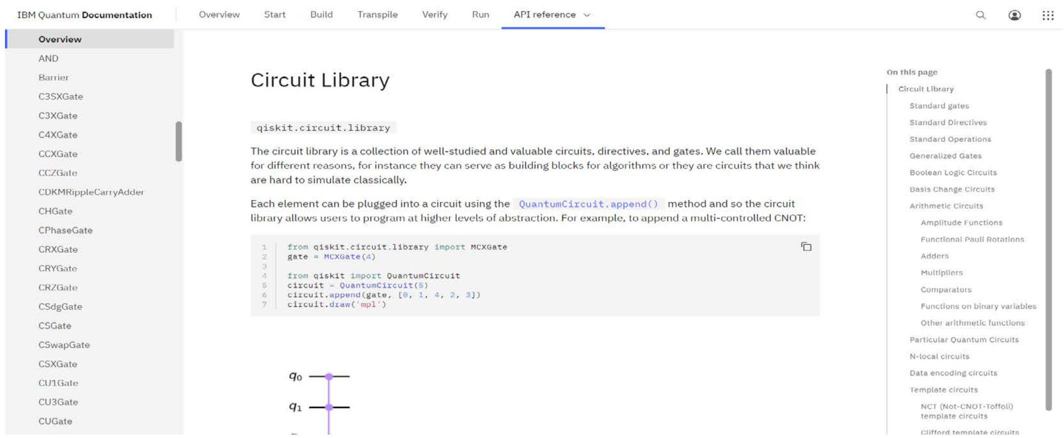


FIG. 05 - The IBM Quantum Computer

1.1.A IBM Quantum Computing [FIG. 05]

Since IBM launched the **Quantum Experience** [2] in May 2016, it has been consistently increasing its quantum computing offerings. IBM has not only allowed users to try out quantum computers through the internet but, by 2021, improved the technology behind it and developed **software tools**. These advancements aim to make QC **easier to use** for more people (The Quantum Mechanic, 2023).

One of IBM's standout features is offering real quantum computer cloud programming environments like the **IBM Quantum Lab** (Quantum Lab, 2023). This means users can run quantum circuits on actual machines just by using their normal computer (The Quantum Mechanic, 2023). By utilizing Qiskit as the main library built on **Python** (Quantum Lab, 2023), IBM offers a significant advantage as this language is widely utilized in fields like machine learning and data science, making the **transition** to quantum **easier** for individuals who are already able to program it.

IBM Quantum Lab tough is not the only tool available for QC, but it's part of a **bigger picture** that includes other platforms and services like QuTech's Quantum Inspire, Amazon Bracket, Microsoft Azure Quantum, D-Wave Leap, Rigetti's quantum cloud service, Alibaba Cloud Quantum Development Kit, and Strangeworks Quantum Computing Platform (The Quantum Mechanic, 2023). In this competitive field, IBM doesn't just provide tools and services; it's also pushing to make quantum computing widely available by trying to provide something anyone can use (The Quantum Mechanic, 2023).

Using IBM's quantum lab resources in this research not only allows for the exploration of **quantum computing through ChatGPT** but also greatly **supports the accessibility objectives of the thesis.** The easy-to-use interface and the availability of the Qiskit database through OpenAI's tool make accessing and interacting with quantum computing simpler, highlighting the importance of this approach in improving accessibility.

[2] Quantum Experience: It's an internet platform offering both public and premium access to cloud-based quantum computing services provided by IBM.

1.1.B Accessibility of Quantum Computers

An approach to **enhance accessibility** is through **classical education** in quantum technology (QT) which greatly benefits from diverse teaching strategies. According to Vermaas et al. (P. Vermaas, 2022), learning about quantum computing should involve a mix of subjects like physics and engineering, pointing out the need for academia to quickly respond to the demand for experts in this rapidly evolving field. However, creating educational content that caters to different learning needs is **still a challenge.**

Another possible path is through **democratic knowledge.** The World Economic Forum's Quantum Computing Governance project (World Economic Forum, 2022) also highlights the significance of **making the public more aware** and engaged with quantum computing. This involves clearing up misconceptions, building trust, and facilitating conversations between the public and those involved in quantum computing. The aim is to promote the responsible and ethical advancement of quantum technologies.

In the early phases of quantum computing development, there's a great chance to win the public's trust by:

1. **Raising awareness** about quantum computing to build trust.
2. **Dispelling myths** and **managing expectations** through informed discussions.
3. **Drawing lessons** from effective public awareness efforts in science and technology.
4. Supporting **open conversations and participation** in the ethical progress of QT.
5. Encouraging **honest, trusting interactions** between the public and scientists.

In this research, the aim is to achieve accessibility by combining education with democratic knowledge, particularly by attempting to connect a tool **accessible** to all like ChatGPT, and seeing if it can be utilized as an **educational medium.**

1.2 ChatGPT

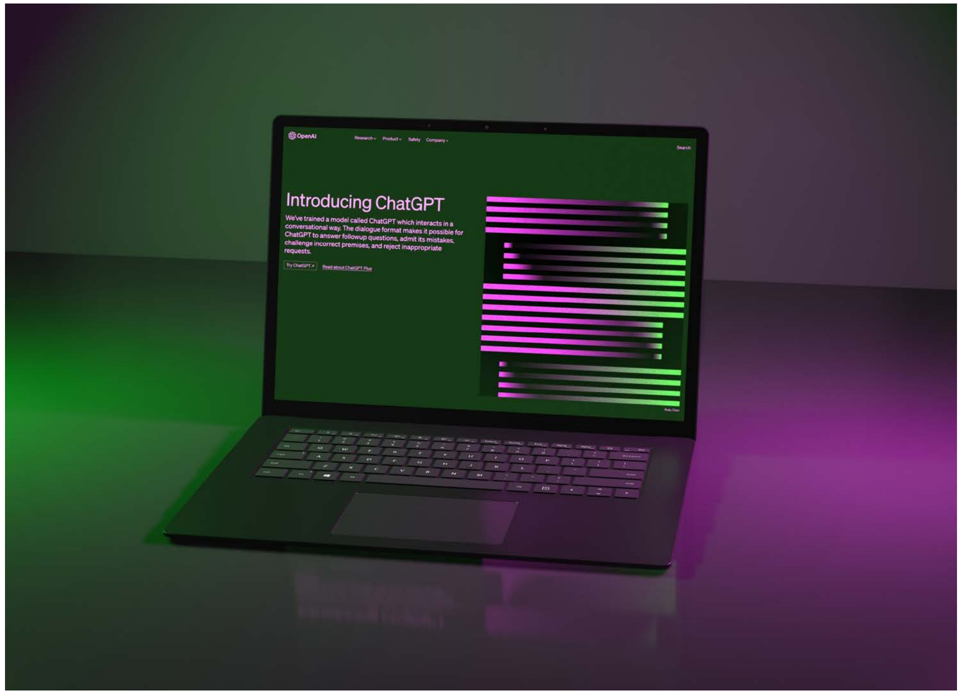
ChatGPT is an **AI chatbot** that uses the Generative Pre-trained Transformer (GPT) architecture crafted to have conversations, producing **text that mimics human responses** based on the input it gets (OpenAI, 2023) [FIG. 06].
This technology has significantly impacted Natural Language Processing (NLP), offering the ability to generate c**oherent and contextually appropriate replies.**

It's useful for a range of NLP tasks, including translating languages, summarizing texts, and providing answers to questions. ChatGPT improves through **reinforcement learning** from human feedback (S. Sohail 2023), which helps it understand and adapt to human preferences over extended conversations.

An update on November 8, 2023, showcases ChatGPT's evolution, introducing the option for users to **create customizable versions** of ChatGPT. This breakthrough allows for the adaptation of ChatGPT to meet specific requirements by adding specific instructions, knowledge, and skills. This development marks a significant step forward in AI, offering **tailored digital interactions** and highlighting a move towards AI tools that focus more on the **user's needs.** The launch of the GPT Store in 2023 underlines this direction, creating a space where developers can benefit from their unique GPT creations (OpenAI, 2023), making these customizable GPTs even **shareable between users**.

Despite these advances, ChatGPT has its **challenges** (S. Singh Gill et al., 2023), including issues like content bias, misinformation, and the difficulty in understanding how it makes decisions, which are often due to the way it's programmed and trained. There are also concerns about how it's used, such as the potential for unethical applications, copyright issues, and becoming too dependent on the technology, which raises ethical questions.

FIG. 06 - ChatGPT welcome page by OpenAI



1.2.A Education

The potential of AI in education is valued by UNESCO which outlined **general guidelines** for its use focusing on the two-fold effects of AI, promoting a holistic approach and the support of local AI advancements. UNESCO advises that educational institutions should employ ChatGPT creatively and responsibly, ensuring it aligns with the principles of academic integrity and course goals. They suggest updating curricula to include AI literacy, ethics, and skills, emphasizing that ChatGPT cannot replace the essential human qualities of creativity and critical thought, which are fundamental to higher education (UNESCO, 2023).

In education, there's a growing emphasis on **appreciating the learning journey** rather than just focusing on the result, representing a different view of education that fosters critical thinking and problem-solving skills. Educators are urged to demystify AI for students, prioritize the learning process, and cultivate skills that extend beyond the capabilities of AI. Additionally, there's an acknowledgment of AI's constraints in education, along with an emphasis on the importance of a collaborative **partnership** between humans and AI in the **learning journey** (L. Cao & C. Dede, 2023).

However, using ChatGPT in education comes with its set of **challenges**, including threats to academic honesty, the delivery of incorrect information, biased responses, a limited knowledge base, and difficulties in multitasking and grasping context (S. Neendoor, 2023). On the **upside**, ChatGPT makes **education more accessible to individuals on different levels**, from knowledge gaps to language barriers, by providing detailed explanations and examples and assisting in creating educational materials. This is especially why the tool has been selected for this research.

1.2.B Programming tool

Since the research looks at the complicated task of quantum computing programming, it's important first to see how ChatGPT works as a tool in regular coding.

ChatGPT has become an important resource in the field of **software engineering** [FIG. 07] and **natural language processing**. Its use as a coding assistant and debugging tool stands out, offering crucial help to developers. This includes providing code suggestions, aiding in debugging efforts, and conversationally answering programming questions. The way ChatGPT interprets human input **naturally and intuitively** is particularly beneficial for programmers, especially those who are **new to the field** (J. White, 2023; S. Sohail 2023).

The impact of ChatGPT on programming education has also been a subject of study, with research by R. Yilmaz and F. G. K. Yilmaz R. Yilmaz and F. G. K. Yilmaz, 2023) exploring its effects from the student's viewpoint.

Their findings point to ChatGPT's effectiveness in **boosting computational thinking**, enhancing programming confidence, and motivating students.
Benefits include its natural language processing capabilities, quick feedback, tailored learning strategies, support for multiple languages, and access to a vast array of resources. ChatGPT's ability to elaborate clear explanations, examples, and practical applications adds significant **value** to the educational process (R. Yilmaz and F. G. K. Yilmaz, 2023).

However, **challenges** like unstructured learning, limitations in data handling, and the necessity for additional tools (especially specific software needed) highlight areas that need **further development** (R. Yilmaz and F. G. K. Yilmaz, 2023). In tasks that require intricate reasoning, such as performing arithmetic, ChatGPT has shown it can handle these with competence. Yet, its current versions have limitations, suggesting that there's still room for technological enhancements (S. Sohail et al., 2023).

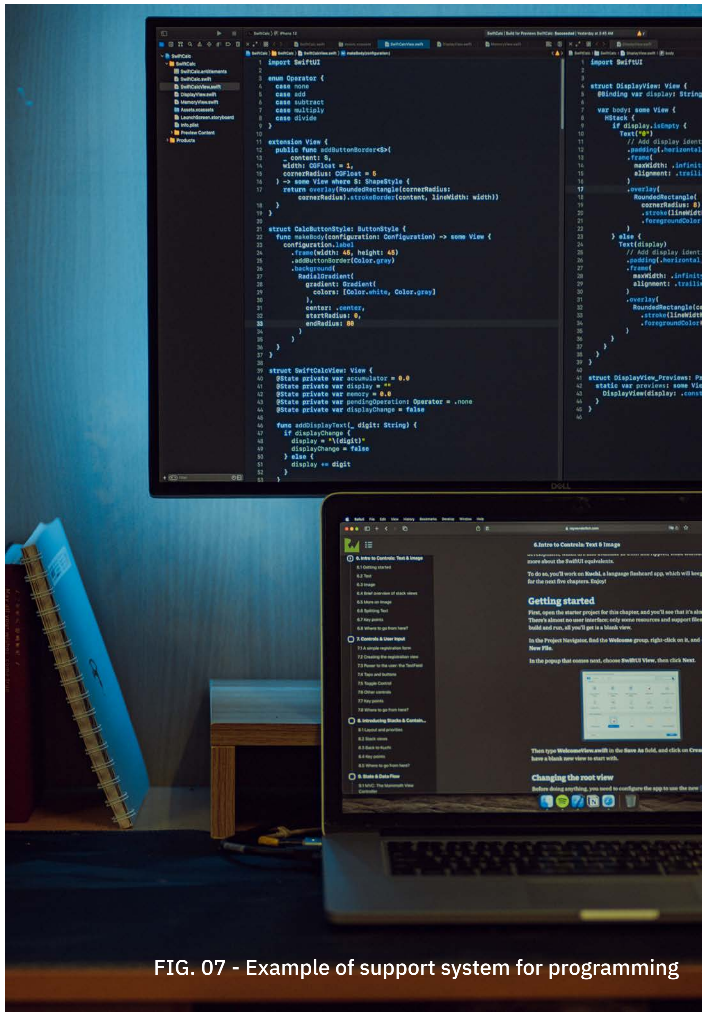


FIG. 07 - Example of support system for programming

CHAPTER 2

FRAMING HYPOTHESIS

2.1 Problem Statement

In **higher education**, people often gain specialized knowledge through structured academic programs. These programs are carefully designed to offer deep insights and expertise in **particular areas of study**. They include demanding courses and practical training, all aimed at preparing students for their future careers in specific fields. While this specialized knowledge is beneficial for those aiming for careers in these fields, it can also pose challenges for individuals who wish to **explore beyond their academic boundaries** and expand their intellectual horizons (V. D'Agnese, 2016).

For individuals looking to broaden their knowledge and delve into various subject areas, **ChatGPT** serves as a valuable tool and resource, acting as an **exploratory platform** (UNESCO, 2023) to interact with, investigate, and interpret data. Quantum computing exemplifies a domain that is typically reserved for experts with specialized knowledge.
However, with the power of GPT models individuals with varying levels of expertise could engage with quantum computing concepts and applications in a more accessible and intuitive manner.

The knowledge gap between specialized higher education and broader intellectual exploration is bridged by accessibility. **Accessibility** refers to the ease with which individuals can access information, resources, and opportunities for learning and exploration (Council of Ontario Universities, 2012). By leveraging smart technologies and innovative approaches, accessibility enables individuals to **overcome barriers to learning and engage** with diverse subjects and disciplines (M.N.I. Sarker, G.M.M. Alam, M. Wu, D.Li, 2019). Through accessible platforms and resources, individuals can expand their knowledge, pursue their interests, and cultivate a deeper understanding of the world around them, ultimately empowering them to pursue lifelong learning and intellectual growth.

FIG. 08 - ChatGPT as an accessibility layer between quantum computers and everyday users

2.2 Hypothesis

The hypothesis explores the idea that **ChatGPT** can be used by people who **don't have expert knowledge** in quantum mechanics to help them write **quantum algorithms** as a starting point to get **involved with quantum technologies** by suggesting that being an expert in quantum theory is not a requirement to create basic quantum algorithms.

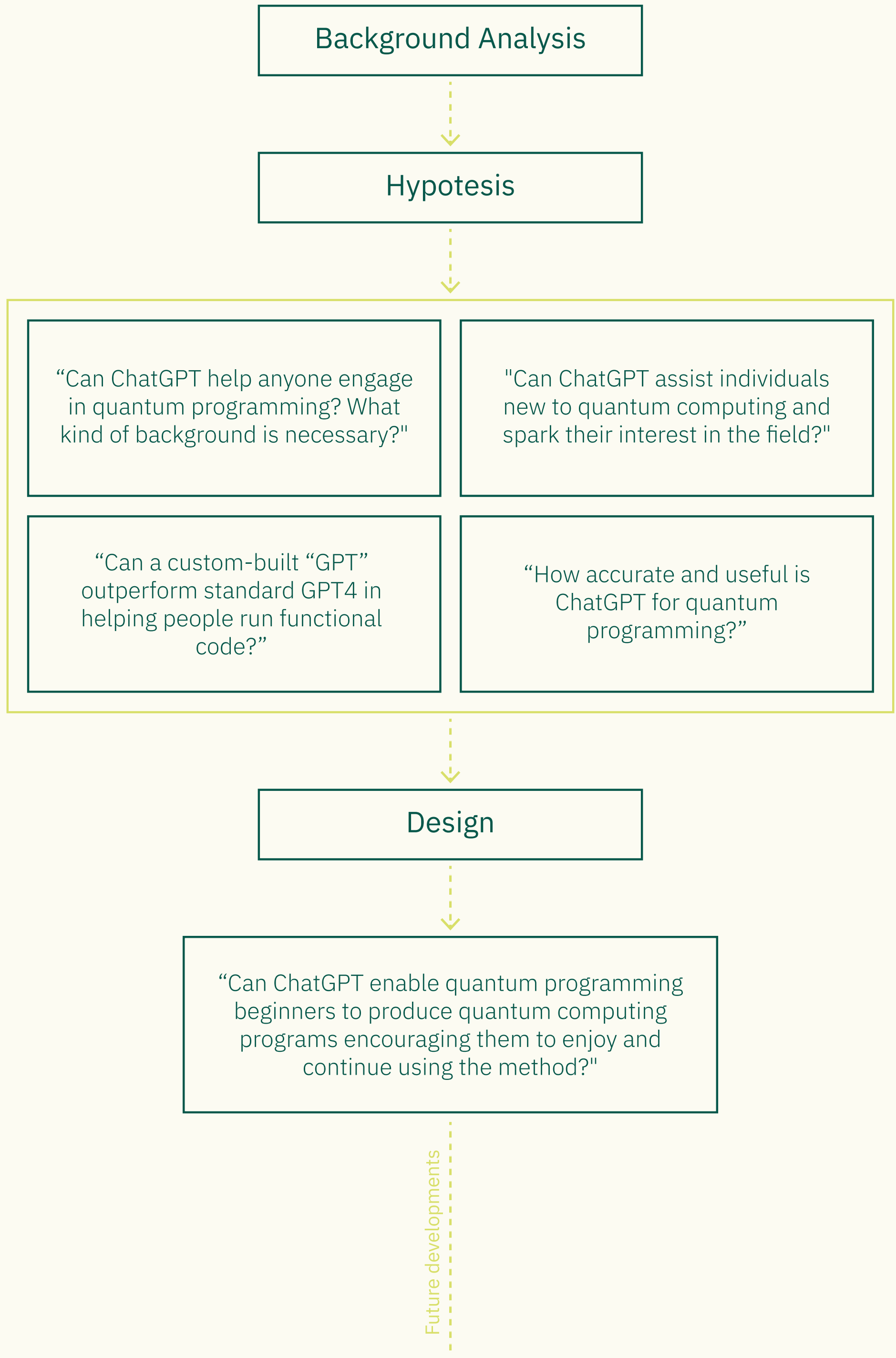
The focus of this discussion is on the key question, "How Might ChatGPT Improve the Accessibility of Quantum Computing?"
It suggests that **ChatGPT** could play an essential role in **bridging the knowledge gap** [FIG. 08] because is **accessible to everyone**, and it has proven to be an **effective educational tool** that offers personalized learning experiences for students. Ideally, this would allow people who are not experts to learn about and start working with the **basic concepts of quantum algorithms**.

CHAPTER 3

METHOD

The method used in analyzing the theme and creating the final output is based on a series of **research questions.** By answering these questions **using human-centered design methods**, the necessary requirements for the design and evaluation of its actual implementation have been outlined.

"How Might ChatGPT Improve the Accessibility of Quantum Computing?"



CHAPTER 4

BACKGROUND RESEARCH

Understanding the Design Context

4.1 Interview with experts

Before conducting the interviews, brief questionnaires [APPENDIX - II.a] were administered via email to experts from the academic field at TUDelft, to gather information.
The questions were designed to assess the **ideal audience** for the project, focusing on the level of preparation needed to comprehend complex subjects like quantum mechanics and coding. Additionally, insights were gathered regarding the suitability of a particular **academic background** for the ideal user and which domains would benefit the most from instruction for non-experts [APPENDIX - II.b].

As part of the research process, two online interviews were conducted with **Taha Selim** [3] and **Freek Pols** [4]. During the conversation with Taha Selim, three potential coding approaches were identified: experts using supervised learning, individuals already in the field utilizing reinforcement learning, and complete beginners embarking on new learning experiences. This interview also highlighted challenges such as defining the criteria for "working code," whether it denotes error-free code or code that achieves its intended purpose. Additionally, it delved into the foundational knowledge required by non-experts to identify and understand errors.

General findings indicate that the **assumption** regarding the ideal target audience, being non-experts, is **partially accurate**, with personal interests playing a significant role. The questionnaire also suggests that individuals with **classical coding or quantum knowledge** could mostly benefit from using ChatGPT as a tool in quantum. While a profound understanding of quantum mechanics is not essential, having a **basic grasp** can be advantageous, especially in addressing potential issues since the language of code may pose challenges for non-coders.

[3] Taha Selim: PhD Candidate, Institute for Molecules and Materials (IMM), Radboud University, Nijmegen

[4] Freek Pols: Assistant-professor in Science & Engineering Education at Delft University of Technology

4.2 Ideal Background for Non-Experts

"Can ChatGPT help anyone engage in quantum programming? What kind of background is necessary?"

To address the question, **User Test #1** aimed to investigate how users' expertise and background could influence their ability to use and understand the method for obtaining the code. Specifically, it sought to determine if **differences in comprehension** were linked to **users' prior knowledge**.

To begin, a broad group of potential users who might be interested in and benefit from the method was identified. A framework [APPENDIX - III.a] was established for defining the ideal user profile, with a focus on two key attributes: the **ability to program** for quantum and classical computers, and a **basic understanding of quantum computers**. From these subgroups, three distinct categories were chosen for the user test: **quantum experts**, **coding experts**, and **non-experts**, each consisting of two individuals [FIG. 09].

Non-experts	Experts in Coding	Experts in Quantum
P1: MSc in Mechanical Engineering.	**P3:** MSc in Computer Science, focusing on cybersecurity	**P5:** MSc degrees in Applied Physics, specializing in quantum physics.
P2: MSc in Design for Interaction	**P4:** MSc in Aerospace Engineering	**P6:** MSc degrees in Applied Physics, specializing in quantum physics.

FIG. 09 - User test participants and their background

The objective of the test was to **program Grover's Algorithms** [5] and was divided into three phases [FIG. 10]. The first phase focused on data collection, emphasizing the user's background to understand their starting point. The central phase was all about interaction and coding, where participants engaged with ChatGPT to develop codes that could be implemented in the IBM quantum computing simulator. The final phase was dedicated to a thorough evaluation.

[5] Grover's Algorithm: is a quantum computing algorithm that efficiently searches through unsorted information to find the desired solution using fewer steps compared to classical methods.

The results [APPENDIX - III.c] from the test provided valuable insights. Firstly, it was observed that participants generally required **more time** than initially expected to complete their tasks. Furthermore, out of the six participants, **three** managed to **successfully create a final code.** Interestingly, two participants, P3 and P5, achieved this within the same session, while participant P6 required additional time. Moreover, the completion of the codes by the three participants led to three distinct outcomes, emphasizing the diversity in approaches and understanding among them.

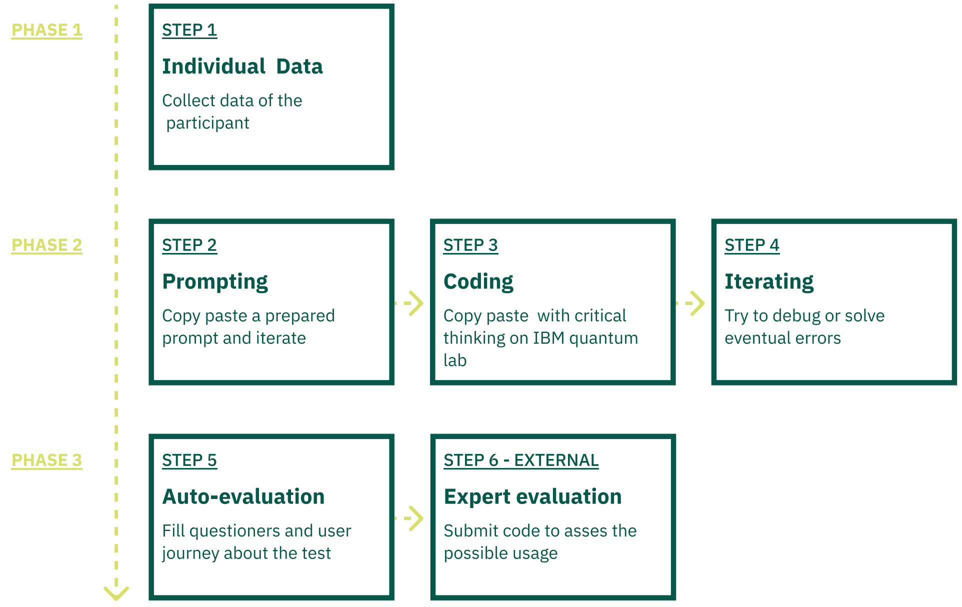


FIG. 10 - User test #1 structure

The further examination offered insights into how each participant perceived their work. FIG. 11 showed that **quantum experts** demonstrated a **high level of confidence** and competence in their tasks, displaying assurance in the results they achieved. On the other hand, the **coding experts**, while self-assured in their coding skills, expressed **uncertainty** about the correctness of their codes. In contrast, the two **non-experts** exhibited a lack of confidence and awareness in their work.

Braking down the findings for each category overall it's possible to say that **non-expert teams**, faced challenges, leading to **confusion and repetitive errors** while working with the IBM simulator. Their reliance on copying and pasting code, along with a lack of critical thinking, resulted in frustration.
Coding experts benefited from ChatGPT's interactive and straightforward approach, streamlining their coding process. Their familiarity with coding languages enabled them to **predict** possible outcomes, thereby **simplifying** the process of error iteration and decision-making.

Quantum computing experts achieved error-free results, refining ChatGPT-generated code. They used their expertise to ask precise questions, **combining technical knowledge with intuitive understanding** and graphical schemes for effective collaboration.

Question	Experts in Quantum (Avg)	Experts in Coding (Avg)	Non-experts (Avg)
How confident do you feel about your final result from 1 to 5, where 1 is not very confident and 5 is very confident?	3	4.5	2
How well do you believe you understood the final code from 1 to 5, where 1 is I didn't understand anything and 5 is I understood everything?	2	3.5	4
How much do you believe your background helped you in understanding the final code from 1 to 5, where 1 is very little and 5 is a lot?	3	3.5	4.5

FIG. 11 - Users' self-perception of their expertise

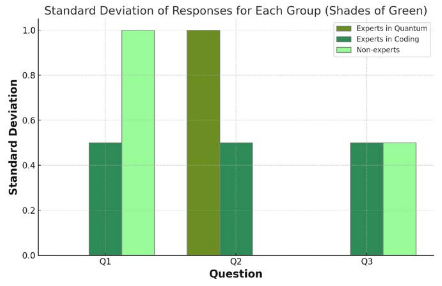


FIG. 12 - Standard deviation of responses for each group across the three questions

Following a one-hour interview with Dr. Taha Salim undertook a meticulous **evaluation** of the final codes from participants **P5 and P3.** The objective was to assess whether the final code given by chatGPT and the users' knowledge effectively fulfilled the requirements set in the initial prompt [6]. A significant part of the discussion revolved around the analysis and comparison between the two quantum computing experiments [FIG. 13-14].

[6] Test Prompt: I want to develop a code to break cryptography utilizing the Grover algorithm to run on the IBM simulator with 32 qubits. (...)

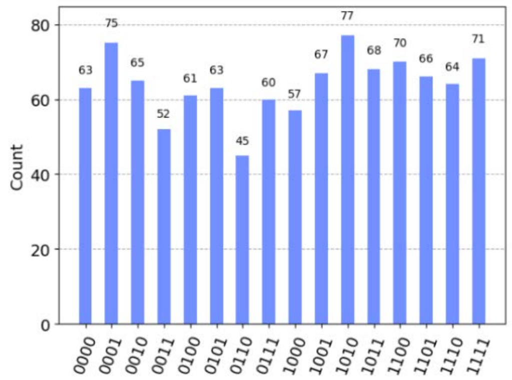


FIG. 13 - P3

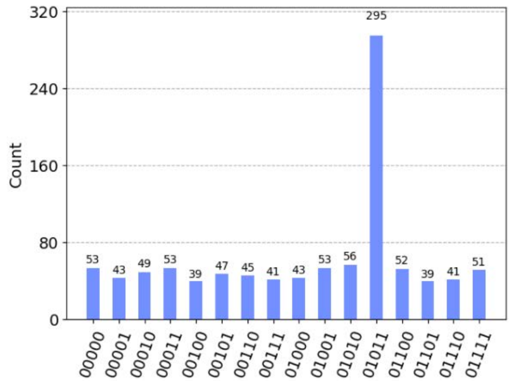


FIG. 14 - P5

In **P3**'s chart [FIG. 13], the results are **evenly distributed**, indicating that no specific answer was favored as expected. This even distribution could be due to excessive noise [7] in the quantum system or a failure of the algorithm to perform the task effectively. Therefore, the results from P3 appear to be either **incorrect or inconclusive.**
In contrast, the chart for **P5** [FIG. 14] displays a distinct pattern: one outcome ("0110") significantly outperforms the others, suggesting that the algorithm has effectively amplified the probability of the **correct answer**. This peak is a characteristic feature of Grover's algorithm when it operates correctly, signifying a potential success in cryptography breaking in P5's case.

Dr. Salim's overall perspective highlights the significance of thorough testing, a solid **understanding of quantum principles**, and awareness of the method's strengths and limitations. He sees the methodology behind the code **positively**, finding it generally useful and effective in about 70-80% of cases. However, he also warns that it might not work for everyone, stressing the importance of **having basic knowledge** to anticipate problems and assess outcomes.

In conclusion, having a **smaller code knowledge** or a understanding of **fundamental quantum mechanics** is noted as **advantageous**, with **both quantum experts completing** the task, **one out of two coding experts** doing the same, and **both non-experts failing** to do so. Being able to **anticipate** and address potential **errors** becomes crucial, facilitating more efficient design and debugging processes, and ensuring a smoother transition from the conceptual stage to practical implementation. The **gap between backgrounds** underscores the complex nature of translating theoretical knowledge into practical, functional quantum codes.

[7] Quantum Noise: a type of background disturbance that occurs because of the inherent uncertainty in the behavior of tiny particles, as predicted by quantum physics.

4.3 ChatGPT's Role in QC Engagement

"Can ChatGPT assist individuals new to quantum computing and spark their interest in the field?"

The role of ChatGPT was addressed in the workshop [APPENDIX - IV.a] involving students from the Industrial Design Engineering program at TUDelft. The aim was to observe how **beginners** in both quantum theory and coding **navigate the method** and to understand their perspective toward it. Specifically, the objective was to **evaluate the engagement and experiences** of non-experts as they delved into quantum coding. The workshop was divided into **two sections**: one centered on ChatGPT and its role in **creative coding**, and the other with the integration of **creative coding of quantum computing**. The decision to start the workshop with basic coding languages like HTML, CSS, and Java was made to provide a gentle introduction to coding with ChatGPT before diving into the complexities of quantum computing.

Before delving into the workshop it is important to highlight that **creative coding** was chosen because emphasizes **artistic and expressive possibilities** rather than only focusing on functional outcomes. It involves using code to create art, interactive installations, and digital visualizations and encourages **breaking traditional coding boundaries** to explore new expressions and digital creativity (T. Rodenbröker, 2022) [FIG. 15].

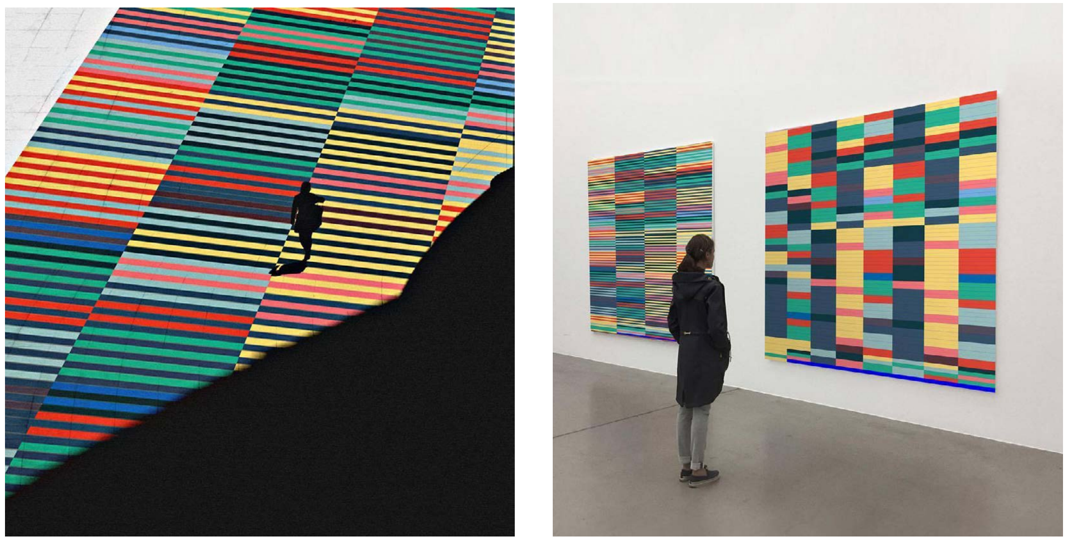


FIG. 15 - Graphic representations of the musical structure by Rodenbröker

Quantum computing creative coding, as showcased in the second part of the workshop, is an extension of classical coding. Notable examples include research from Cornell University (J. R. Wootton, 2020), which explores algorithmically generated content for manipulating qubits to create and modify images of landscapes, resulting in pixelated effects [FIG. 16]. This article is just one among several; additional artistic forms supported include Rothko-inspired generative Art (R. Huffman, 2020) [FIG. 17], Bubble Art (R. P. Sandhir, 2021) [FIG. 18], and Fractal Art (Qiskit, 2022) [FIG. 19]. These sources of inspiration were further explored by workshop participants and served as the foundation for their creative pursuits.

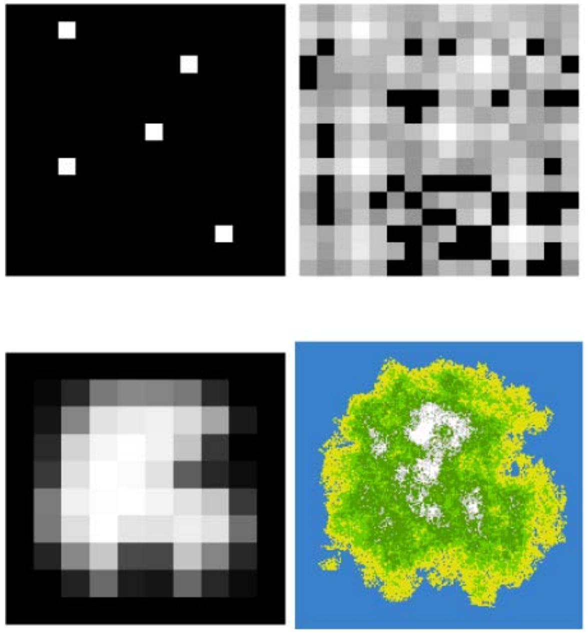


FIG.16 - Terrain generation manipulation

FIG. 17 - Rothko-inspired generative Art

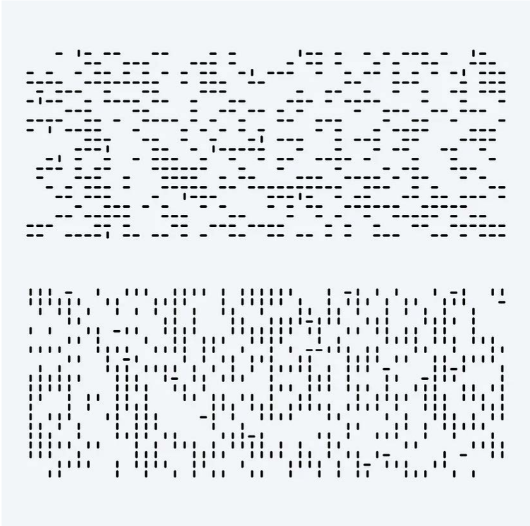
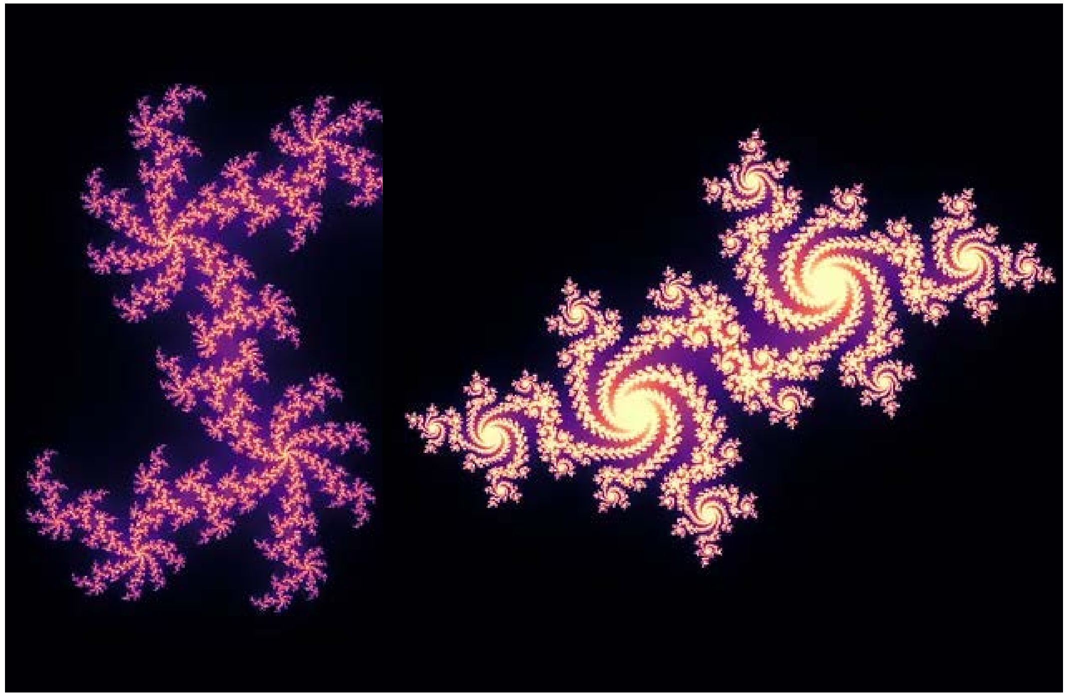
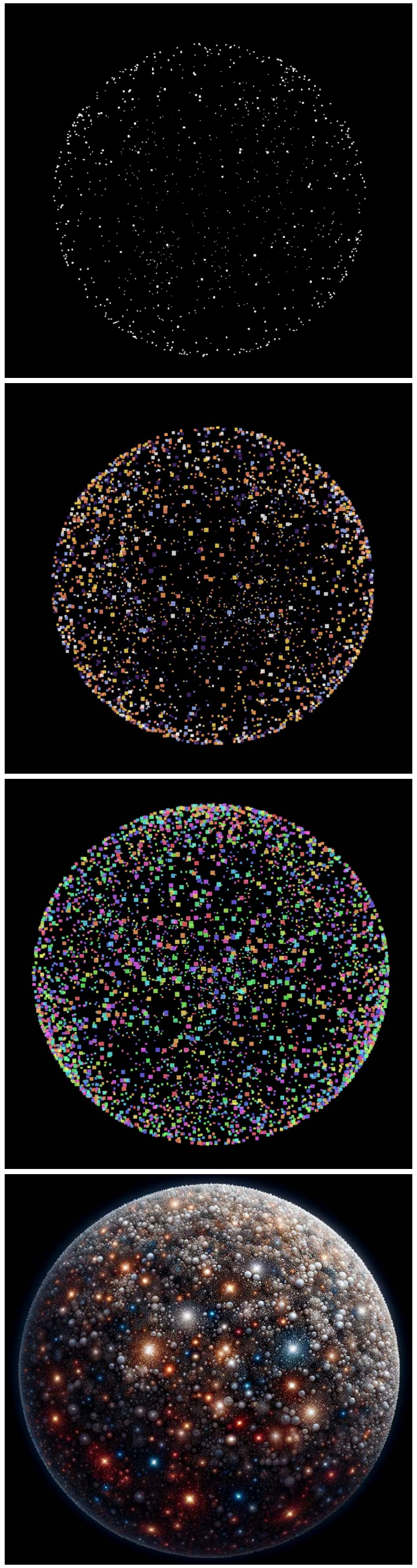


FIG. 18- Bubble art with noise

FIG. 19- Two fractals produced with Qiskit running on real quantum hardware





After the first part dedicated to classical code [APPENDIX - IV.a], the participants began the quantum creative coding with a theoretical session on quantum computers.
The objective of this part of the workshop was for them to **generate a visual component**. They were tasked with iterating the process using both **ChatGPT** and the **IBM quantum simulator.**
The activity was organized in pairs to encourage collaboration, with one person coding while the other took notes and then switched roles. Following the workshop, a brief feedback session was conducted, serving as a crucial tool for understanding the **emotional and intellectual responses of the participants** to the workshop.
Particularly noteworthy among the results [APPENDIX - IV.b] achieved by the participants are **visually intriguing approaches.** Often, the more complex and visually appealing outcomes are the result of user iteration, where the individual has learned how to **incorporate their personal touch into the quantum visualization** project. Here are a series of examples.

The initial example depicted in [FIG. 20] showcases the evolution from a **quantum randomization input to the generation of a galaxy.** Initially, the participant's inquiry to ChatGPT lacked specificity, expressing a desire for a visual representation that epitomized randomness. As a result, ChatGPT suggested creating a quantum galaxy map. Expanding upon this suggestion, the participant refined the design, introducing layers of intricacy to the artwork. Subsequently, they opted to utilize the drawing as a basis for further enhancement in DALL-E, resulting in a final visual output of high quality.

FIG. 20 - Set of images from Room 01 in the IDE workshop.

In the second example, the participant chose to **reverse the workflow** after realizing the tool's potential. They decided to generate the data first and then use it in IBM. Following a brief iteration in ChatGPT to acquire the necessary IBM code, the participant obtained the preliminary [FIG. 21] data and then **requested ChatGPT to recreate those data visually** in the style typical of IBM [FIG. 22]. Once this was achieved, they advanced further by asking ChatGPT to convert that code into JavaScript and create an **animation** on Codepen [FIG. 23].

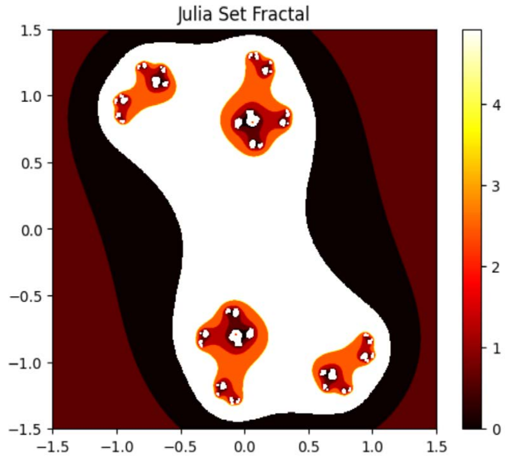


FIG. 21 - First data was manipulated in Room 06

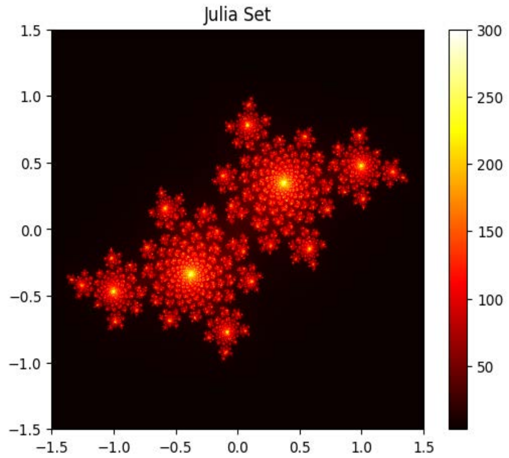


FIG. 22 - Iteration on ChatGPT in IBM style

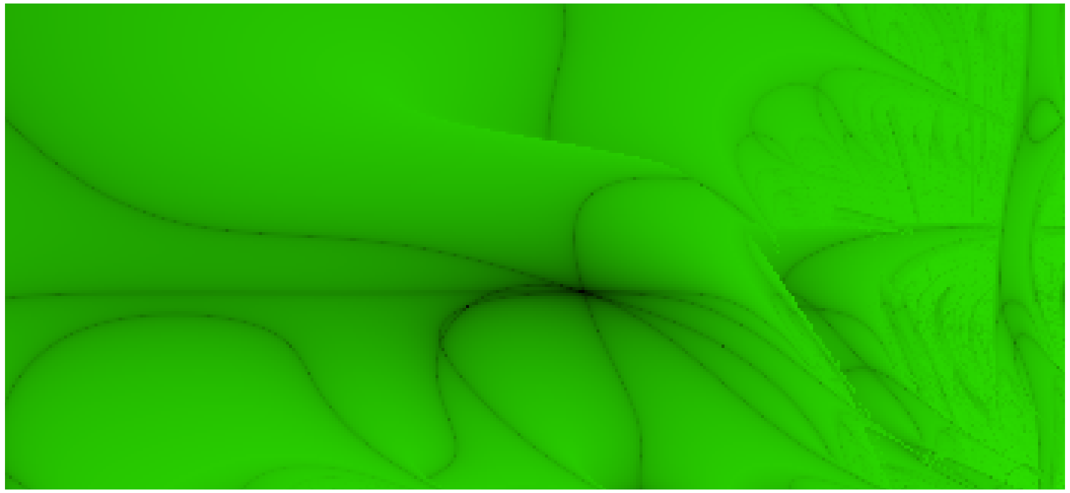


FIG. 23 - A screenshot from the Codepen gif

In the last example, users in the breakout room collaborated to achieve a dual outcome from their experiment. Initially, they read the article on **fractal art** available on the Miroboard (Qiskit, 2022) and decided to attempt transforming the data from their histogram into something similar. The first step involved generating numerical data on IBM, using code from ChatGPT [FIG. 24]. Subsequently, in this case, the data were processed graphically through ChatGPT using DALL-E [FIG. 25] and also brought to IBM to be visualized as an animation. The idea for this animation was to *"create a sinuous movement from deep red to dark blue"*. However, the animation was quite slow to materialize, leading the two users to repost the code in ChatGPT and directly request a final **animation** that would include all the executed states [FIG. 26].

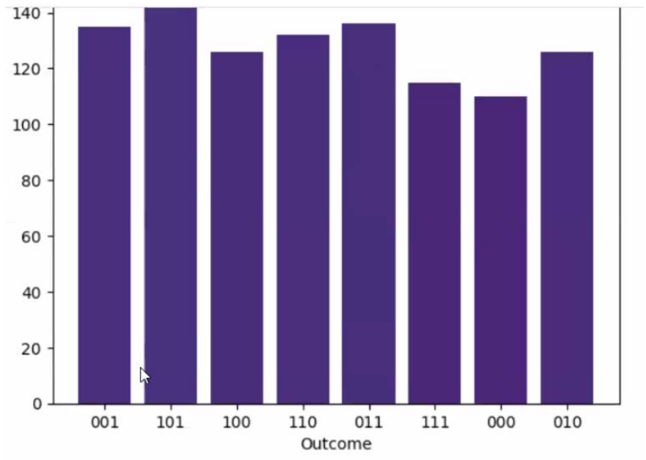


FIG. 24 - Step 1 of Visual results from Room 09

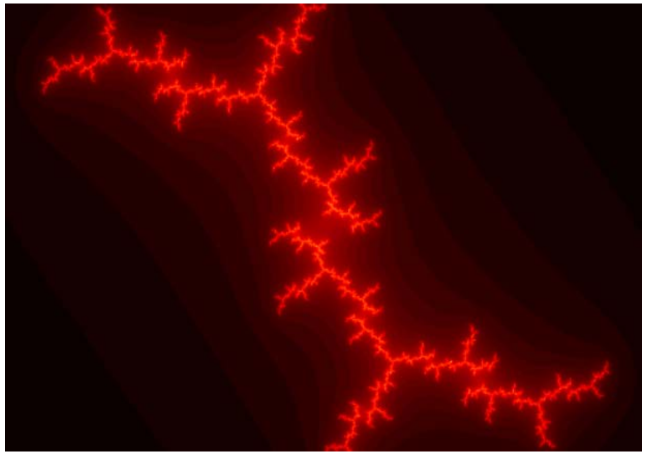


FIG. 25 - Step 2 of Visual results from Room 09

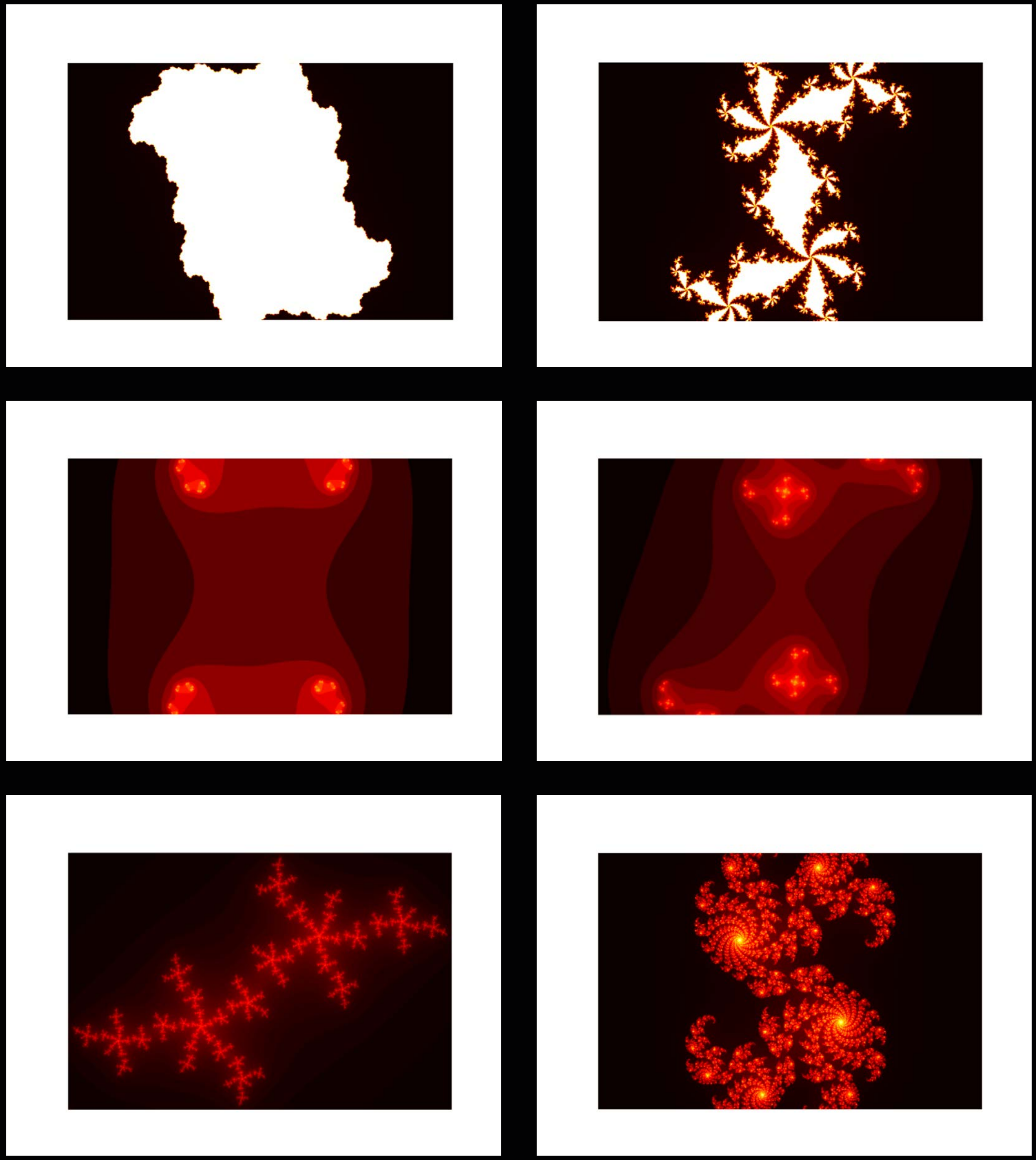


FIG. 26 - Screenshot of the different stages of the animation

All visual outputs were accompanied by **comments and iterations**, which were then used to collect data for further analysis to identify patterns and trends.

The section titled ***"User Experiences and Interaction Patterns"*** [FIG. 27] investigates how individuals engage with and respond to the proposed method, focusing particularly on their **interactions with GPT.** Within the ***"Exploring Interactions with Learning Outcomes"*** cluster, the study examines how user engagements lead to valuable discoveries and refinements. Some participants express their **need for assistance** or detailed guidance, while others **explore alternative approaches** to achieve their desired results. Although these comments often seek clarification, they generally convey **positivity** and do not indicate significant challenges. On the other hand, the ***"Trial and Error"*** cluster reveals moments where the process was **not consistently smooth**, with some participants resorting to trial-and-error methods to progress. Issues and limitations encountered during this phase pose **challenges** for users, such as difficulty in determining the next steps or understanding the rationale behind certain outputs. Lastly, ***"User's Wants"*** documents users' desired outcomes and instructions provided to GPT for the final design or visual output, ranging from specific requests to more open-ended prompts.

The section ***"Technical Insights and Workflow Adaptations"*** [FIG. 28] delves into the technical challenges encountered by users during the workshop, lightening aspects of the method that were difficult or technical. In ***"Problems and Limitations"*** the focus shifts to the **issues** users faced in **implementing steps**, especially due to technical obstacles with GPT. This encompasses operational challenges with the OpenAI tool, such as **memory limitations** when tackling overly complex tasks, as well as the consequences of **imprecise prompts** leading to unexpected alterations in output. ***"Trial and Error"*** illustrates scenarios where users initially grappled with the tool but ultimately overcame obstacles through iterative experimentation. For instance, participants mentioned needing **multiple attempts** to incorporate desired colors and movements, yet found success by guiding ChatGPT along the way. Lastly, ***"Good Working Process"*** consolidates positive feedback on the technical effectiveness of GPT within the process, with remarks highlighting seamless integration with the Quantum Lab after copying the prompt.

The section ***"User Sentiments and Learning Outcomes"*** [FIG. 29] delves into the **emotional responses and educational progress** observed among participants during the workshop. It focuses on individual experiences and developmental journeys, shedding light on emotional trajectories and knowledge acquisition. A notable pattern that emerged was the **cycle of trial and error**, wherein participants alternated between attempts and mistakes, leading to various emotional outcomes like **frustration** or **annoyance**. **Confusion** also played a role, triggered by both the process and content of the method, resulting in mixed sentiments among participants. While positives and negatives coexisted, negative feedback was less frequent, often highlighting methodological difficulties. Conversely, positive feedback showcased a generally **favorable attitude and curiosity** toward quantum computing, tempered by an awareness of the complexity of the subject.

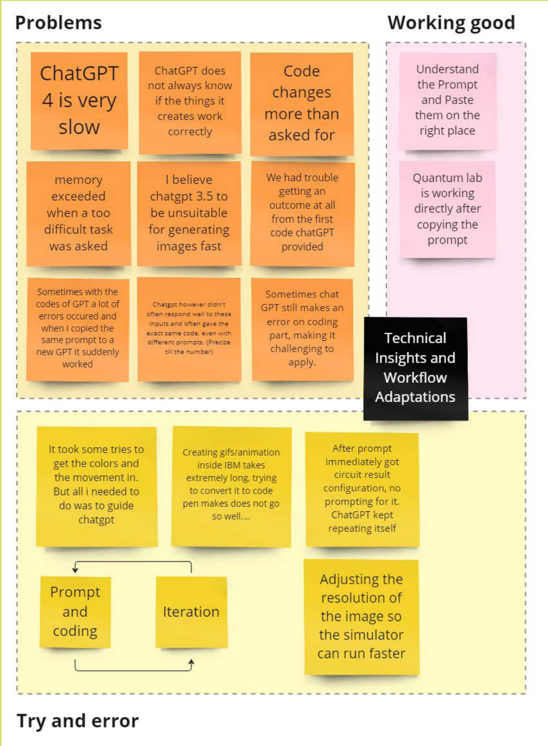
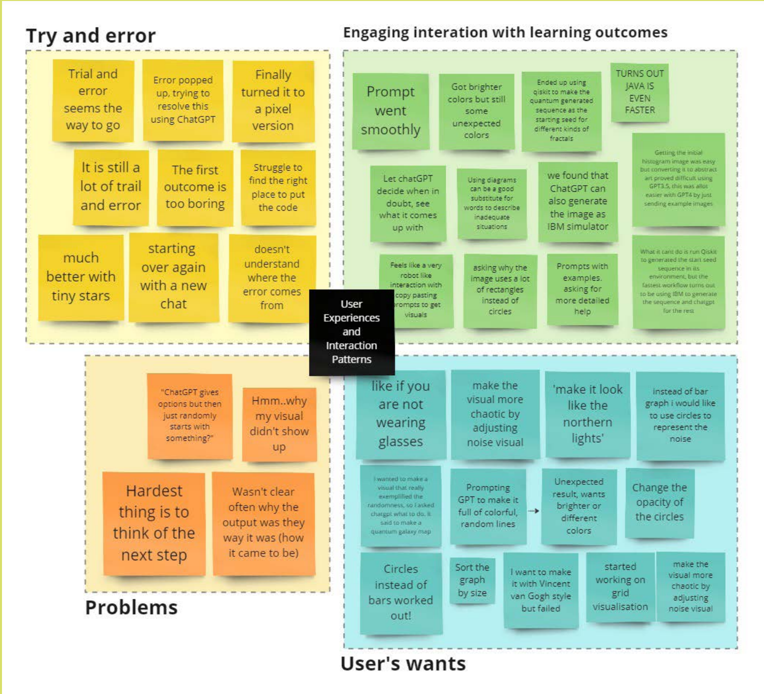


FIG. 27 - Screenshot of the cluster "User Experiences and Interaction Patterns"

FIG. 28 - Screenshot of the cluster "Technical Insights and Workflow Adaptations"



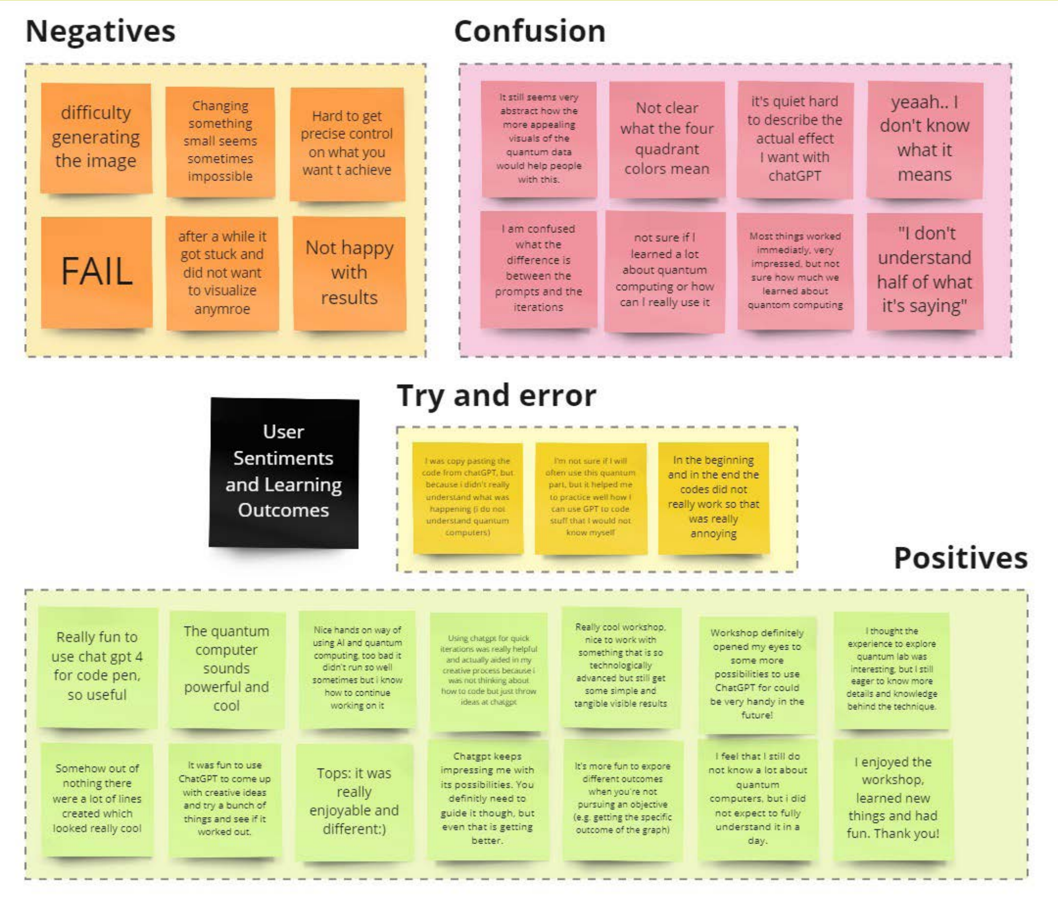
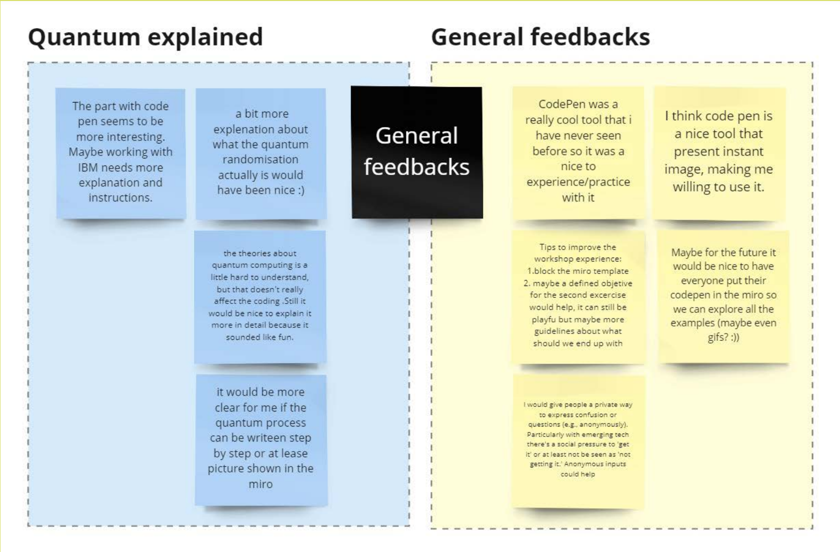


FIG. 29 - Screenshot of the cluster "User Sentiments and Learning Outcomes"

FIG. 30 - Screenshot of the cluster "General Feedback"



The section on ***"General Feedback"*** [FIG. 30] delves into users' comprehensive perspectives on the workshop, addressing their **suggestions** and identifying any structural shortcomings. Within the ***"Quantum Explained"*** subsection, participants highlight challenges encountered regarding the theoretical aspects of quantum mechanics during the workshop, indicating a desire for a more thorough introduction to the theory. This section holds particular significance as it encapsulates all feedback about the workshop's structure and execution, offering valuable insights for future enhancements.

Overall the **workshop successfully achieved its goals**, simplifying the coding process for non-experts and reducing their apprehension about engaging with technology . However, limitations such as the workshop's little depth of knowledge in quantum computing and time constraints led to some **confusion** among participants.
The results showed that participants found the classical computing aspect enjoyable and were able to create projects with minimal expertise. Similarly, some participants produced **intriguing visual outputs** in quantum creative coding despite having a limited understanding of quantum theory.

Regarding the research question, *"Can ChatGPT assist individuals new to quantum computing and spark their interest in the field?"* findings confirmed that **ChatGPT can indeed help users with limited expertise in quantum theory** and coding to develop complex quantum algorithms. Participants expressed a greater **affinity for the technology** overall but **acknowledged the need for a deeper understanding** to fully comprehend their actions. In particular, **65%** of participants left the workshop feeling **less intimidated** by approaching quantum computing, **70% were intrigued** and wanted to know more, and **100%** of them declared that they were **not scared** about facing this complex subject [FIG. 31]. Additionally, it is to be noted that some participants really add their personal expertise in the methods for reaching interesting visual outputs, bridging the expertise knowledge.

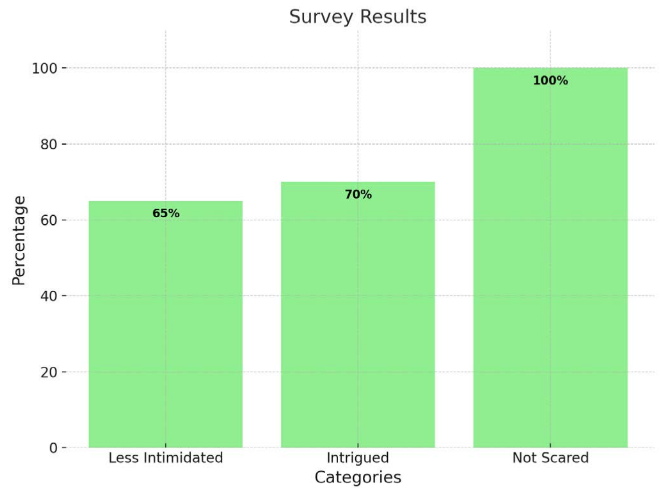


FIG.31 - %Results from the final feedbacks session

CHAPTER 5

DESIGN DIRECTION

5.1 Design positioning

To effectively position the design, it was necessary to **contextualize** the system, ensuring that the outcomes interact with various components and entities. The interaction in FIG. 32 involves a central entity represented by the group "task-user-final result". **The user is assigned a task to accomplish via OpenAI and IBM, which leads to an outcome through their actions.** On one hand, OpenAI's ecosystem, including tools like ChatGPT, is involved, while on the other, there is IBM, specifically the IBM Quantum Lab and Qiskit. Ultimately, the **objectives of the learning experience** and the **value of the process** are maintained. This interconnected framework illustrates that the final result is not a singular output but rather a mix of various contributing factors.

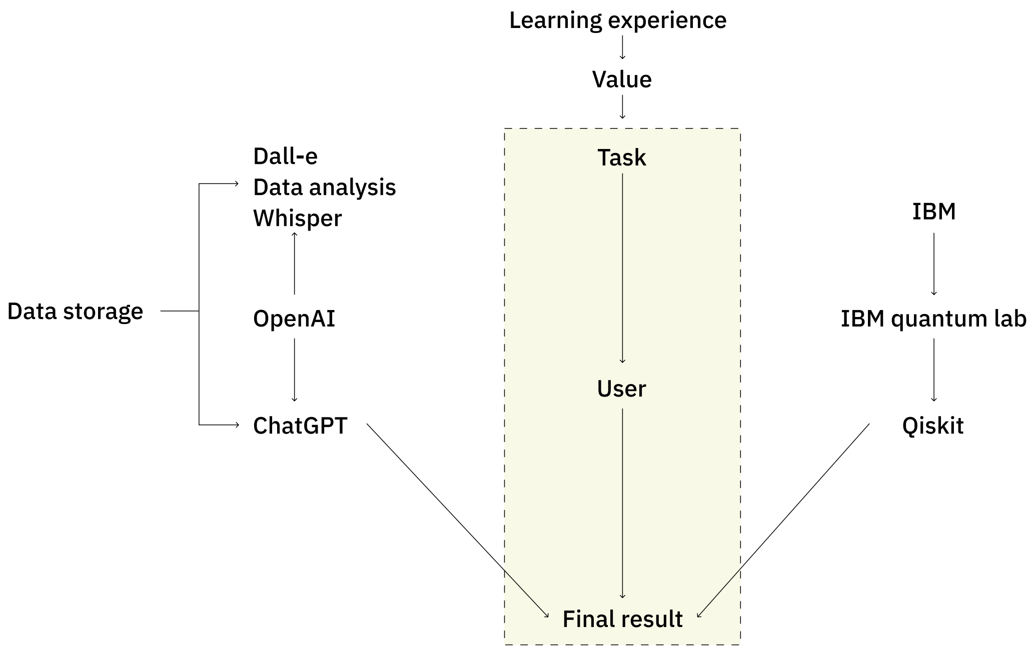
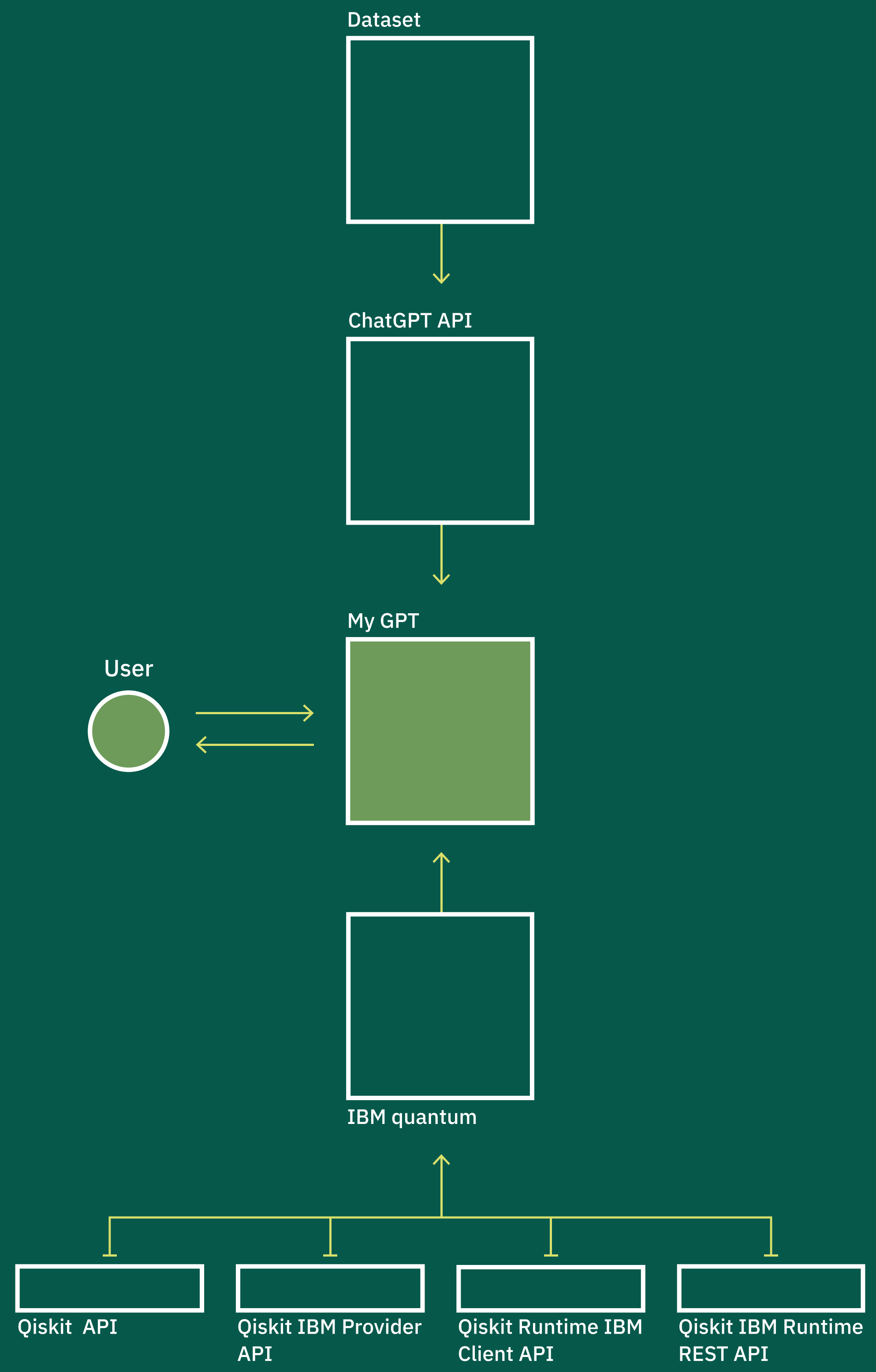


FIG. 32 - Context mapping scheme

Considering this intersection, the **design** had to seamlessly integrate into the typical user flow, acting as a **bridge between the realms of ChatGPT and IBM** [FIG. 33]. The design was envisioned to function as the primary educational bridge that users engage with during this process.

FIG. 33 - Mapping of the User Interaction



5.2 Design goal

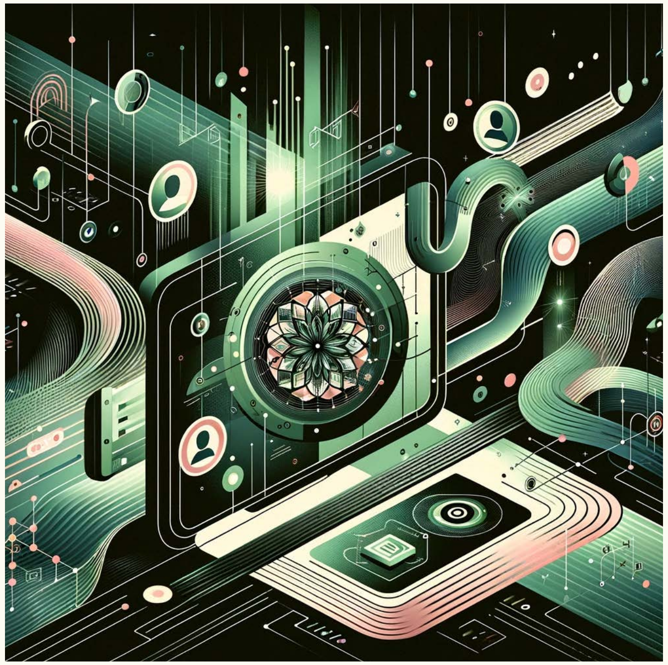


FIG. 34 - The design goal visualised by ChagtGPT

The goal is to establish an accessible online platform that facilitates quantum computer programming for individuals without prior expertise in the field.

The intention is to enable users to **effortlessly generate quantum code**, **fostering curiosity** and **promoting further exploration** of quantum computing.
In this setting, users from diverse backgrounds are encouraged to **explore different coding methods**, learn from mistakes, and improve their algorithms, **regardless of their initial understanding** of quantum computing or coding.

5.3 Assessment criteria

The assessment criteria are used to determine **if the objectives are met** and if user requirements are addressed comprehensively in the final design. Specifically, the evaluation focuses on the following aspects:

1. The user’s ability to **generate a final code that fulfills the established objective.**
2. The user’s development of **positive feelings towards the process**, encourages **sustained interest** rather than causing frustration or discontinuation.
3. The user’s motivation to **utilize the method again in the future.**

For the **first one**, the user should be able to **complete the assigned** tasks and reach the conclusion of the test. The tasks may be creative (thus less technical) or technical, based on the user’s initial expertise level and corresponding to the target user identified by User Test #1 [See 4.2].
For the **second criterion**, the user should feel **positively engaged with the technology** and not be daunted by it. The method should encourage them to proceed and contribute to the collective aim of achieving the final result, following their expertise.
For the **final criterion**, the user should be **motivated to see the benefits of the method**, focus on its potential usage, and particularly desire to use it again in practice.

CHAPTER 6

DESIGN RESEARCH

Creating and improving the Design

During the exploration of possible outcomes, OpenAI released, for ChatGPT-4 users, **custom GPTs that perfectly aligned with the project's design goals** (OpenAI, 2023) [See 1.2].
To assess the tool's validity and effectiveness, the research needed to **validate these custom GPTs** and identify any differences or discrepancies between them.
After the first iteration with the costum GPT **"Quantum Explorer"** [APPENDIX - V], asecond version named **"Quantum Buddy Custom GPT"** [APPENDIX - VI] was made to be tested.

6.1 Comparing Quantum-based GPT Models to GPT-4

"Can a custom-built "GPT" outperform standard GPT4 in helping people run functional code?"

To evaluate the performance of the newly developed GPT **Quantum Buddy**, the aim was to identify any **differences** or **unique features** compared to the classical GPT.
To achieve this objective, in **User Test #2** participants with a certain level of **quantum knowledge** were required to **distinguish the responses** between the classical GPT and the quantum one. Specifically, participants came from the Quantum QUEST program (QuSoft, 2024) and the Applied Physics master's program, specializing in quantum mechanics, at TU Delft. Despite their diverse educational backgrounds, these users had the basic proficiency in Qiskit programming which was necessary to assess the results. The test involved a total of five participants, resulting in the generation of 10 codes [APPENDIX - VII.c] .

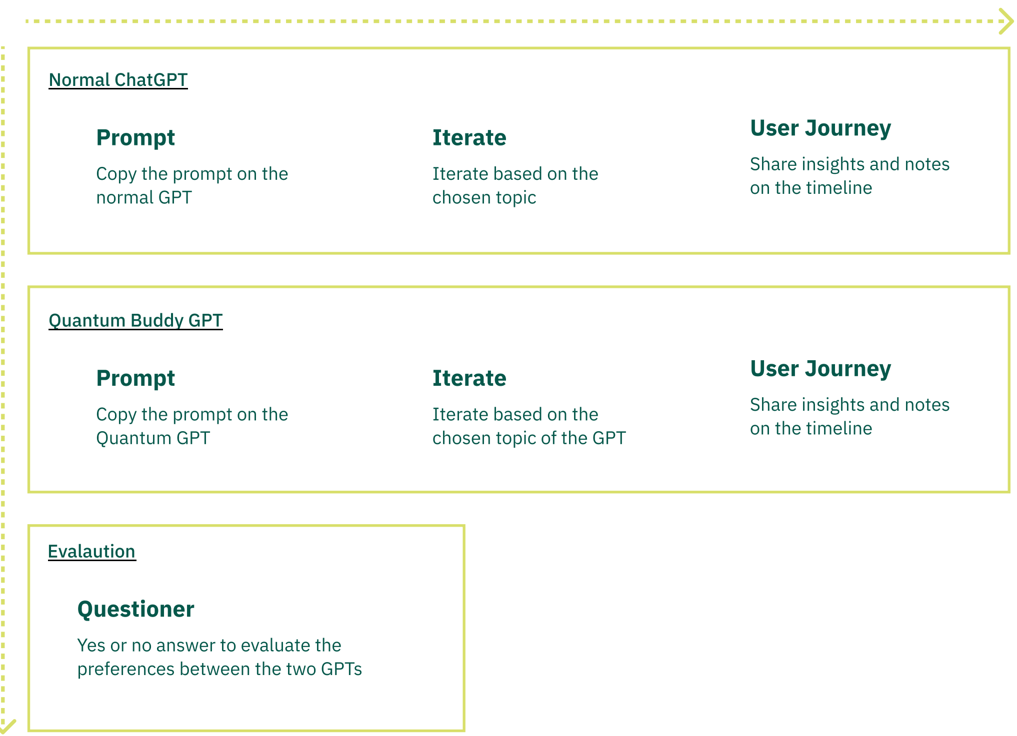


FIG. 35 - Structure of the workshop

The format of the test in FIG. 35, follows a linear yet iterative approach, consisting of **three distinct stages**: Prompting and Iteration, User Journey Collection, and Evaluation. Each of these phases is executed using **both GPT versions** to highlight any differences, and after these comparisons, an evaluation is conducted through a series of inquiries.

In the initial stage, participants are tasked with copying and pasting a pre-prepared generic prompt [8] that remains consistent for both GPTs. This prompt already includes some guidance for the user journey, allowing the GPTs to initiate a dialogue leading to a final solution. Following the completion of the prompting stage, the iteration process begins, characterized by a back-and-forth interaction between ChatGPT and IBM, facilitating revisions if the code is incorrect or fails to meet the requirements. Afterward, users establish a customizable user journey timeline [FIG. 36] and repeat the process for the second GPT. Once these steps are concluded, polarized yes-or-no questions and ratings are employed for intentional polarization.

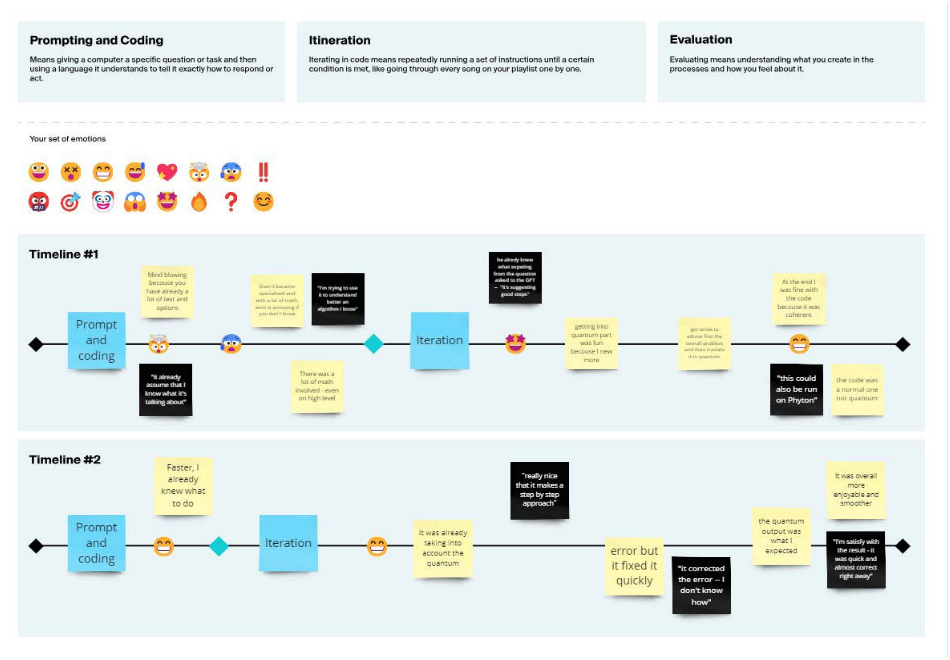


FIG. 36 - P1 User journey map to show user iteration with the two GPTs

[8] "I want to have a structured user test for a young enthusiast with a background in quantum mechanics and coding. first, explain the aim of the test. The objective of the test is to conceptualize, develop, and refine an algorithm that leverages the unique capabilities of quantum computing. ask me if I'm ready and wait for my reply. Then, in a new prompt, explain to me step by step what I'm going to do. Start with conceptualization: Begin by choosing a field and understanding the unique problem you wish to solve. Give some options such as as exploring fields like Cryptography, Machine Learning, Chemical Simulations, and Optimization Problems in the conceptualization stage. wait for my response. then, in a new prompt, go to the stage of Development: Start coding your algorithm with guidance from ChatGPT. Don't worry if you're not an expert coder; ChatGPT will help you translate your quantum understanding into a working code. Once you have the code go to the following stages in a new prompt: Refinement: Test and refine your algorithm. Finalization: Finalize your code and prepare it for submission to run on an IBM quantum computer. All along keep a cheerful and simple language with emojis."

This systematic gathering of data [APPENDIX - VII.b] formed the basis for organized **clustering analysis**, which categorized the data into different interaction phases: prompting, iteration, and evaluation. Each phase was further divided into two sections, one for the standard GPT and one for the Quantum Buddy.
A significant observation during clustering was the **number of comments** made for each stage, particularly about the evaluation phase. Not all participants felt they reached a conclusive evaluation phase, with many focusing their observations on the iteration phase. Indeed, the **middle phase** was the most **content-rich**, involving the trial-and-error element, which is a crucial aspect of the process. Additionally, a second color-coded evaluation was introduced to categorize participant feedback, with distinct classifications for comments as positive, negative, or neutral general observations.

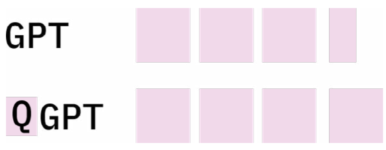
Positive and negative observations vary throughout the different stages of the process.
During the **prompting** and coding phases, there was generally **positive** sentiment, partly attributed to the astonishment at the **capabilities** of the GPT (*"Mind-blowing because you already have a lot of text and options"*), and partly because of the **response speed** and accuracy in QuantumGPT (*"I can already see that it is quicker in some passages and more focused (on quantum)"*). Upon comparison between the two, it was evident that while both performed well, the **quantum version stood out** due to fewer errors.

During the **iteration** phase, a more balanced and intriguing picture emerged. Both versions of the GPT showcased their respective strengths and weaknesses.
Negative feedback arose from **errors** and the subsequent iterations required for their resolutions.
With the standard GPT, two types of errors were evident: one in **code creation**, which P2 failed to resolve, resulting in the participant not reaching a final result, and another in **problem classification**. In this case, P1 observed that the generated code for solving their problem was not specific to quantum computers but rather standard Python language code, applicable to any computer.
As for the **Quantum GPT**, errors seemed consistently **linked to code generation**, as noted by one participant who mentioned: *"Unfortunately, when we tried to solve this, I got stuck and couldn't generate more answers."* This issue may have been closely related to the **dataset** loaded into the GPTs.

However, these error incidents were followed by **problem resolution** in 4 out of 5 cases for both the standard and Quantum GPT, where the **unresolved error was the same** for both. It was from these resolutions that **positive comments** were generated, such as *"... then I saw that it gave it to me but at the end so it was still there even if not really well explained"* for the standard GPT and *"error but it fixed it quickly"* for QuantumGPT.
Furthermore, other comments about the GPT were about its **effectiveness** in framing the quantum problem since *".. it's already giving to me the quantum instance and the visualization tool"* and it's the ability to **ordinate** code *"I liked the way this structured the code (libraries are all above)"*.

In the **final phase**, there wasn't an abundance of insightful observations. However, what was discerned was a **generally positive experience** with the method and its problem-focused resolution approach.
The **only negative** comment pertained to the standard GPT and highlighted that *"eventually we solved the error but we needed to ask for the whole code again instead of fixing the cell with the error".*

Overall, **both** versions demonstrate comparable problem-solving abilities, with the **Quantum GPT slightly outperforming** the standard version, especially in tailoring solutions to quantum-specific themes.
This trend is evident in the **average scores** [APPENDIX - VII.b], where the standard GPT receives a rating of 3.5 out of 5, while the Quantum GPT achieves a slightly higher average of 4 out of 5 [FIG. 37].
Interestingly, both versions exhibit **high efficiency in resolving errors**, successfully addressing issues in 4 out of 5 cases, with **one unresolved error common to both**. When participants were asked about the **response speed** of the Quantum GPT to complex computational tasks compared to the standard ChatGPT, the majority responded affirmatively. Furthermore, a significant majority noted that the Quantum GPT provides **more accurate and detailed responses** to technical or scientific queries.



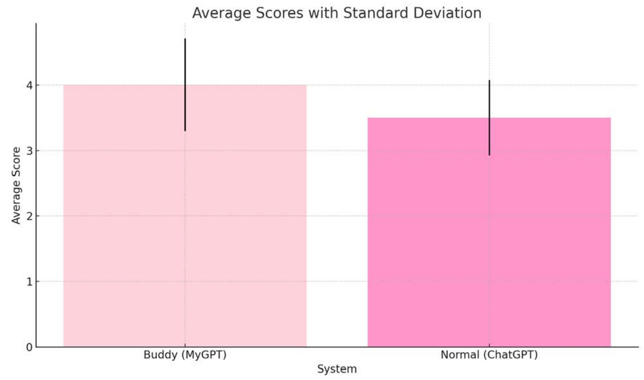


FIG. 37 - Average rating and standard deviations from participants' prospective

6.2 Assessing GPT Code Responses

"How accurate and useful is ChatGPT for quantum programming?"

The expert Taha Selim was invited to assess six codes from P1, P2, and P3 from the previous user test as proof of confirmation of the custom GPT's value. The objective was to determine the **capabilities of the two GPT** versions and what factors contribute to their qualities [APPENDIX - VIII].

Quantum Buddy, as observed in **P1**'s case [FIG. 38], shows closer alignment with initial queries due to its quantum framework, attributing differences between GPT models to their distinct approaches. Different outcomes may result from participants' diversity query methodologies. In **P2**'s case, good code structuring is evident despite a syntax error blocking progress. Similarly, in **P3**'s scenario, although the Quantum Buddy demonstrates greater precision, numerical resolution remains a challenge. The assessment primarily focused on technical correctness and ChatGPT's effectiveness in explaining quantum concepts. Observations by Professor Selim [FIG. 39] underscore the importance of **robust reasoning** behind the code, affirming the **validity of the overall approach** given the complexity involved.

It's important to highlight that GPTs need to be both **quick and focused** on answering particular questions accurately to enhance their performance. This is in line with the importance of **crafting precise queries** for the GPT, as seen in the shortcomings noted during the discussions of the second participant, indicating a lack of effective question formulation. Moreover, it's crucial to acknowledge that **GPTs depend on existing databases**, which may present **difficulties** with the latest library versions and coding functions, as evidenced by the experiments conducted by P2 and P3 with their respective codes.
Regarding the database, it was noted that **Qiskit** also had some **limitations**. The errors encountered during the participants' experiences mainly pertained to **syntax issues.** This difficulty is not exclusive to this scenario but is also common in other domains utilizing Qiskit, arising from its frequent updates in libraries and usage methodologies. Such rapid advancements present a **challenge** for timely integration into GPTs, indicating the intricacy and the differing durations each participant devoted to working with the GPT for IBM.
Although the previous point can be identified as limitations, it was emphasized more that the **reasoning** about how the GPTs address problems is the main thing to consider.

Generally, the **accuracy** of the GPT responses relies on the **reasoning process**, which plays a significant role in this evaluation. If a code demonstrates **good reasoning** but contains **syntax errors**, as observed in the cases we examined, the **issue is minor** and often associated with data inaccuracies. Yet, the capacity to develop **something of value** remains intact. Artificial intelligence stands out as a powerful tool in programming, not just for its speed but primarily for its capability in logical reasoning ("*AI can be a tool to code quantum coding because it can get the reasoning*").

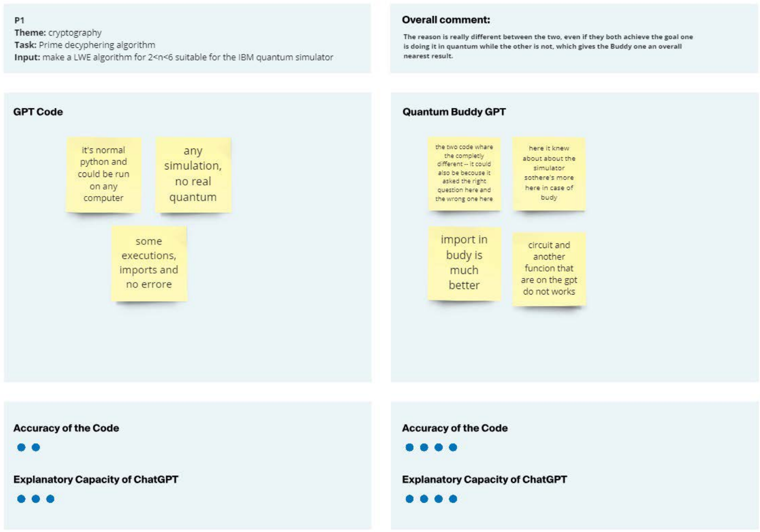


FIG. 38 - P1 results from Taha Selim's perspective

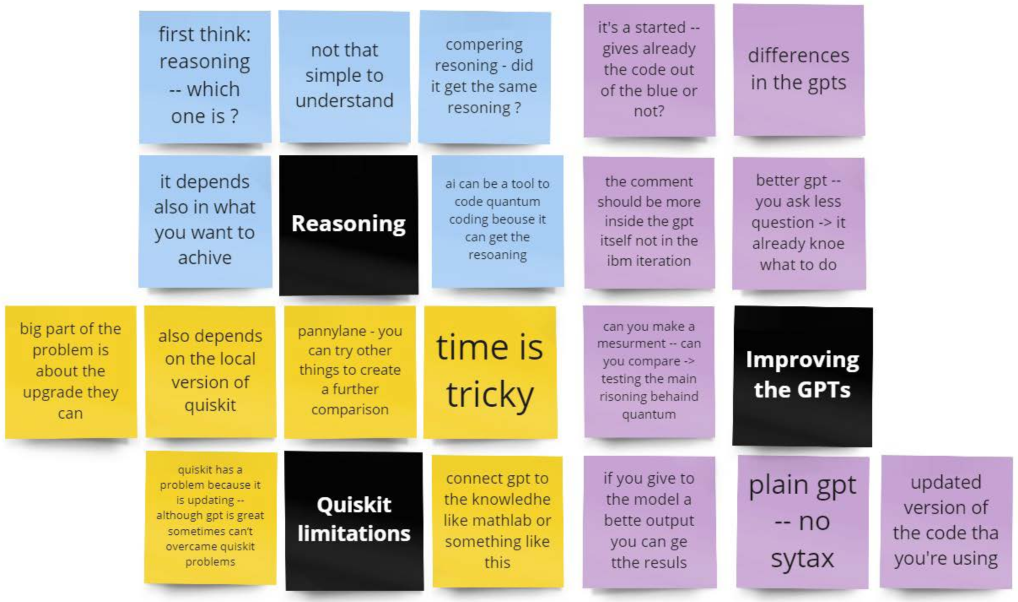


FIG. 39 - The cluster of notions that helped to draw conclusions

CHAPTER 7
DESIGN OUTPUT

Quantum Buddy 2.0

https://chat.openai.com/g/g-HuukcppqT-quantum-buddy-2-0

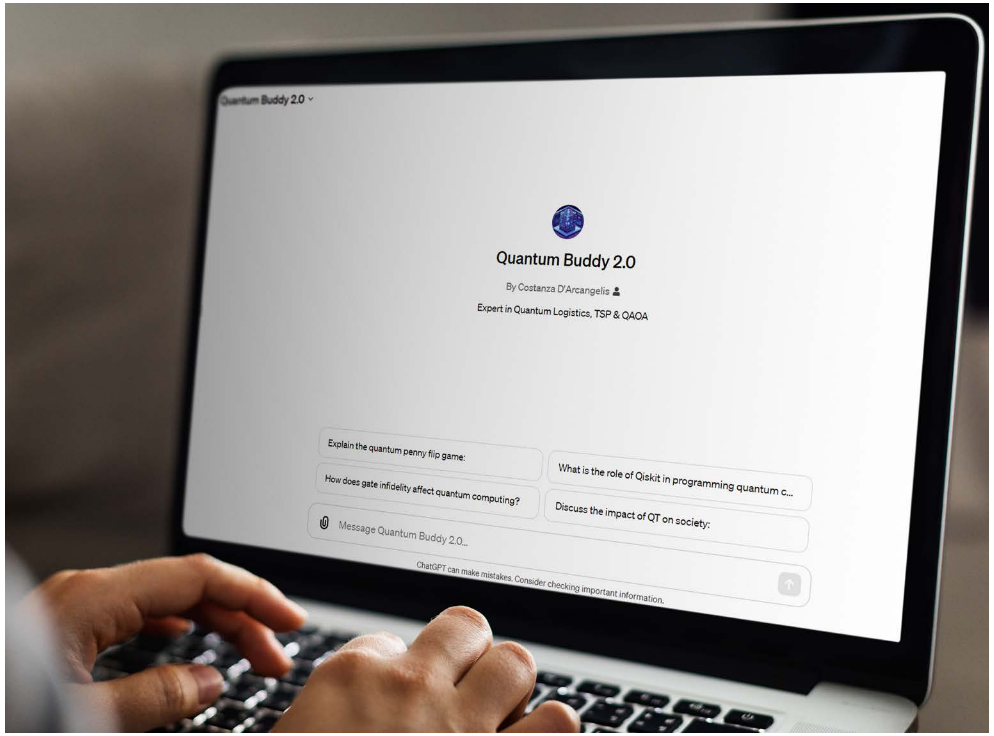


FIG. 40 - A screenshot of Quantum Buddy 2.0

FIG. 41 - The profile picture of Quantum Buddy 2.0

7.1 The design [FIG. 40]

The design output has led to the development of a **personalized GPT** known as **Quantum Buddy 2.0** [APPENDIX - IX], which represents the latest advancement in the custom GPT model. It has been carefully refined based on insights and shortcomings identified in previous versions. This ultimate iteration incorporates systematic improvements and adjustments, g**uided by feedback and practical evaluations** from earlier trials, to address any deficiencies and integrate valuable lessons learned during initial testing phases.

After analyzing insights from User Test #2 [See 6.1] and observing the deployment of Quantum Buddy, significant adjustments were made to develop Quantum Buddy 2.0 GPT. One notable improvement was the **expansion of the model's database**, particularly in three crucial areas: the **Draw function, Quantum Finance library, and Qiskit Machine Learning library.**
The model now incorporates comprehensive Qiskit libraries, presented in file formats containing all codes and images generated up to the final design, along with data from User Test #1, the IDE Academy workshop, and User Test #2.

Crucial aspects for the refinement of this ultimate version included **improving integration with IBM's quantum simulator** for a more seamless and efficient interface, integrating updates customized for the finance sector and machine learning domain, with a specific focus on improving **compatibility with Qiskit libraries**, and enabling connections to external resources to offer supplementary information on specific topics, such as recommending relevant literature or websites.

7.2 Design Evaluation

"Can ChatGPT enable quantum programming beginners to produce quantum computing programs encouraging them to enjoy and continue using the method?"

The final evaluation of the design was carefully develop to assess the latest version of the GPT model, focusing on the **three assessment criteria** outlined at the outset [See 5.3]. Initially, the assessment analyzed the model's ability to **assist users in generating code** that met the initial task requirements. Secondly, it evaluated improvements in the overall user experience by ensuring an **enjoyable coding process**. Lastly, it measured the **user's motivation** to utilize the method again.

The final assessment test involved six participants with **coding backgrounds**, three from Data Science Engineering, one from Aerospace Engineering, and two from Statistics and Probability. Individuals were instructed to provide solutions to a Traveling Salesman Problem (TSP) [9] about route optimization in the Netherlands.

Participants were tasked with utilizing the **Quantum Buddy 2.0** GPT model and sharing their experiences, outlining the process they undertook to develop their solutions. Additionally, they were encouraged to offer **feedback** on the usability, effectiveness, and overall experience of using the method. This comprehensive evaluation [FIG. 42] aimed to gather insights into how the method performed in **real-world scenarios** and its potential impact on users with coding expertise.

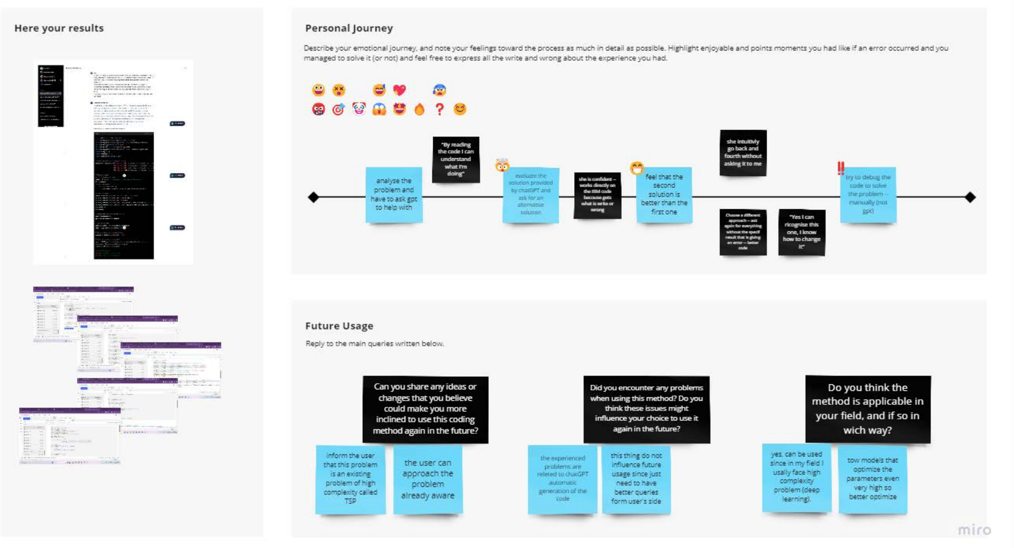


FIG. 42 - Template after P1 User Test

The **first** and most controversial criterion [See 5.3] of generating coherent code was demonstrated by writing the **resolution codes** for the TSP problem.

Having an initial template model as a reference point [APPENDIX - X.d] made it possible to compare libraries, syntax, and reasoning when needed. In particular, the optimization library used in the TSP was noted to have changed following an **update** on 01/02/2024, resulting in **five out of six participants** being **unable** to complete the task.

P1, P2, and P3 were completely unable to solve the problem due to a syntax error and got stuck. Specifically, P1 faced an issue with "Qiskit.optimization" and then encountered another problem related to "permutations_of_length" not being defined. P2 and P3 encountered the same "Qiskit.optimization" problem but at two different stages of the problem-solving process: the first during library importation and the second while executing the TSP (Traveling Salesman Problem) function. Due to these types of errors, it was decided after each test to enhance Quantum Buddy with the data obtained. This led to a slight improvement in the performance of P4 and P5, who were both able to achieve data visualization, with P5 even organizing it into a matrix. Unfortunately, the "Qiskit. optimization" error persisted later on. P6 was the only participant able to complete the test. By incorporating their own understanding of the problem into the queries for GTP, the user managed to bypass the "Qiskit.optimization" library and find a solution.

To sum up, the common issue centered on the *Qiskit.optimization* library (IBM, 2024), which was updated with the new version, causing changes in its naming and settings. This update made it **difficult for ChatGPT to understand the corrections**, as it was only updated until the previous version of the software. However, it's important to note that to keep the experiment running, the custom GPT was **updated daily** with data from **previous users** [APPENDIX - X.c] and information from the official website. This daily update process showed that **P4 and P5 made progress** compared to previous testers, while **P6 successfully solved the problem** and provided the solution: Utrecht - Amsterdam - The Hague - Rotterdam - Utrecht (182km) [FIG. 43].

[9] "Suppose we have 1 truck that is tasked with driving to Amsterdam, Rotterdam, and Den Haag, starting in and returning to Utrecht. The problem to test is to determine the best order of visiting these cities using a quantum computer algorithm instead of the normal one. Data: Distance between cities: Amsterdam-Den Haag: 53km; Amsterdam-Rotterdam: 59km; Amsterdam-Utrecht: 46km; Den Haag-Rotterdam: 32km; Den Haag-Utrecht: 56km; Rotterdam-Utrecht: 51km"

The second **assessment criterion** [See 5.3] involved checking if the **overall user experience** had improved by ensuring that the coding process was enjoyable and user-friendly. This includes considering aspects such as ease of navigation, clarity of instructions, and whether users are satisfied and engaged as they use the system.

Overall, participants had a **good experience** [FIG. 44]. They found the theoretical explanations provided by the GPT helpful in understanding the steps and concepts they missed (*"The explanation of the problem was concise and clear"*). They also felt **confident in addressing the problem**, especially at the beginning, as they had a general idea of what they were supposed to do (*"I knew the TSP so setting the problem after the initial prompt was quite duable"*). Even when errors occurred, they stayed **positive**, knowing that debugging is a common part of everyday coding (*"...As I'm used to encountering errors of this type in my job"*). In the end, it's worth noting that they all wanted to continue working beyond the allotted time for the test, eager to **explore more** and debug further due to their curiosity about the results.

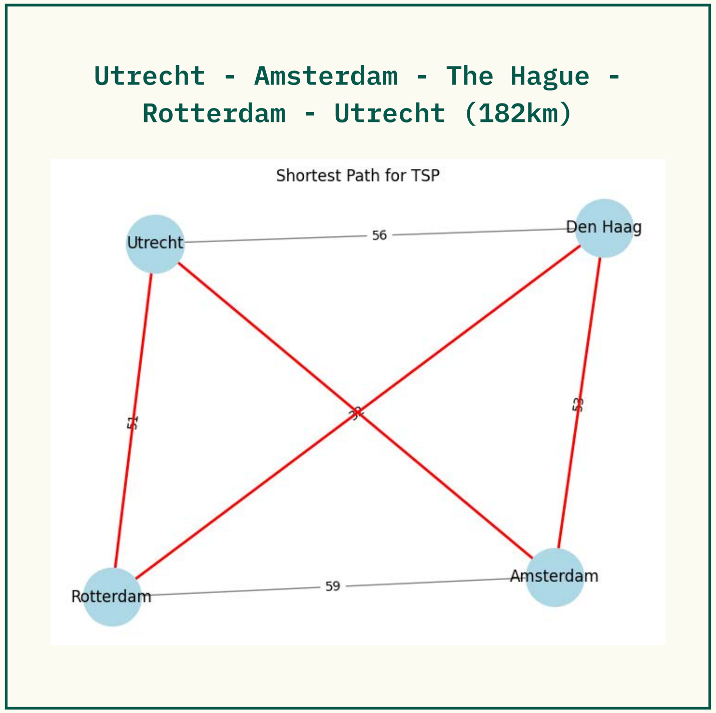


FIG. 43 - Results from P6

FIG. 44 - Part of the luster rating good experiences in the test

Furthermore, the **last criterion** [See 5.3] was checked on how the users **wanted to use the method again in the future**. This involved looking at whether users showed **interest or excitement** in continuing to use the method or platform for similar tasks or projects. Factors such as how useful they found it, how easy it was to use, and how satisfied they were with it all, helped figure out if they would use it again. In addressing this issue, users answered questions [APPENDIX - X.a] about what they **thought** of the method and how they might **use it in their work** or life.

Overall, most users mentioned the **main issue was with datasets** and libraries [APPENDIX - X.b]. They all agreed that the problem wasn't with the code itself, which they found to be pretty much what they expected. Instead, the problem lay with the libraries they were given (*"Provide a "guide" to get better results from ChatGPT"*). Moreover, some agreed that guidelines about prompt and quantum computing would be a useful tool to pair with the method [FIG. 45] (*"Mainly it's about data I think, and things that can be implemented"*).
However, this kind of problem didn't make them think the method was useless. Most of them mentioned [FIG. 46] they were used to using GPT as a coding helper, so they didn't see a problem using the **quantum method** when they **needed to** (*"This thing does not influence future usage since just need to have better queries from the user's side"*).
They also discussed the **potential of quantum computing in their field**. They all believed it could be really **useful** [FIG. 47], especially for processing **big datasets** quickly. Many were already aware of the possibilities and said quantum computing could be used in cryptography, optimization, and machine learning, and they didn't rule out using it in the future.

FIG. 45 - Reply classification from users Question 1

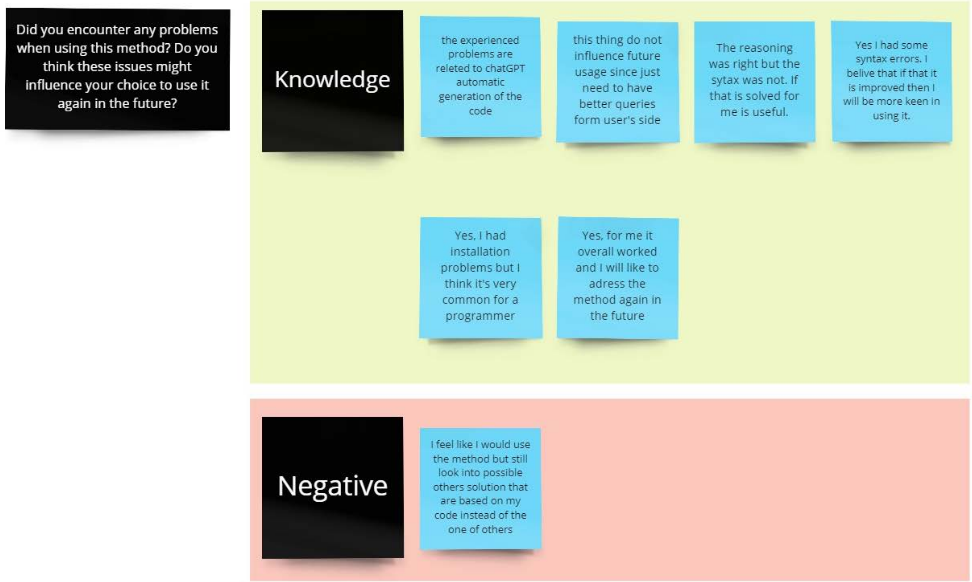


FIG. 46 - Reply classification from users Question 2

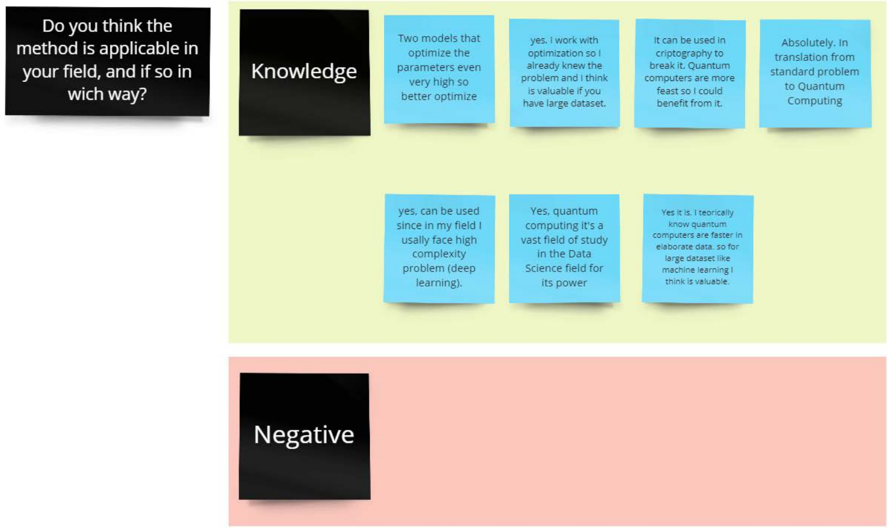


FIG. 47 - Reply classification from users Question 3

In summary, the evaluation indicates that all **six out of six users are satisfied** with the method's **reusability** and **overall performance**. However, when it comes to **creating code that functions properly** and aligns with the question, **five out of the six** users reported **negative** experiences [FIG. 48].

The **failure** of the first criterion to generate code coherent with the initial problem query **highlights** significant areas for **future improvement** and underscores the importance of gradually incorporating data to achieve solutions.
It suggests that although the method has potential, the specific aspects of libraries and update timing need to be addressed and solved. Ideally, by slowly introducing data and carefully adjusting the process, **users can reduce possible errors** and enhance the overall performance of the method as demonstrated throughout the evolution of the results from this user test.

Criteria	Positive	Negative
1	1	5
2	6	0
3	6	0

FIG. 48 - Graphics of participants' perceptions

CHAPTER 8

FINAL REFLECTIONS

8.1 Conclusions

Overall, the study employed a mix of **qualitative and quantitative methods**, following **human-centered design** principles and drawing from theoretical knowledge acquired during the Master's program in design for interaction. The research approach was centered on **addressing specific research questions** to gain a thorough understanding of the hypothesis under investigation.

"Can ChatGPT help anyone engage in quantum programming? What kind of background is necessary?"
In summary, having a **smaller coding knowledge or a grasp of fundamental quantum mechanics is seen as beneficial** with 2/2 quantum experts completing the task, 1/2 coding experts doing the same, and 2/2 of the non-experts failing at it. The ability to foresee and tackle potential errors becomes vital, making the design and debugging processes more effective and ensuring a seamless progression from the conceptual phase to practical application.

"Can ChatGPT assist individuals new to quantum computing and spark their interest in the field?"
The research findings validated that **ChatGPT is effective** in assisting users with limited knowledge of both quantum theory and coding to create intricate quantum algorithms. Participants generally exhibited an **increased interest** in the technology but recognized the **importance of acquiring a deeper understanding** for better comprehension. 65% of them left the workshop feeling **less intimidated** by approaching quantum computing, 70% were **intrigued** and wanted to know more, and 100% of them declared that they were **not scared** about facing this complex subject.

"Can a custom-built "GPT" outperform standard GPT4 in helping people run functional code?"
Both versions exhibit similar problem-solving abilities, with the **Quantum GPT slightly outperforming the standard version**, especially in addressing quantum-specific themes where both versions efficiently resolve errors in 4 out of 5 cases, with one common unresolved error. Participants generally agree that the **Quantum GPT responds faster to complex tasks and provides more accurate and detailed responses to technical queries.**

"How accurate and useful is ChatGPT for quantum programming?"
The performance of GPTs depends on their ability to respond to **specific inquiries.** GPTs are known to rely on existing **databases**, which can pose **challenges** related to compatibility issues and coding functions, as evidenced by experiments conducted by participants P2 and P3. Despite encountering limitations such as syntax errors, codes demonstrating **good reasoning** were considered **valuable**, defining it as a **criterion for accuracy.**

"Can ChatGPT enable quantum programming beginners to produce quantum computing programs enabling them to enjoy and use the method again?"
The evaluation results reveal users' **satisfaction with the method's reusability** and overall experience **six out of six** times. Despite this general satisfaction, the **challenge** of generating functional and aligned code is evident, giving **five out if six negative** responses from users. However, these findings also pinpoint the **need for the refinement** of libraries and update timing. By addressing these aspects and gradually integrating data while fine-tuning the process, users have the potential to reduce errors and enhance the method's performance.

To address the thesis question, ***"How Might ChatGPT Improve the Accessibility of Quantum Computing?"*** it can be affirmed that **ChatGPT has been shown to facilitate the entry of non-experts into the field of quantum computing** by providing coding assistance, refining approaches to quantum theory, and enabling customization of content through the new GPT-4 feature.

In conclusion, this research acts as a **preliminary validation** of the potential for **large language models** to serve as an **accessibility layer to quantum computing**, utilizing the newly developed **Quantum Buddy 2.0**, a customized GPT-4 model, refined through iterative feedback and testing. The findings demonstrate that **ChatGPT** significantly **eases the process of programming quantum computers**, underscoring its role in making quantum computing (QC) accessible. It facilitates learning and improves performance across **diverse backgrounds**, enabling **beginners** to experiment with creative coding, aiding **coders** in grasping quantum mechanics, and increasing the efficiency of quantum computing **experts**.

Despite encountering **challenges** such as syntax errors and code alignment issues, it is crucial to recognize that this research represents the **beginning** of a broader inquiry, highlighting opportunities for refining and improving the approach.

8.2 Limitations

Important **limitations** to consider for the **design output** include the rapidly expanding and **evolving capabilities of ChatGPT.** As ChatGPT continues to develop and improve, it may become increasingly proficient in handling a wider range of tasks, potentially **diminishing the demand for specialized versions** like ChatGPT-4 Quantum Buddy 2.0. This trend suggests that the need for specific adaptations or versions tailored to particular domains or tasks could diminish **over time as the classical ChatGPT** model becomes more **versatile and effective.**

Additionally, changes in **Qiskit's programming language** could potentially affect the **quality of database responses**, which is already becoming a noticeable issue due to the last updates and modifications in the libraries and methodologies. This issue highlights the **importance of staying updated** with the latest advancements in Qiskit and adapting the **custom GPT accordingly** to ensure compatibility and effectiveness in addressing users' needs. A practical example of this future possibility has been demonstrated during the evaluation test, where further applicability of potential codes in the database needed to be assessed following the last update of Qiskit from version 0.45 to version 1.0 in February 2024

Therefore, in future developments, **Quantum Buddy 2.0** might either become obsolete or serve as a versatile tool, enabling users from diverse backgrounds, including those with advanced knowledge in other areas, to **customize the GPT for their quantum computing needs.** However, it's important to note that for Quantum Buddy 2.0 to remain a valuable tool, ongoing development, and **updates are necessary** to adapt to changes in both ChatGPT and Qiskit, ensuring its relevance and effectiveness in facilitating quantum computing tasks for users. This underscores the significance of **continuous improvement** and **adaptation to evolving technologies** to maintain the utility and efficacy of Quantum Buddy 2.0 in the dynamic landscape of quantum computing.

8.3 Key takeaways

1. **Simplifying Programming:** ChatGPT makes programming quantum computers much easier, as shown as demonstrated through various qualitative and quantitative design research experiments.

2. **Help for All Levels:** ChatGPT helps individuals with different skill levels, enabling novices to engage in creative coding, helping coders to understand quantum concepts, and allowing quantum experts to operate more efficiently.

3. **Easier Access:** This research initially validates that large language models like ChatGPT can act as an "accessibility layer" to quantum computing, making it easier for a wide range of stakeholders to engage with quantum computing technologies.

4. **Wider Public Use:** The findings suggest that ChatGPT and similar large language models can significantly lower the barrier to quantum computing for the non-experts, potentially accelerating quantum development across various societal domains.

5. **More Research Needed:** While these findings are promising, they represent the beginning of a much larger exploration into the potential of large language models in quantum computing.

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Image references:

[Fig. 05] Flickr: https://www.flickr.com/photos/ibm_research_zurich/collections/72157674795610517/

[Fig. 06] Unsplash: https://unsplash.com/it/foto/un-computer-portatile-seduto-sopra-un-tavolo-ILyeoImR8Uk

[Fig. 07] Unsplash: https://unsplash.com/it/foto/monitor-del-computer-a-schermo-piatto-nero-acceso-per-la-visualizzazione-del-sito-web-koOdUvfGr4c

[Fig. 15] TCC website: https://timrodenbroeker.de/what-is-creative-coding/

[Fig. 16] Medium: https://medium.com/qiskit/introducing-procedural-generation-using-quantum-computation-956e67603d95

[Fig. 17] Medium: https://medium.com/qiskit/rothko-inspired-generative-quantum-art-6f34ca9d17cb

[Fig. 18] Medium: https://medium.com/qiskit/how-i-use-quantum-computing-to-create-bubble-art-d6c01f3ec2e

[Fig. 19] Medium: https://medium.com/qiskit/creating-fractal-art-with-qiskit-df69427026a0

[Fig. 40 Freepik Mockup: https://www.freepik.com/free-psd/website-template-laptop-screen_3383792.htm#query=Mockup%20computer&position=0&from_view=search&track=ais&uuid=0a7730fb-f2eb-485d-9d00-ce58d2b8cb41

Appendix

The QR code below contains the link to the folder for accessing the data.

The premise is that since the thesis and online tests were conducted, all the data is on digital platforms more easily accessible from a computer.

All categories with "QR" refer to the folder.

https://www.dropbox.com/scl/fo/ug40c12lm74480jm90jmy/h?rlkey=ii8l2b1pej7vhipa7py2caxt9&dl=0

[I] Original Project Brief

DESIGN FOR our future

TUDelft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy". Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name ______

initials ______ given name ______

student number ______

street & no. ______

zipcode & city ______

country ______

phone ______

email ______

Your master programme (only select the options that apply to you):

IDE master(s): ( ) IPD (★) DfI ( ) SPD

2nd non-IDE master: ______

individual programme: - - (give date of approval)

honours programme: ( ) Honours Programme Master

specialisation / annotation: ( ) Medisign

( ) Tech. in Sustainable Design

( ) Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair Dr. Lomas dept. / section: HCD-DA

** mentor Deborah Nas dept. / section: DOS

2nd mentor ______

organisation: ______

city: ______ country: ______

comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30 Page 1 of 7

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair Dr. Lomas date 4-10-2023 signature

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: ______ EC

Of which, taking the conditional requirements into account, can be part of the exam programme ______ EC

List of electives obtained before the third semester without approval of the BoE

YES all 1st year master courses passed

NO missing 1st year master courses are:

name ______ date - - signature ______

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: APPROVED / NOT APPROVED

Procedure: APPROVED / NOT APPROVED

comments

name ______ date - - signature ______

How Might ChatGPT Improve the Accessibility of Quantum Computing? project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 08 - 09 - 2023 16 - 02 - 2024 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

According to the report of the World Economic Forum 2022, due to the recent advancements in quantum computing technology, stakeholders in the field have a distinctive chance to establish trust with the general public by raising awareness about quantum computing, given its early development and adoption stage. (World Economic Forum, 2022) Among the opportunities that the report emphasizes include the possibility not only of an academic collaboration but also of a democratic knowledge of quantum computer usage. [Fig.1] (World Economic Forum, 2022) Obviously, this vision opens the debate on the challenges to address to achieve the final goal:

- Communication regarding quantum computing is not inclusive, not considering the diverse levels of knowledge and interest within the general population.
- The interface of a quantum computer is not easy for everyone to use. It's hard to understand, and the main way to communicate with it is through code. (Zeki C. Seskir, 2022)
- Explaining the quantum programming logic isn't straightforward for non-programmers.

The opportunity that arises for the academy plays a key role in developing a broad, interdisciplinary quantum computing knowledge, especially focusing on educating and sparking interest in quantum mechanics and providing guidelines for practical use. (P. Vermaas, 2022)

One of the possible tools to use is ChatGPT as an example of LLM. Over the past year, there has been a significant surge in the development of generative AI, which has brought it into a more accessible daily use for all. (Y. K. Dwivedi, 2023)
One of the examples of usage of the AI for such complex topics is the use of LLM as a tool to code. [Fig.2] In the specific case of ChatGPT, there has already been some recent research which highlights the pros and cons of considering such a tool in the field of education.
The usage of natural language to communicate with the AI makes it possible for the user to address problems in a more familiar way, enabling them to communicate without having specific knowledge of the code language. This interaction with the chat made it possible to have positive aspects such: an easy access, quick responses, personalised learning, multiple language support, clear explanations, examples and applications when needed and the possibility of debugging and feedback. On the other hand, though, the usage of AI as a tool also has negative ones like unstructured learning, limited data or algorithms and lack of integration with second-base software needed for programming. (R. Yilmaz, F. G. K. Yilmaz, 2023)

- World Economic Forum project community on Quantum Computing Governance (2022) Quantum Computing Governance Principles, Insight report 2022
- Zeki C. Seskir (2022) Quantum Games and Interactive Tools for Quantum Technologies Outreach and Education, https://doi.org/10.1117/1.OE.61.8.081809
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- Y. K. Dwivedi (2023) Opinion Paper: "So what if ChatGPT wrote it?" Multidisciplinary perspectives on opportunities, challenges and implications of generative conversational AI for research, practice and policy, https://doi.org/10.1016/j.ijinfomgt.2023.102642
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introduction (continued): space for images

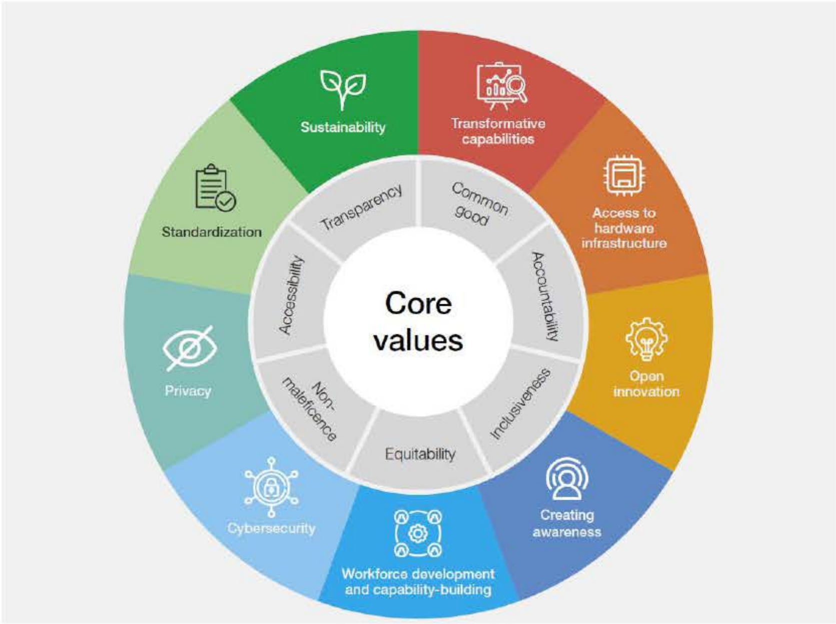


image / figure 1: The Forum's Quantum Computing Governance Principles: themes and cross-cutting core values

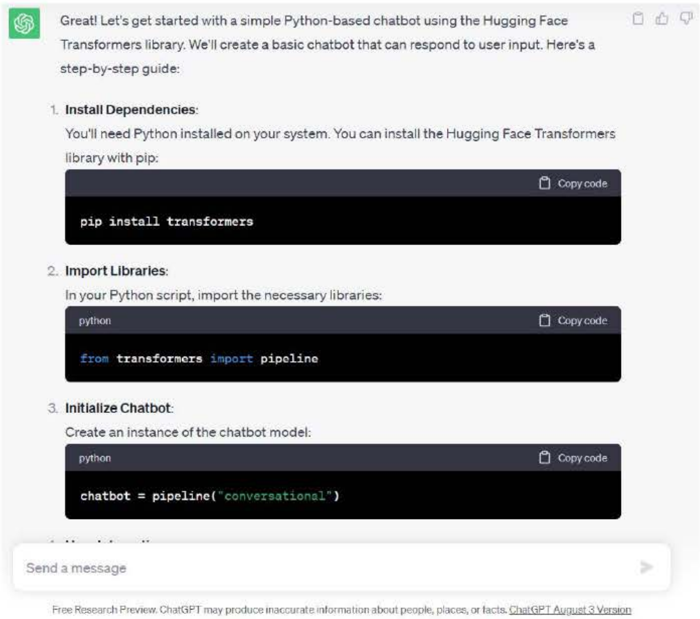


image / figure 2: Screenshot of chatGPT as a tool to program an intelligent chatbots with Python

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

The goal of the project is to answer the main research question: How to enable people with either no coding expertise or no quantum knowledge to program a working algorithm for quantum computers with ChatGPT? Braking it into sub-questions, the thesis aims to prove or disprove these assumptions by creating a design and testing it with experts in the final stage. The questions are:
• (target) Who Could Benefit from This Approach?: To understand how to use this application and determine its level of difficulty and language complexity, it's important to define the target audience.
The assumption is that people interested in the technology but not necessarily with coding skills would like to learn how to code. In particular, they are divided into 4 possible categories: Classical Code Quantum maestro, Classical Code Quantum Voyager, Quantum theory maestro, and Quantum code newbie.
• (usage) How to make programming accessible for non-experts?: How to help people who aren't experts in either coding or quantum computers to write a complex algorithm using ChatGPT.
The assumption is that ChatGPT can provide clear, well-explained code with comments that work and help the user understand what they're doing.
• (design) How to design for intuition?: How to create an intuitive interaction suitable for non-experts.
The assumption is that working on the interaction between the user and the chat by means of prompt engineering could help non-experts write and understand the context of the algorithm by giving possible personalization with learning paths, and interactive methods.
• (understanding) How can quantum computer codes be explained?: When non-experts start coding for quantum computers, they should know why they're doing it. The design should make it clear and practical how quantum computers can be used. The assumption is that using examples will make understanding the field easier to grasp.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

The aim of the design is to use ChatGPT, an example of a Large Language Model, as a tool to educate people interested in coding quantum computers to write working algorithms with guidance and context in the field of quantum computing.

The final design will be based on the answer to the previously listed research question.

The general expectation is to have a final design which could guarantee easy comprehension by giving examples of possible applications of the quantum code, an explanation of the lines of code to use and hints about code logic.

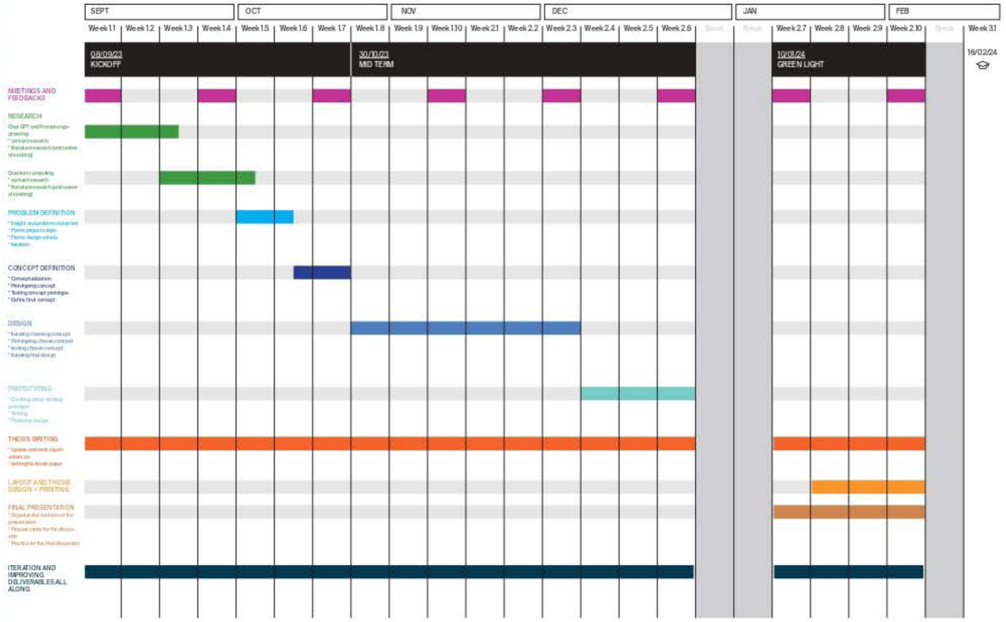
The method for achieving this objective can be as follows:
• Frame desired design goal: Clarify the project's overarching goals and the specific inquiries it should address.
• Formulate Research Questions: Frame research questions that the project seeks to answer, delineating the key aspects to be explored.
• Frame assumptions: Develop hypotheses regarding how to address the research questions, opening the way for testing their validity.
• Literature review: analyse the material in the academic world to confirm or move the direction of the project given by the research questions.
• Data Collection: Initiate collaborative sessions to gain relevant data.
• Data Evaluation: Use the gathered data to assess the validity of the assumptions, determining whether they were affirmed or not as the conclusion of the thesis.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 8 - 9 - 2023

16 - 2 - 2024 end date



MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

The primary reason that motivated me to delve into this topic is my strong interest in new technologies, which grew during my master's program at TUDelft. I believe that the thesis I am presenting serves as a comprehensive reflection of the two educational paths I pursued, particularly in the final year of my master's studies.

On one hand, my fascination with artificial intelligence, particularly its captivating dimensions, drove me to explore this field through various elective courses I took during the third quarter. These electives allowed me to delve into different aspects, including ethics and social implications. The course IAIRM (Interdisciplinary AI Research Methodology) was instrumental in this exploration, along with discussions about language and prompt formation introduced in the EDI (exploring design intelligence) course.

Conversely, the other part of my academic journey revolved around the study of another innovative technology: quantum computers. My involvement as a research assistant introduced me to this technology, not merely from a technical or physical perspective, but more in terms of its intricate socio-ethical landscape. While researching, I observed that this field faces similar challenges in terms of public understanding that artificial intelligence encountered a decade or so ago.

This realization piqued my curiosity to merge these two aspects into a single project. This project not only enhanced my professional skills and knowledge in AI and prompt engineering but also aim to provide tools for those, like me in the past, who approach the realm of new technologies without prior experience, yet wish to gain deeper insights.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

[II] Interviews
a. Questionnaires (QR)
b. Findings
Out of all the experts contacted, only two responded, shedding light on several points: The assumption about the ideal target audience being non-experts is partly true, but a keen interest is necessary. Those with minimal coding or quantum knowledge might also find the method of chatGPT beneficial. While a deep understanding of quantum mechanics is not crucial, a basic grasp can aid in addressing potential issues, especially since the language of code can be daunting for non-coders. A significant consideration raised is how to verify if the outcomes of the approach are correct, indicating an area for further investigation.

[III] User test #1
a. Framework for Identifying Potential Users (QR)
b. Template (QR)
c. Participant's results (QR)
d. Miroboard results (QR)

[IV] IDE workshop
a. Miroboard workshop (QR)
b. Miroboard results (QR)
c. Results collection (QR)

[V] Quantum Explorer
a. GPTs V1 - Quantum Explorer
The initial version of GPT was developed using the OpenAI "myGPT" tool. As a trial version, its creation aimed to comprehend the underlying mechanisms. This version was constructed to create a custom AI capable of understanding the realm of quantum mechanics. The prompt provided to the AI was as follows:

"Quantum Explorer is a cheerful, beginner-friendly assistant for quantum computing, designed to adapt to various expertise levels: 'Newbie', 'Code Expert', and 'Quantum Mechanics Expert'. It offers customizable learning paths for each user, tailoring content and recommendations based on their knowledge and goals. Quantum Explorer provides accessible explanations, incorporating emojis for a friendly approach. For newbies, it covers basic concepts; for code experts, programming aspects of quantum algorithms; and for quantum mechanics experts, advanced theoretical discussions. It uses relatable phrases and analogies, ensuring that learning about quantum computing is engaging and informative. Quantum Explorer's goal is to guide users through a personalized journey in quantum computing, making it a rewarding experience for everyone."

Named Quantum Explorer, Version 1 was then independently evaluated to gauge its capabilities. The testing involved assessing the chatGPT's response to a hypothetical general request, given the tester's background as a designer.

"I would like to create a combination of lights that is always different for an LED panel that I want to install. Can I do it with a quantum algorithm?"

Subsequently, the GPT inquired about the tester's level of expertise and proceeded to create a practical guide outlining the subsequent steps. After obtaining the code and applying it within the IBM quantum lab, the GPT was requested to produce a visualization of the quantum state. It accomplished this through a visual representation from DALL-E, and later, it was asked to provide an image of what the final result might look like once implemented in the initially proposed design.

b. Link for Quantum Explorer (QR)

[VI] Quantum Buddy
a. GPTs V2 - Quantum Buddy (QR)
Understanding that GPT could be enhanced with raw data, the individual decided to advance it further and make some modifications. The improved version, named Quantum Buddy, maintained the same initial prompt as its predecessor but distinguished itself through additional data and capabilities.
Initially, there was a desire to comprehend and acquire knowledge about the Python code and Qiskit used in the IBM quantum simulator. To achieve this, the working code generated during the thesis research process has been used. The new material code was provided first, followed by the new drug code, then the quantum Grover algorithm, and finally, the creative quantum coding developed for the first workshop.
To gain a comprehensive understanding of the available algorithms, was decided to incorporate quantum algorithms currently utilized in the field of quantum computing. Additionally, a general knowledge of quantum computers was incorporated, based on the paper "Quantum computing for non-physics," (E. Rieffel, W. Polak, 2000) along with an understanding of the workings and structure of the IBM quantum lab (J. Coles, 2018). Recognizing the capabilities of GPT-4, the GPT was also tasked with reading images from the IBM simulator results and describing them according to the user's expertise level.
To summarize, as the GPT itself acknowledged, this new version possesses the ability to: "...discuss a wide array of quantum computing topics and algorithms. I understand quantum parallelism, the nuances of quantum mechanics, the behavior of photon's polarization, and the implications of quantum measurements.

I'm familiar with qubits, quantum key distribution, multi-qubit systems, and the intricacies of quantum gates and transformations. I can delve into advanced quantum algorithms like Shor's and Grover's, explain quantum Fourier Transforms, and discuss quantum error correction. Moreover, I recognize the need for innovative programming techniques to exploit the full power of quantum computers. Whether you're curious about the fundamentals or advanced aspects of quantum computing, I'm here to guide and provide insights."
Before presenting it to users, a preliminary personal iteration was conducted, particularly focusing on the potential prompts of the test. It was decided to iterate a data cluster algorithm based on the application of quantum computers for machine learning.
This test evaluated all the desired features of the GPT:
- the creation of coding knowledged on a clear explanation of the steps,
- the ability to read images and explain them at different levels,
- the capacity to create examples for clearer understanding,
- the ability to generate images for better comprehension.
After this initial independent test, GPT-V2 was compared with a standard GPT in the second user test.

b. Link Quantum Buddy (QR)
c. Data in the GPT (QR)

[VII] User Test 2
a. Miroboard Test (template) (QR)
b. Miroboard Results (QR)
c. Participants results (QR)

[VIII] Evaluation User Test 2
a. Miroboard Test (template) (QR)
b. Miroboard Results (QR)

[IX] Database Quantum buddy 2.0
(QR)

[X] User test 3
a. Miroboard Test (template) (QR)
b. Miroboard Results (QR)
c. Participants results (QR)
d. Solution of the problem (QR)

COSTANZA D'ARCANGELIS
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MASTER THESIS, DESIGN FOR INTERACTION
TUDELFT