Online-Journals.org

iJOE International Journal of Online and Biomedical Engineering

iJOE | eISSN: 2626-8493 | Vol. 22 No. 7 (2026) | OPEN ACCESS

https://doi.org/10.3991/ijoe.v22i07.61025

PAPER

The Triangle of Options, a Curriculum Design Method for Quantum Technologies

C. Samoila[1,2] (✉),
D. Ursutiu[1,3],
H. A. Modran[1],
C. Gherman (Dolhascu)[1],
J. Tudorache (Nistor)[1]

[1]Transylvania University of Brasov, Brașov, Romania

[2]Romanian Technical Science Academy, Bucharest, Romania

[3]Romanian Academy of Scientists, Bucharest, Romania

csam@unitbv.ro

ABSTRACT

We are witnessing a conceptual revolution in the possibilities of manipulating information through quantum technology. This revolution also affects the workforce, so it will also affect the education system. Even if some of the things we use on a daily basis, mobile phones, lasers, and satellites, use quantum technology, there is no education dedicated to the field. The paper looks at current quantum technologies, both 1.0 and 2.0. and notes the inertia in the modernisation of education, the persistence of linear thinking and approach to the detriment of the nonlinear one that quantum technology contains. It is shown that, due to the lack of predictability of the future evolution of quantum technologies and the partial coverage of the requirements of the quantum field by several general disciplines (quantum physics and mathematics), education does not offer stand-alone curricula oriented on quantum technology. A thorough analysis of the new areas of learning that quantum technology introduces has allowed us to imagine a system for designing curricula dedicated to this field, capable of responding to the extremely diverse requirements of the industry.

KEYWORDS

quantum pedagogy, Waltz method, quantum technology

1 INTRODUCTION

The emergence of quantum technologies (1980) [1] determined, in the first phase, small changes in the classical curriculum. This is because neither the industry has expressly requested graduates specially trained for this field nor the education has reacted to the novelty of the field. For several years now, quantum technologies have been developing exponentially and in academia, there has been talk of "*quantum pedagogy*" in which, for the first time, the relativity of knowledge transferred through education is being talked about. Compared to the concepts of classical pedagogy, this approach can lead to a complete reset of the way of approaching learning [2]. While classical pedagogy mostly trains "*interpreters*," better or worse of the concepts transmitted through teaching, "*quantum pedagogy*" wants to transform the "*interpreter*"

Samoila, C., Ursutiu, D., Modran, H. A., Gherman (Dolhascu), C., Tudorache (Nistor), J. (2026). The Triangle of Options, a Curriculum Design Method for Quantum Technologies. *International Journal of Online and Biomedical Engineering (iJOE)*, 22(7), pp. 26–37. https://doi.org/10.3991/ijoe.v22i07.61025

Article submitted 2026-02-11. Revision uploaded 2026-03-17. Final acceptance 2026-03-19.

into a creator. The philosophical basis of the new pedagogy says that the world is not naturally made up of 1s and 0s, as stated by classical computer science, but is made up of quanta. All physical interactions in nature cannot be naturally divided into these small arbitrary units, 1 and 0, but are based, at the limit, on a minimal quantum dimension. As a result, the laws of computer science should be the laws of quantum mechanics applied at atomic and subatomic levels and not those based on Boolean algebra. This aspect alone should give food for thought.

The most important reason that drove quantum technology was national security. Piracy-resistant systems are based on quantum technology and are being developed by both the US and China in a competition that has produced tangible results. The need for higher training in the quantum field is about to become a social command. The government signal of the existence of this order was given by the adoption in the US of the law "*National Quantum Initiative Act*" (NQIA) [3], which started the massive financing of the field, requiring in parallel a workforce development strategy. The NQIA Act defines the need for quantum technologies for the storage, transmission, manipulation, measurement of information, and computation. Quantum industries, formed by companies that apply quantum technologies to their products or that offer quantum technology to others to complete their products, have emerged. It is obvious that everyone who works in these industries uses the "*quantum*" workforce or rather is trained for the quantum field. A momentary snapshot of the institutions that have begun to develop the quantum field would contain the consortium "*Quantum Economic Development*" (QED) [4]; the "*Institute of Electrical and Electronic Engineers*" (IEEE), which organizes IEEE Quantum Week; the "*National Quantum Coordination Office*" [5], which promotes the correlation of the academic field with the industrial one; the University of California Berkeley for quantum computing; the University of Colorado Boulder for quantum sensing and distribution; and the University of Illinois at Urbana-Champaign for quantum architectures and work networking. National research centres and laboratories such as Argonne [6] for quantum networks, sensors, and standards; Brookhaven for quantum computing; Fermilab [7] for quantum materials and systems; Lawrence Berkeley [8] for quantum algorithms and devices and Oak Ridge [9] for topological quantum materials have emerged. With a delayed reaction speed, the European Commission adopted in 2016 the project "*FET Flagship*" [10] based on the "*Quantum Manifest 2.0*" [11], which defined the four pillars of the development of quantum technologies, namely, communication, detection, calculation, and simulation. The first activities in the quantum industry, which appeared due to needs or due to advanced research at the academic level, are the fine control of quantum states through quantum sensors, quantum communication networks, hardware that uses superconductors, trapped ions, or photonic qubits, and increasing the reading speed of algorithms by running on quantum computers, cryogenic laser hardware, or vacuum.

2 METHOD

The paper uses the Waltz 2003 model [12] for the analysis of the quantum technology field and presents the synthesis of the findings resulting from this analysis in the form of a system of curriculum design. Two functions have been attached to the model. The first function, called "*hypothesis*," is related to the fact that the available evidence is limited and often dominated by subjectivism. The hypothesis from which it was started is that in the near future the field of quantum technology will become a necessity for the training of the advanced workforce. A second function, called the "explanation," was then added, attempting to join the direct evidence analysed and other indirect evidence that fits the hypothesis. As a result, the paper will see three "*spaces*" (Waltz): a *data space*, in which the evidence supporting the paper and market trends has been taken from the literature and synthesized tabularly; a *space of arguments*, in which the statements made by the literature have been reviewed from another perspective, generating a new set of hypotheses; and an *explanatory* space. In this last space, the contradictions between classical pedagogy and the one required by quantum technology were analysed and the unpredictability of quantum technology development was highlighted, in contradiction with the desire for stability in the students' careers. Also, in the explanatory space was considered the information from the data space, which, supported with coherent and credible explanations, generated the method of designing curricula for quantum technology presented in the paper as a development tool.

3 RESULTS AND COMMENTS

It starts with a review of some phenomena that take place at the quantum level, phenomena that are already used in technologies with industrial applicability (refer to Table 1) and that introduce changes in the knowledge required by the existing curricula. The table, although not exhaustive, immediately highlights the shortcomings in current education, especially since it includes technologies already applied in some industrial products, without them having (only accidentally) a correspondent in the training of graduates.

Table 1. Applied phenomena in quantum technology research

Crt. No.	The Quantum Phenomenon	Detailing
1	**Nonlinear superconducting circuits**	Qubits with superconducting super inductive circuits, have an architecture with access to energy levels of interest $\|0\rangle \leftrightarrow \|1\rangle$ and can be controlled by changing the external magnetic flux. The chip with transmon-type superconducting qubits is an anharmonic oscillator because of the presence of a Josephson junction that works like a nonlinear inductor. Qubits based on superconducting circuits are noisy and very sensitive to external factors.
2	**Trapped ions**	Charged atomic particles (ions) can be confined and suspended in free space using electromagnetic fields. Lasers serve to couple between internal states and external states of motion.
3	**Neutral atoms in optical networks**	An elementary quantum network has been created. The two nodes of the network send, receive, and store information through the communication made by a single photon traveling along a Fiber optic cable.
4	**Electron spin**	The magnetic spin of the electron has two states, "*up*" and "*down*", which can be manipulated. Radiation with precise frequencies is applied to change the spin. By keeping the spine in the same position, it can be used as a memory device.
5	**The double quantum dot**	It exists when electrons close in a static potential fault in a semiconductor. Due to the limitation their energy spectrum is quantifiable. Control by both magnetic and electric fields is allowed.
6	**Coupled quantum wires**	The state is characterized by the presence of an electron moving in either wire. The movement can also be controlled without a magnetic field. Shorter quantum gates, coherence, and higher operating frequencies than other solid-state implementations are thus ensured.

(Continued)

Table 1. Applied phenomena in quantum technology research *(Continued)*

Crt. No.	The Quantum Phenomenon	Detailing
7	**Vibrational overlaps in cold molecules**	It is because if two fermions are cooled and trapped in an optical network, they can simultaneously exist in two vibrational states, that is, they manifest an overlap.
8	**Molecular magnet**	It refers to the so-called SMT transistor—which has a single molecule and three terminals, a pair of metallic or graphene electrodes and a third electrode capacitively coupled to the molecule.
9	**With the rotation of nitrogen centres in diamond**	A micrometric resonant magnet allows, by using electrically generated spin currents, to control the Rabi oscillation frequency of the spins of the nitrogen centres in the diamond.
10	**Electron spin of liquid helium**	Electrons floating on the surface of liquid helium are electrostatically manipulated and have a reduced decoherence.

A careful analysis of the above will convince the reader that in current quantum technologies there are notions on which current analytical programs do not stop (except for physics). In addition, the content of the table above underlines the strong experimental character of the phenomena used in quantum technologies and highlights the fact that the experimental part of educational laboratories is far below the needs for advanced knowledge required by these phenomena. However, the endowment of these laboratories cannot be at the level of the requirements of these special phenomena due to the enormous costs involved, so a dilemma arises. Is it possible to develop a workforce in the field of quantum technologies at the university level, or is it left to the discretion of companies to develop it, depending on the interests of the moment, the specialised equipment they have and the prospects for valuing products on the market? The answer to the dilemma can only be given by the interested parties, so a much closer collaboration is required than today between industry and higher education.

A (somewhat incomplete) systematisation of known quantum technologies (Table 2) should show the way forward in updating the curriculum. Is the idea of modernising existing specialities at the university level feasible, or should another way of implementing quantum technologies in the curriculum be sought?

Table 2. Quantum technologies 1.0 and 2.0

Nr. Crt	Technology Class	Phenomenology and Technical Content	Quantum Principles Used	Fields of Application
1	**Quantum technologies 1.0**	Lasers	– Spine, – Tunnel effects, – Energy quantification.	**Industrially Products**
2		Semiconductors		
3		Magnetic Resonance		
4		Optical Fiber		
5	**Quantum technologies 2.0**	Overlay	– Trapped ions – Molecular magnet – Vibrational overlaps in cold Molecules – Neutral atoms in optical networks – Coupled quantum wires, etc.	**Quantum computing** – Calculation – Detection – Communications – Simulators
6		Entanglement		

It is obvious that industry is and will be the main player in preparing the workforce for quantum technology on the experimental side due to the endowment costs that education cannot meet. She did not detach herself from the academic environment but tried to compensate for the parts of knowledge that this environment had not yet introduced into the curriculum. The industry, aware of the commercial potential of quantum applications, has strengthened its ties with research, trying to bring new discoveries in the field into production as quickly as possible.

However, it can be said that the evolution of quantum technology is unpredictable. This explains the slowness of education to define independent curricula for quantum technology and the fact that today, education, at the request of the industry, offers only postgraduate courses with a profile focused on general skills such as physics, quantum mechanics, electronics, software, artificial intelligence, etc. These postgraduate trainings are useful to existing personnel in quantum manufacturing companies to strengthen their culture in the immediate understanding of the quantum world. For the same reasons, the industry is calling for a greater emphasis on STEM education in traditional training lines [13]. So, it seems that at this point it is more important to adapt to the demands of high specialisation in the industry than to define dedicated curricula that serve quantum technology. The reluctance to introduce quantum technology curricula, both of industry and, hence, of education, is based on a number of objective aspects that manifest themselves in today's world, namely:

- There are no career opportunities. The quantum industry exists on such a small scale that successful careers can be counted on the fingers of the hands.
- To the question of how the assertive in the quantum industry got to the position they have, the answer is that they were in the right place, at the right time, with a wealth of knowledge appropriate to the requirements of the moment, knowledge that was not obtained specifically for a career in the quantum industry but that allowed them to specialise in a position necessary for the industry. So, for the most part, the situation of those who work in quantum technology is the random result of a happy adaptation to the workplace. Another way of access, much faster, was the transition of specialists working in advanced research in the quantum field to industry, recommended by the skills acquired during research and confirmed with articles and research contracts related to a quantum aspect, especially if they attacked topics with the potential to be transformed into a product on the market.
- To the question asked to employers in the quantum industry about what skills they want from their employees, the answer is relatively useful to education because the skills required do not refer to those acquired in school but to those acquired in advanced research, and these, in turn, are indirectly related to the technology that the employer wanted to develop. There is no integrator of all the necessary skills, but only specialisations on dedicated skills.
- The fields of the quantum industry are so different that to the question, 'what training and education programmes would be recommended to accumulate the knowledge and skills necessary for the industry?', the answers would be very different, reflecting the direct interest related to the production of each one. There are no programmes that make the employee competent, from the moment of employment, in any field of the quantum industry.

What new challenges does adapting to quantum technologies entail? With the answers to this question, some curricula for the university environment may be outlined in the future. The field of quantum computers, which is very current, is chosen to illustrate the challenge-adaptation binomial.

- The first challenge would be to learn how to write code for quantum computers. This requires an understanding of quantum principles, algorithms, and programming languages [14].
- Another challenge is to master the correction of quantum errors, i.e., to protect the information stored in qubits and to correct the decoherences caused by noise [15]. It must be understood that ambient noise produces phase changes of the wave function in a random manner, which harms the correctness of a quantum calculation.
- A third challenge is given by the stochastic nature of quantum physics. As a result, quantum computing has a statistical nature that requires in-depth knowledge of the methods of mathematical statistics. Quantum annealing or quantum machine learning, to refer to just two examples, cannot be understood and approached without statistics [16], [17], and [18].

A first conclusion is that only the sequence of these challenges of quantum computing shows that the basic training existing in higher education is not adapted to the diversity of problems related to quantum computing but allows specialisation in a narrow field of industrial applications [19], [20].

Another conclusion that follows from the above is the strongly interdisciplinary character of the preparation for quantum computing in particular and quantum technology in general. A single university department cannot administer a quantum technology curriculum. That is why curricula must be interdepartmental. The curriculum must be approached starting from a general image that is as suggestive as possible.

Another finding is that there are two trends in this newly created market: one given by the immediate requirements of the industry that involve ADAPTATION based on existing knowledge plus short postgraduate courses and a second to BUILD a dedicated and flexible curriculum of targeted training for quantum technologies.

As a result, summarising most of the current trends in the quantum technology market, the authors built the so-called "*Triangle of Options*", a system of curriculum design for basic and special problems (see Figure 1).

The nucleus from which the triangle of options is built is formed by the trio of physics, informatics and materials (the vertices of the triangle). The three areas are fundamental in order to be able to approach quantum technology on a higher level. In the area of the triangle formed by the three fundamental areas is the knowledge transmitted in the current education system. Enough, as it was said, you have up for adaptation.

Given the findings of the above analysis, in order to be able to approach quantum technology, each of the "*peaks*" must be supplemented with some classical quantum-orientated chapters. This need can be realised, at the stage of development described earlier, through additional courses. What are they? As can be seen from the titles given in the rectangles in Figure 1, these chapters are not at all simple, and most of the time they do not have a monodisciplinary character either, being always supported by a high mathematical apparatus. An attempt has been made to provide as complete a picture as possible of the additions needed to acquire quantum technology at the appropriate level, but the final choice will be decided by the market and its needs. That is, the industry, the final beneficiary. An important role in the selection of options is also played by advanced research in the quantum field, which revealed the field and implemented it in production on a small scale but sufficiently edifying to define the development potential of the field.

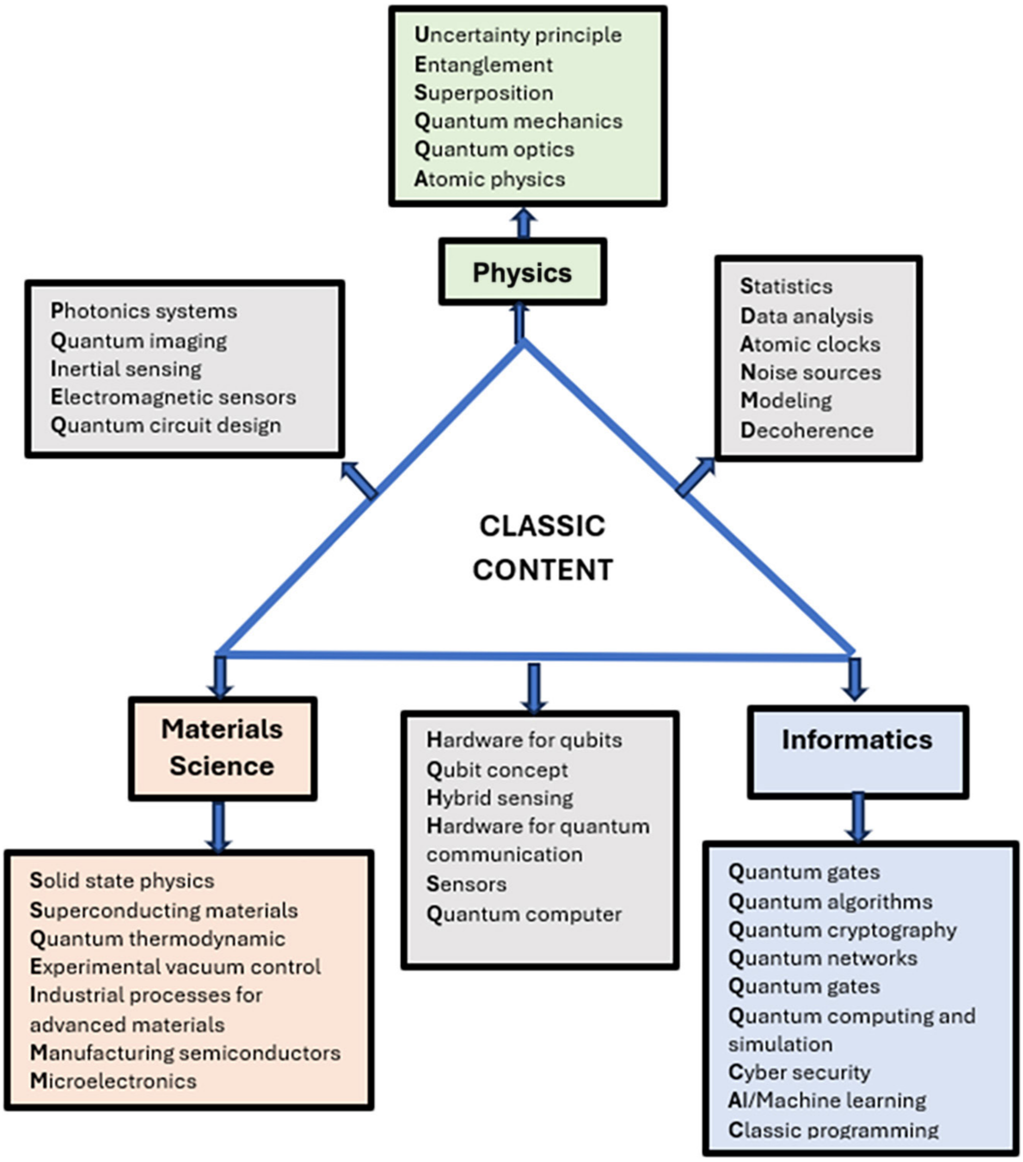

Fig. 1. Options triangle

Quantum technology also has branches of specialisation that include only two nodes of the triangle of options, i.e., the binomials: materials-physics, materials-informatics, and physics-informatics (sides of the triangle). In these cases, apart from the additional chapters necessary for the development of the fundamental areas, the triangle also offers chapters to deepen these binomials. Relevant are, for example, the chapters necessary for the development of quantum computing knowledge from the material informatics side of the triangle of options, better known by those who have concerns in the field. The form of organisation of these chapters is the following:

- or by supplementing the existing chapters, combining the classic content with the new fields (in the case of quick and to-the-point specialisations),

- either through summer schools when the chapters are not limited to their own students but are extended to several geographical areas and also include adults sent by industry for specialisation,
- Either through a one- or two-year master's degree when the training of the workforce also has a prospect of immediate employment and a promising career.

As a conceptual approach, it can be said that until now quantum technology has been the prerogative of physics. When research for quantum computers began, the importance of materials science was seen. The properties of materials, at the nanometre, atomic and subatomic scales, differ from those manifested at the macro scale, and thus materials become extremely important in quantum hardware (according to some about 67%) [21], [22], [23]. Also, when it comes to computers, computer science has also been seen as a decisive discipline (according to some, 62%) [24], [25], [26]. Going into the depth of quantum computing has shown big differences compared to classical computer science. First, by replacing bits with qubits (two-state material devices) that make the leap from Boolean algebra to the quantum world. As a result of this transition, quantum algorithms run in a multidimensional vector space and provide probabilistic results. For computer scientists, it is therefore a matter of retraining and completing knowledge, especially regarding the intimate properties of matter.

As said at the beginning, quantum technology also required a transition from the logic that is practised today to a pedagogical logic built on the relativity of knowledge. Can quantum technology be included in the known theories of learning? Table 3 tries to formulate some points of view.

Table 3. Correlations between learning theories and quantum learning

Crt. No.	Learning Theory	Summary Content	Aspects in Quantum Learning
1	**Theory of goal setting**	The objectives are established by the SMART method (specific, measurable, aggressive, realistic, time-limited). These, then, are divided into smaller objectives to reduce complexity. The division stops when there is a guarantee of full understanding by the student.	Quantum learning can apply the method described only that some of the objectives of the SMART method cannot be fulfilled (e.g., Measurable)
2	**Behavioral learning theory**	Learning is due to the interaction between students and the environment, i.e., based on stimuli and responses.	There is a limit regarding the environment to which quantum learning refers. It cannot be realized directly through the senses but needs sophisticated intermediaries to bring the quantum environment into contact with the student's senses.
3	**Adult learning theory**	It makes the difference between a young person and an adult when approaching learning. Adults have behind them an experience on which new knowledge is built. In addition, they can learn at a different pace than young people, not depending so much on the pace of the instructor. In addition, adults have a decisive incentive, that of the career on which the well-being of their family depends.	Quantum learning fits perfectly into this theory, and the best proof is that those who work in quantum technology came here with general knowledge and specialized in the workplace learning a lot, being motivated by their career.
4	**Microlearning theory**	It applies the principle that if the information is presented in concise amounts, the mastery of the material becomes guaranteed.	The application of this method is recommended in quantum learning because quantum knowledge is particularly complex and supported by a very advanced mathematical apparatus compared to that acquired in general training. Dividing them into "amounts" of knowledge facilitates overcoming this complexity.

(Continued)

Table 3. Correlations between learning theories and quantum learning *(Continued)*

Crt. No.	Learning Theory	Summary Content	Aspects in Quantum Learning
5	**Constructivist theory**	It is based on the practical finding that students learn better when, on their own, they discover or experiment, or when they have direct contact with other students with the same concerns of discovery.	In quantum learning this is difficult to apply because experimental learning requires sophisticated equipment to which access is limited. The part with collaboration in teams with the same concerns (teambuilding) is also positive for quantum learning because this is how you directly learn the quantum industrial technologies that you cannot master only through theoretical knowledge.
6	**Learning curve theory**	He claims that long-term learning is favoured by pre-establishing content repetition intervals. It is based on the "Forgetting Curve" of Ebbinghaus H.	The method can also be applied to quantum learning, especially if you consider the difficult mathematical part that supports quantum phenomena.
7	**The theory of learning through gamification**	To stimulate concentration, and engagement in learning and to combat boredom, aspects often found in formal learning, the transmission of knowledge using the structure of games is used.	It will be difficult to imagine game structures that convey the complexity of the quantum world. Those who would design the games must be experts in quantum technology, to understand it extremely well to transfer it to the games.
8	**Sensory theory**	It is based on the stimulation of the senses (sight-75%, hearing-13%, and touch, smell, and taste-12%). Among the modern means used are video methods and VI (Virtual Reality) methods.	To understand the quantum world, a sophisticated mathematical apparatus is used. Even the experimental part of this world requires a complicated apparatus that makes indirect contact between the quantum world and the student. Most of the phenomena in the quantum world cannot be seen, so most of the sensory theory is annihilated.
9	**The theory of learning by telling stories**	Knowledge is embedded in stories.	The quantum world lends itself to stories because it is difficult to visualize. To arouse the interest of young people, the method can be used.
10	**Social learning theory**	It is an extension of the behavioural theory and claims that the acquisition of new knowledge can be done more easily by observing and imitating the actions of colleagues and teachers.	For now, the quantum world does not have a social character. Learning by imitation is a big barrier given the small number of experts in the field and the small-scale industrialization.

The content of Table 3 reinforces a previous statement, namely that of interdisciplinarity as a method of teaching quantum technology. This strong interdisciplinary character means that no theory of learning can cover the needs of knowledge transfer for the quantum field on its own. It can be seen that parts of each theory of learning must be used, combining and adapting the principles of these theories to the requirements of learning quantum technology.

4 CONCLUSIONS

1. The paper proposes a system for designing curricula in the field of quantum technology, regardless of their complexity or the fields to which they refer, i.e., trivalent (Materials-Physics-Informatics) or bivalent (Materials-Informatics, Physics-Materials, Physics-Informatics)
2. While classical pedagogy, trains interpreters (better or worse) of the knowledge transmitted, quantum technology requires a different pedagogy, quantum pedagogy that is already said to want to transform the learner from performer into creator.

3. The development of quantum computing shows that physical interactions in nature cannot be naturally divided into small arbitrary units, 1 and 0, but are based, at the limit, on a minimal quantum dimension. As a result, the laws of computer science should be the laws of quantum mechanics applied to atomic and subatomic levels and not those based on Boolean algebra.
4. Quantum technologies, applied in industry and advanced research, use notions that current analytical programs do not address. The question arises as to what a new curriculum should look like in order to include them.
5. The analysis of the content of quantum technology emphasises the strong experimental character of the phenomena used and highlights the fact that the experimental part of the educational laboratories is far below the needs of the advanced knowledge required by these phenomena. It takes a significant material effort or the joint use of research and industry equipment for the growth of specialists in the field.
6. At the moment, the evolution of quantum technology is unpredictable. For this reason, instead of developing stable curricula, postgraduate courses are offered, especially at the request of the industry, with a profile focused on skills such as nonlinear physics, quantum mechanics, electronics, software, artificial intelligence, etc. (so emphasis is placed on strengthening fundamental knowledge to ensure adaptability).
7. The paper proposes a method for designing curricula in the quantum field. The method is flexible; it also contains the classical learning part and the adaptation of classical knowledge to specialisation requests on subfields belonging to quantum technology, depending on the requests of the beneficiaries.
8. It is considered that quantum technology, seen as the field that will dominate the scientific world in the coming years, is the most entitled to demand a strong orientation of general and high school education towards STEM education.

5 ACKNOWLEDGEMENT

The work was developed under the auspices of the CVTC (Centre for Valorisation and Competence Transfer) Centre of Transylvania University in Brasov.

6 DECLARATION OF INTEREST

We declare and undersign that this paper is an original and common work of all the authors. We also declare and warrant that our contribution to this paper does not infringe on any copyright or other proprietary right of others.

7 REFERENCES

[1] J. T. M. De Hosson, “Electronic states near dislocations in transition-metals: An application of quantum-chemistry in technology,” *International Journal of Quantum Chemistry*, vol. 18, pp. 575–582, 1980. https://doi.org/10.1002/qua.560180229

[2] T. Sauer, “Massimiliano Badino and Jaume Navarro (eds.), Research and pedagogy: A history of quantum physics through its textbooks. Berlin: Edition Open Access, 2013, pp. 296. ISBN 978-3-8442-5871-4. €37.84 (hardback),” *British Journal for the History of Science*, vol. 48, no. 3, pp. 530–532, 2015. https://doi.org/10.1017/S0007087415000485

[3] GPO, "PUBLIC LAW 115–368," 2018. [Online]. Available: https://www.congress.gov/115/plaws/publ368/PLAW-115publ368.pdf
[4] https://quantumconsortium.org/
[5] quantum | gov, "The National Quantum Coordination Office," 2024. [Online]. Available: https://www.quantum.gov/nqco/
[6] https://www.anl.gov/
[7] https://www.fnal.gov/pub/science/index.html
[8] https://www.lbl.gov/
[9] https://www.ornl.gov/
[10] https://ec.europa.eu/futurium/en/content/fet-flagships.html
[11] https://ec.europa.eu/futurium/en/content/quantum-manifesto-quantum-technologies.html
[12] E. Waltz, *Knowledge Management in the Intelligence Enterprise*. Boston, London: Artech House, 2003.
[13] https://uknqt.ukri.org/
[14] M. A. Nielsen and L. I. Chuang, *Quantum Computation and Quantum Information*. Cambridge: Cambridge University Press, 2010, p. 702. https://doi.org/10.1017/CBO9780511976667
[15] A. Fedorov, "Evaluation of decoherence for quantum control and computing," Ph.D. dissertation, Dept. Phys., Clarkson University, New York, United States, 2005.
[16] M. Cerezo, G. Verdon, H. Y. Huang, L. Cincio, and P. J. Coles, "Challenges and opportunities in quantum machine learning," *Nature Computational Science*, vol. 2, no. 9, pp. 567–576, 2022. https://doi.org/10.1038/s43588-022-00311-3
[17] E. H. Houssein, Z. Abohashima, M. Elhoseny, and W. M. Mohamed, "Machine learning in the quantum realm: The state-of-the-art, challenges, and future vision," *Expert Systems with Applications*, vol. 194, p. 116512, 2022. https://doi.org/10.1016/j.eswa.2022.116512
[18] D. Edwards and D. B. Rawat, "Quantum adversarial machine learning: Status, challenges and perspectives," in *Second IEEE International Conference on Trust, Privacy and Security in Intelligent Systems and Applications (TPS-ISA 2020)*, 2020, pp. 128–133. https://doi.org/10.1109/TPS-ISA50397.2020.00026
[19] S. J. Wei and G. L. Long, "Efficient simulation of an open quantum system in duality quantum computing," *Quantum and Nonlinear Optics IV*, vol. 10029, 2016. https://doi.org/10.1117/12.2245869
[20] S. Gunther, N. A. Petersson, and J. L. DuBois, "Quandary: An open-source C+ plus package for high-performance optimal control of open quantum systems," in *Proceedings of Second International Workshop on Quantum Computing Software (QCS2021)*, 2021, pp. 88–98. https://doi.org/10.1109/QCS54837.2021.00014
[21] K. Hatakeyama-Sato, T. Kashikawa, K. Kimura, and K. Oyaizu, "Tackling the challenge of a huge materials science search space with quantum-inspired annealing," *Adv. Intell. Syst.*, vol. 3, pp. 200–209, 2021. https://doi.org/10.1002/aisy.202000209
[22] K. Kitai *et al.*, "Designing metamaterials with quantum annealing and factorization machines," *Phys. Rev. Res.*, vol. 2, p. 013319, 2020. https://doi.org/10.1103/PhysRevResearch.2.013319
[23] B. Bauer, S. Bravyi, M. Motta, and G. K. L. Chan, "Quantum algorithms for quantum chemistry and quantum materials science," *Chem. Rev.*, vol. 120, pp. 12685–12717, 2020. https://doi.org/10.1021/acs.chemrev.9b00829
[24] F. Arute *et al.*, "Quantum supremacy using a programmable superconducting processor," *Nature*, vol. 574, no. 7779, pp. 505–510, 2019. https://doi.org/10.1038/s41586-019-1666-5
[25] D. J. Egger *et al.*, "Quantum computing for finance: State-of-the-art and future prospects," *IEEE Transactions on Quantum Engineering*, vol. 1, pp. 1–24, 2020. https://doi.org/10.1109/TQE.2020.3030314

[26] C. Hughes, D. Finke, A. German, C. Merzbacher, P. M. Vora, and H. J. Lewandowski, "Assessing the needs of the quantum industry," *IEEE Transactions on Education*, vol. 65, no. 4, pp. 592–601, 2022. https://doi.org/10.1109/TE.2022.3153841

8 AUTHORS

C. Samoila, Prof., Univ. at Transylvania University of Brasov, Romania. Is a PhD leader in the field of materials science. Full member of the Romanian Technical Science Academy. Member of IAOE from 2006. Reviewer of Materials MDPI Journal, Metals MDPI Journal, and other Web of Science journals (E-mail: csam@unitbv.ro).

D. Ursutiu, Prof., Univ. at Transylvania University of Brasov, Romania. Is a PhD leader in the field of telecommunications. Full member of the Romanian Academy of Scientists. Honorary President of IAOE. CVTC President (E-mail: ursutiu@unitbv.ro).

H. A. Modran, Lecturer at Transylvania University of Brasov, Romania. Member of CVTC. PhD in the field of Telecommunications (E-mail: modranhoria@gmail.com).

C. Gherman (Dolhascu), PhD student at Transylvania University of Brasov, Romania. PhD in the field of Telecommunications (E-mail: catalina.dolhascu@yahoo.com).

J. Tudorache (Nistor), PhD student at Transylvania University of Brasov, Romania. PhD in the field of Materials Engineering (E-mail: juliana.nistor@liebherr.com).