



The Quantum Technology Open Master: widening access to the quantum industry

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Abstract

In this article we conceive of the *Open Master*, a new form of Transnational Education, as a means of enhancing accessibility to specialist expertise in Quantum Technology. Through participatory action research conducted during the setup and operation of a pan-European pilot project, the QTedu Open Master (QTOM), we examine the viability of this educational model to offer flexible learning opportunities to STEM Master's students through the setup and year-long operation of an online course exchange platform. A crucial lynchpin in the Open Master model are the mechanisms of *local accreditation* available for the awarding of credit, which we divide into distinct course types varying in formality and applicability. Furthermore, we have elucidated the strategies taken by staff to successfully implement the Open Master and benefit from its transformative value, building long-lasting communities within and between faculty, and scaling up educational offerings across Europe. With this research, we reflect on a possible future for QT Education.

Keywords: Quantum Technology; Online Learning; Transnational Education; Organisational Change; Internationalisation; Credit Transfer; ECTS; Community Building

1 Introduction

1.1 Quantum Technology: a specialist industry

Quantum Technology (QT) is a rapidly developing industry, with the potential to drastically influence society over the next decade [1–3]. There is therefore an urgent need for a trained workforce of quantum-capable graduates able to supply the industry with specialist skills. As of now, fields such as cryptography and cryogenics suffer with far fewer job applicants than there are positions [3]. As of now, the predominant route to the skills required is through a PhD program [4]. However, the associated long timeline of 3–5 years is highly limiting for industry growth. For this reason, new QT Master programs are becoming more prevalent across the world. The new programs are intended to offer the competences needed for students to take up employment in specialist fields of QT over a shorter timeframe than a PhD. However, as of now there are relatively few opportunities available – around 40 programs worldwide [4]. Even with the scale-up incoming over the next 5 years, there will still be far more students enrolled in more generalist STEM degree programs such as Physics or Engineering [2], where they do not have access to the research

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and teaching expertise required for an industry career. At a time when it is most needed, there is a lack of accessibility, even for STEM students, to specialist skills in QT.

1.2 Flexible learning in European higher education

Setting up many new Master's programs is no straightforward task. They require substantial funding [5], to undergo extensive national accreditation procedures [6], and a critical mass of teaching faculty spanning a variety of QT subfields, in order to set up. As an alternative, we can consider the tools of the EU's Bologna Process – reforms to higher education ongoing since 1999, intended to make flexible learning opportunities available for all [7]. With a growing emphasis on student ownership and independence [7, 8], it is intended that they “should be able to plan their learning paths on the basis of clear information to acquire the knowledge, skills, and competences that meet both their personal goals and societal needs” [7]. Universities now have access to tools such as the European Credit Transfer System (ECTS), the diploma supplement (degree transcript), and standardised degree classifications [9–11]. Despite this, the evaluators of the Bologna Process have recently highlighted the importance of developing new, more flexible models of education, with “measurable qualitative indicators” [12]. In this article, we envisage one such new model – a form of *open* education – and apply it in the field of QT where it may help to widen access to specialist skills.

1.3 Accessibility through open education

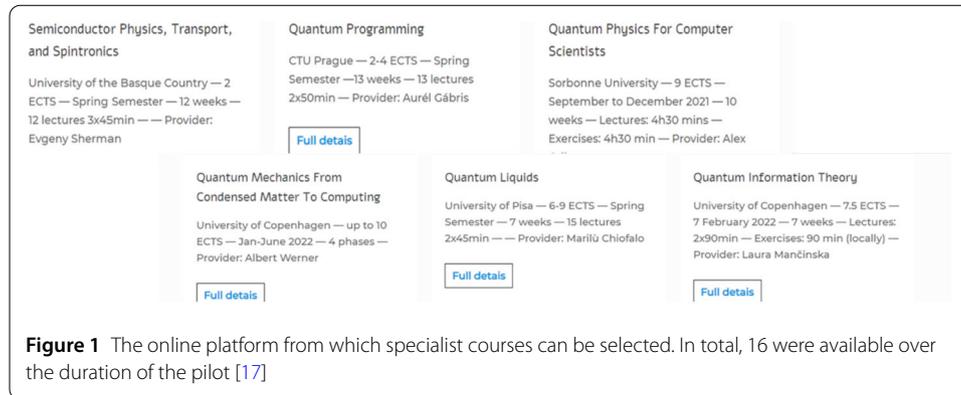
Defined by the European Commission [13] as “a way of carrying out education, often using digital technologies”, “Open Education” aims to “remove barriers and make learning accessible, abundant, and customisable for all”. But how could this be done in practice, when few institutions currently have the research and teaching capacity to offer a full one or two year QT Master program? In an attempt to answer this question, here we introduce and evaluate a new model of open education for Quantum Technology.

This model is based on those from the field of *transnational education* (TNE), which are defined by study modes where “learners are located in a country different from the one where the awarding institution is based” [14]. They vary in content from the level of micro-credentials, individual or sets of courses, to entire programs [15]. Established partnerships and agreements between teaching institutions and those in which students are enrolled (we refer to them as *local institutions*) are such that workload can be recognised and credits awarded locally.

1.4 Building an Open Master

The *Open Master*, as we conceptualise it in this article, is a form of TNE which is intended to address the problem of accessibility in specialist STEM fields such as QT. For a complete treatment of how the Open Master sits within the pantheon of transnational education models, we refer the reader to [16]. Below we describe its formulation in brief.

In the *Open Master*, students enrolled on non-specialist STEM Master degrees (such as “Physics”, or “Engineering”) follow a small number of online lecture courses provided by foreign universities in one or more of the elective (optional) components of their degree programs. As in other kinds of TNE, credit for study is awarded by the local, degree-awarding institutions, rather than the teaching universities (henceforth *providing institutions*). However, unlike other formats, the Open Master does not rely on setting up institutional partnerships. Rather it depends on the local institutions recognising the study



conducted and awarding credits accordingly through an instrument we refer to as *local accreditation*. While making use of the well-established ECTS intended to facilitate exactly this kind of flexibility [10], there is not currently any standardisation for these mechanisms.

In order to investigate the viability of the *Open Master* model, the volunteer pilot *QT-Edu Open Master* (QTOM) project [17] emerged from a thriving community of practice [18] in QT Education, QTedu [19]. Over the academic year 2021-2022, QTOM set up an online platform for exchange of specialist QT courses among 26 partner universities across Europe. From this platform, students of non-specialist STEM Master's programs could select one or more QT courses to study in distance education format (see Fig. 1). This would in effect act as a “Quantum-augmentation” of their STEM degree, and thus help to position them towards a career in the QT industry. With *local accreditation* as a crucial lynchpin to the model's functionality, operation of the pilot was intended as an international experiment to explore, identify, and establish these mechanisms, a research problem formulated below (RQ1).

RQ1: What is the viability of *local accreditation* and the *Open Master* model as a means to widen access to specialist skills in QT?

Much like other recent education models, such as micro-credentials [20, 21] and the European Universities initiative [22], we consider the Open Master model a proof-of-concept which, if viable for scaling up, may be more widely adopted as a solution for flexible learning in emerging technology fields. The European commission uses pilot projects such as these to “test what would be a vision for the future” [23]. There are many examples of such experiments in higher education [24–26], particularly in technology enhanced learning [27], which, like QTOM, begin life as exploratory pilots with little or no funding. In the European QTedu community, there have also been practice-oriented QT education pilots targeting high schools, outreach, and industry training [28–30]. In order that these may grow into “sustainable innovations” [31], it is essential that practitioners and scholars understand how staff who implement pilots, their “champions” [32], can do so successfully, overcoming numerous barriers such as the administrative, attitudinal, and limitations of time [33, 34]. Therefore to understand how future educational innovations may be val- orised, we seek to answer RQ2:

RQ2: What strategies may be taken by staff to implement the educational innovations of a proof-of-concept model such as the Open Master?

Finally, we note that while this research has been carried out through a pilot in the field of Quantum Technology, the *Open Master* model could equally be applied to other emerging

fields which suffer the same specialist accessibility gap, such as Cybersecurity [35], Cryptocurrency [36], the “Internet of Things” [37], and other target areas of the EU’s Digital Decade policy [38].

2 Methodology

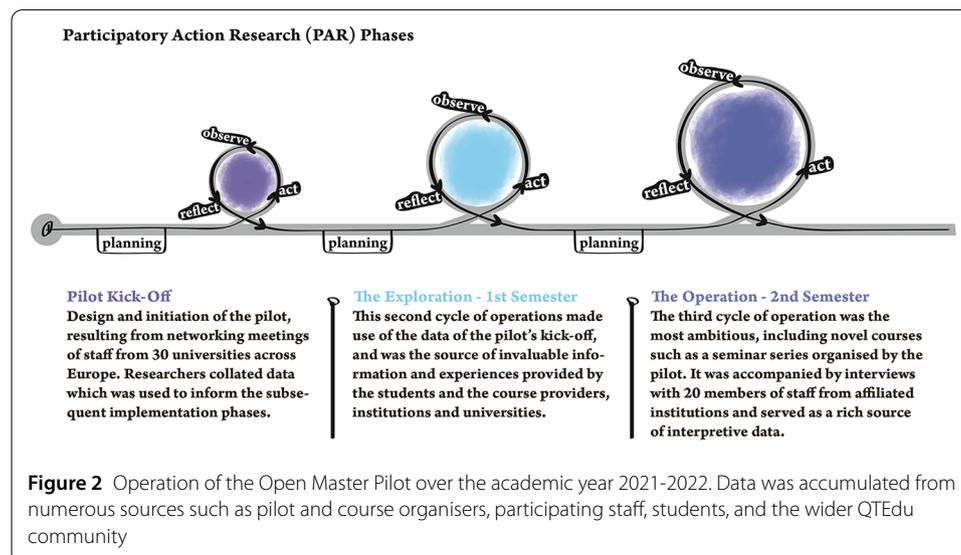
2.1 Participatory action research

Throughout the pilot’s operation, a participatory action research (PAR) paradigm [39] was adopted. Action research is a methodology to address systemic challenges by implementing and evaluating measures intended to change the status quo, whilst simultaneously taking a research approach such that the action taken results in wider value for the scholarly community. In Higher and STEM Education it is used frequently, where action research has addressed the introduction of novel pedagogies, teaching practices, digitalisation, internationalisation, among many others [40, 41].

In this research, PAR was used to implement and evaluate the pilot Quantum Technology Open Master (QTOM), as a means to research the viability of the model (RQ1) and the strategies that may be taken to implement it (RQ2). Characteristic of PAR is a collaborative effort between the researcher and the participants of the research [42, 43]. In the case of QTOM, those are in turn SG, the project organiser, and the local representatives of QTOM who implemented the pilot in their organisations. SG held a unique positionality as the primary researcher, manager and insider to QTOM, yet as an outsider to each participating institution. The use of PAR, methodologically novel in QT education, ensured the successful operation of the QTOM pilot, simultaneous with detailed investigation of new concepts such as *local accreditation*.

2.2 Data acquisition

The pilot project was executed in three phases spanning the initial preparation and kick-off, and two operative semesters (see Fig. 2). Through each phase, we followed an iterative cycle of planning, action, observation, and reflection typical of PAR [44, 45]. These cycles served as a rich source of data, involving planning and implementation of the course



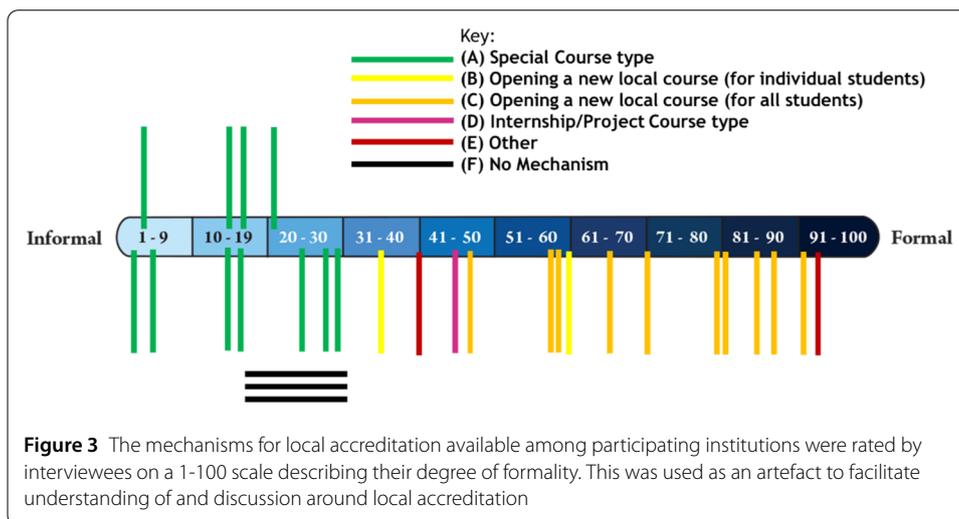
exchange and observation and communication around the resulting experiences from students, staff, and the wider QTedu community (QTedu, 2021). Within each cycle, interpretive field notes were made by [REDACTED AUTHOR INITIALS], and experiences informed the planning of procedures within the next cycle.

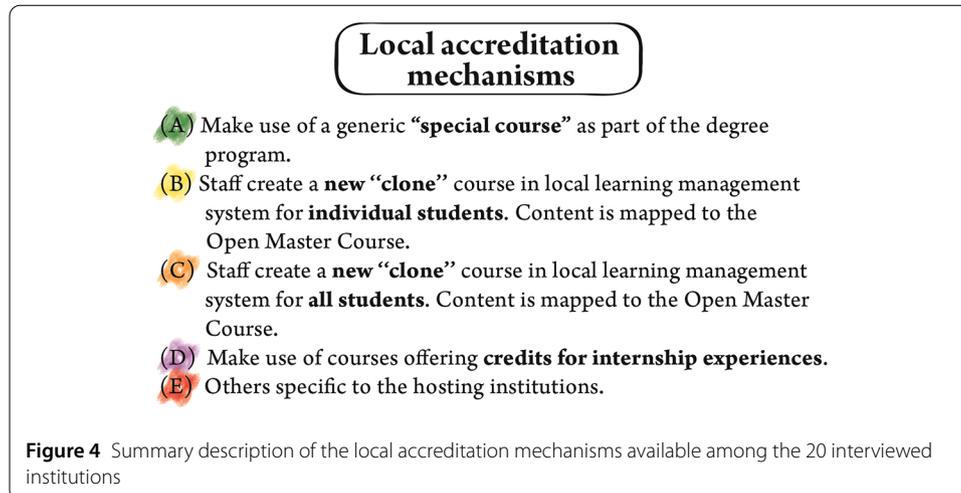
In addition, interviews were conducted with a total of 20 members of staff from universities affiliated with the pilot. The interviewees primarily comprised the local representatives, primarily teaching faculty. They varied in seniority within their institutions, the primary criterion for selection being their understanding of and engagement with the pilot, and knowledge of their local credit awarding mechanisms. Interviews were recorded and fully audio transcribed.

Interviews took place near the end of the second semester of pilot operation, representing the concluding observations of the participants. A semi-structured rubric [46] was followed, modified for the individual context of each interviewee’s participation in the pilot, SG being aware of this through overall administration of the project. For example, when previously aware of particular problems encountered, these were brought up as discussion points explicitly. A clear distinction was always kept between the views of the participants and their impression of the views of the department, faculty, and institution which they represent.

In developing the notion of *local accreditation*, an early sensitising concept [47] was the significant difference in the degree of formality of course accreditation mechanisms. This was clear during the organisation of the pilot, but became further apparent during the interviews when they were described in detail by participants. This conceptualisation led to a graphical representation of the instrument in the form of a 1-100 scale which was included in the rubric as a discussion artefact.

In order to understand the degree of formality of the mechanisms, SG discussed with interviewees examples of formal course accreditation arrangements (such as established Erasmus+ exchange agreements) and informal methods such as those available among some of the pilot organiser’s institutions. Subsequently interviewees rated their own institution’s arrangements between the two extremes (Fig. 3). It should be noted that this scale was used primarily as a methodological artefact [48] to aid in interviewees understanding of local accreditation, to generate discussion, and to help identify features of the





mechanisms. It is not a repeatable evaluation instrument, and as such the exact position of the mechanisms on the scale is not presented as a research finding. However the overall distribution is noteworthy and we consider this in the results section.

2.3 Data processing

Alongside transcripts, detailed notes were made during each interview. In addition, each was tagged with a short descriptive summary of the participation and attitude of the interviewees, in order to ensure the unique context of each was accounted for in the subsequent analysis. Interview notes and transcripts were coded collaboratively using a mixed inductive and deductive approach. A table of codes is available in the appendix. The method of reflexive Thematic Analysis [49] was used to aggregate coded portions of the transcripts, as well as the notes taken during the interviews and overall operation of the pilot, into themes. These describe the challenges, benefits, and strategies for implementation of the Open Master, used to evaluate its viability as an educational model and presented in the Results section. Common themes in the description of the local accreditation mechanisms, and the experiences of staff and students who used them through the course of the pilot, enabled a division into course types A-E, presented in Fig. 4.

3 Results

In this section we first consider the viability of the Open Master model by evaluating its perceived benefits against the challenges which must be overcome to implement it, including the need for local accreditation mechanisms. We then consider strategies taken by the staff members participating, generating the changes within their organisations necessary to make this model of education work.

3.1 Widening access to specialist expertise

Principal benefits cited for students were those which were at the forefront of the design of the project – increased flexibility in learning opportunities, and wider access to more specialist areas of Quantum Technology. Students were offered an education in the latest research-led topic areas which would not otherwise have been available for them. The Open Master was thus considered to help “feed the pipeline” [50] for the emerging QT in-

dustry, by offering a launchpad to PhDs and to jobs in the field. Furthermore, participation in an international community of students, providing skills in intercultural communication, was considered particularly valuable at a time when international experiences have been greatly stunted by the Covid-19 pandemic.

“For students who want to work and do research or doing any job really in the cutting edge of this field, I would like them to take courses from people who are doing research actively. Our goal is, from the pedagogic point of view, well-educated students right? If we can achieve this goal also by collaborating with other institutions, why not?”

3.2 Visibility as a core motivation

For faculty, visibility was frequently cited as a benefit; both internal (for the department, within the institution) and external (for the institution, within the European community). The former was seen as a means to have QT research recognised (and potentially funded and staffed) more by the university, while the latter was intended as a strategic move to foster future collaborations and funding opportunities. In these cases, the relatively small time investment in participation was considered to be worthwhile for the possibility of large benefits in the future. Visibility is a powerful means of creating organisational value [51].

“A goal for being involved in these things is to know what’s going on a little bit in European community and look out for opportunities to collaborate with people or to apply to calls.”

“I hope we’ll have a major impact on, let’s say, the visibility of our local environment and I hope it works the same for others.”

3.3 Growing specialist teaching capacity

The wider community saw great potential in the platform. Faculty at several institutions explained how the shared courses available through the Open Master could enable them to develop new degree programs from scratch, when there would otherwise not be sufficient local teaching capacity to do so. This scenario is not unrealistic, as it is uncommon for QT research to cover the full breadth of advanced subject areas within a single university department, and is a strong limitation on the number of specialist Master programs available worldwide [4, 52]. The Open Master model offers a solution to this challenge. In the European project DigiQ [53], a course sharing platform based on the Open Master model will form the basis of four newly developed specialist QT Master degrees, and a further twelve non-specialist programs “upgraded” by offering shared courses to their students, bypassing the need for a critical mass of local expert teaching faculty.

“QTOM gives us the ability to establish local courses and local content that we otherwise couldn’t. Quantum technologies are so complex that you don’t have all of the knowledge to teach it in one place. There might be some universities with official master programmes in Quantum technology, but not ours. It is much easier to have the best providers from all over Europe who are offering the content.”

3.4 The need for local accreditation

Mechanisms of *local accreditation* are instrumental in the viability of the Open Master model. From the descriptions in the coded transcripts and notes, the pre-existing and newly developed local accreditation mechanisms among the 20 interviewed partners were clustered into 5 categories, A-E, summarised in Fig. 4. Here we describe their common features.

3.4.1 Special course types (A)

The first class of mechanisms are those we describe as “special courses” (A). These are fixed features of study programs designed to be mapped to one-off study opportunities, and intended to offer flexibility for students within their overall program. To do so, a member of staff acts as a guarantor, describing the course content through an online or physical form. Interviewees use of the formality scale (Fig. 3) and the terms used to describe them (such as “joker card” and “free course”) ascribed these course types as a relatively informal and thus pragmatic means to accredit online courses. An example of an A type course, as shown in the course catalogue of one of the pilot participants, is shown in Fig. 5.

Whilst often straightforward to set up, many participants noted significant disadvantages. Courses followed online may not appear by name on the diploma supplement, instead showing a code or generic title such as “traineeship” or “special topic”. Many special courses are limited to a fixed specific number of ECTS (as in Fig. 5), and some involve additional local examination requirements which can be a burden for both staff and students.

“If I give credits to that course, my university treats me as the examiner of that course so I would have to be a hundred percent sure that if they get a grade from that [providing] university it is accurate. So I would have to re-examine the students and they don’t like it typically. So then you do it in a light way, you make it an oral exam for example.”

Furthermore, interviewees described how repeated use of their “jokers” may generate scrutiny from the department, where there was reluctance to introduce changes into the study program outside of exceptions made for individuals. This “case-by-case” nature of the A type courses made them an useful resource for individual students to benefit from the pilot, but impractical as a solution for larger scale implementations of course exchange.

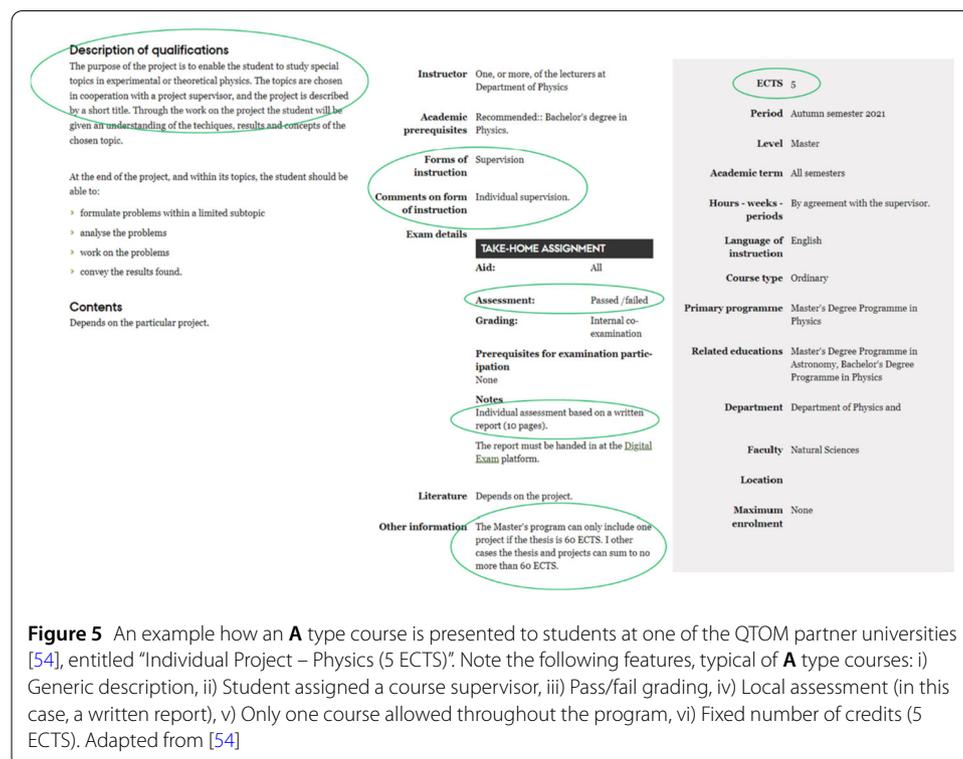


Figure 5 An example how an A type course is presented to students at one of the QTOM partner universities [54], entitled “Individual Project – Physics (5 ECTS)”. Note the following features, typical of A type courses: i) Generic description, ii) Student assigned a course supervisor, iii) Pass/fail grading, iv) Local assessment (in this case, a written report), v) Only one course allowed throughout the program, vi) Fixed number of credits (5 ECTS). Adapted from [54]

3.4.2 Opening new courses (B and C)

More formal systems described by participants were those that involved opening new local “clone” courses of those available through the Open Master. The courses appear in the learning management system of the awarding institution, either for individual (B), or all (C) students on the degree program. Content included in the local course description utilises descriptions provided by the Open Master course, such as learning outcomes and supporting material. Opening new courses in this manner was felt to be more “official”, as these “clone” courses hold the same status as any other elective course in the program, and are listed alongside them in the learning management system (LMS). They also hold advantages such as no restriction on ECTS, and permanent elective status in the curriculum, and thus were often considered to be preferable to the A types.

However, interviewees described numerous barriers to this process, such as the time-consuming nature of the setup, internal auditing, inflexible attitudes of management, and restrictions on changing the program structure due to local government accreditation. In many cases this process was slower and more administratively burdensome than even creating a new course from scratch, “*like a legal process!*” (according to one interviewee).

“Our dean’s office requires many official papers from the partner, and the process to be accepted as an official elective course is roughly one year. In that case, such a course might be accepted as an official elective course by our university.”

The exemplary examples of B and C courses are those where the administrative overhead associated with opening the course are minimised by use of straightforward systems, such as integration directly into the local learning management system. An example of an effective C type course from the Open Master pilot, as it appears in the local institution’s LMS, is shown in Fig. 6. The full details of information accessible to staff and students for this course is available in Appendix 2.

3.4.3 Other course types (D and E)

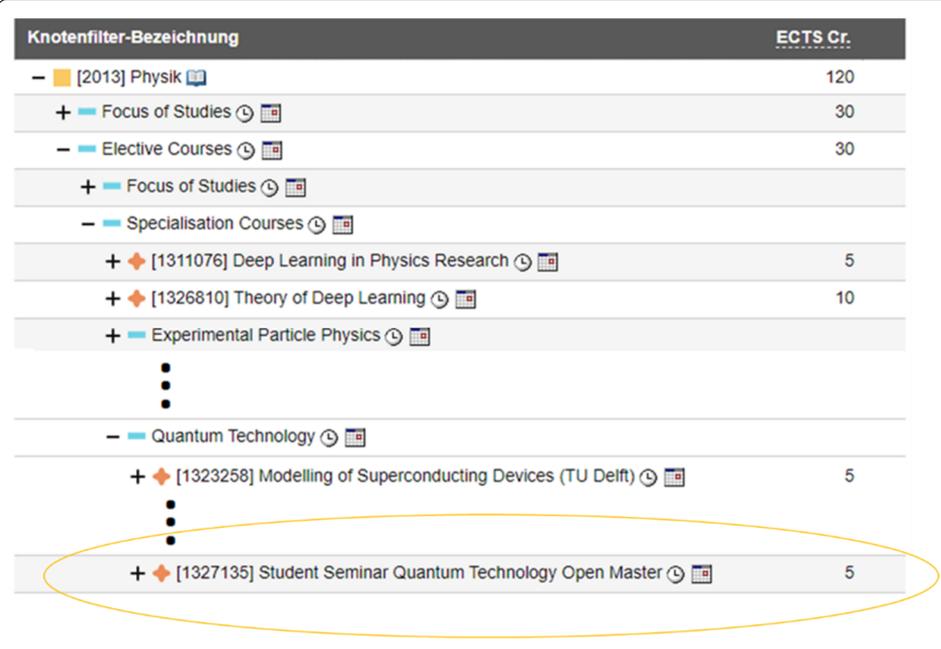
One mechanism (E) available at a participating institution is an automatic recognition of online study, available due to a learning agreement made between Finnish universities [56], indicated on the scale (Fig. 3) by the interviewee as highly formalised. Aside from this, two institutions indicated course types (D) intended to offer credits for online internships or projects. These are not considered in the scope of the Open Master, yet may represent a fruitful direction for future research, as hands-on experiences such as these have been identified as a major contributor to promoting careers in the QT industry. [52, 57, 58].

3.5 Other challenges for the Open Master model

While local accreditation is the crucial mechanism for the functioning of the Open Master, other minor challenges reported by staff include practical issues such as scheduling of lectures, advertising to students, and technical difficulties offering courses digitally. Our findings also indicate two more substantial obstacles to scaling up the model, described below.

3.5.1 Extra workload: handling the finances

A core tenet of the Open Master is that shared courses are made available for all students without cost. In the context of a pilot, the additional workload for the lecturer associated with a few extra students enrolled on their course from abroad is minimal, particularly



Knotenfilter-Bezeichnung	ECTS Cr.
- [2013] Physik	120
+ Focus of Studies	30
- Elective Courses	30
+ Focus of Studies	
- Specialisation Courses	
+ [1311076] Deep Learning in Physics Research	5
+ [1326810] Theory of Deep Learning	10
+ Experimental Particle Physics	
•	
•	
- Quantum Technology	
+ [1323258] Modelling of Superconducting Devices (TU Delft)	5
•	
•	
+ [1327135] Student Seminar Quantum Technology Open Master	5

Figure 6 A “specialisation” elective course (C type) at a QTOM partner organisation. It appears alongside other courses taught both locally, in person, and others taught online, also using a C type mechanism (e.g. “Modelling of Superconducting Devices”, TU Delft). Adapted from [55]

for those who are well prepared for online teaching through their experiences in the pandemic. Interviewees described how this additional time spent was worthwhile to improve the experiences of the students that participated.

“We could see that students wanted to participate and in fact, we all shared the same goal. We want the students to have the best opportunities, so we made it work.”

Even so, difficulties arose when students required exercise material or examinations as part of their local accreditation. The B and C course types, in particular, were often graded on the basis of exercise material. In order to minimise the workload for the volunteer lecturers, one solution is to ask local representatives to conduct their own exercise classes and examinations. In such cases, representatives found that despite being sufficiently expert in the topic areas being studied, it was difficult to grade material or conduct exams when not directly involved in the teaching of the course.

“If you have little experience with this course then you cannot take care of the students yourself”

As a result, some course providers took on the extra responsibility for this themselves, marking student exercises and passing the grades on to the local institution. However, such a model is expensive in time, as noted by Interviewee P:

[For this service] *“I would be charging one hundred or fifty euros or whatever it is. We have a revenue model. If we provide a module effectively for free and also manage the assessment and exam, then if you have twenty students on it we would get two thousand euros to have a TA”* (teaching assistant).

How best to manage the open ecosystem of courses with respect to these financial needs, we consider in the discussion section.

3.5.2 National restrictions and differences

Another set of challenges encountered and frequently referred to by the QTOM representatives are those induced by the national higher education landscape of their countries. Incomplete implementation of the ECTS, for example, led to difficulties in recognition of workload conducted by students through the Open Master. Here our findings echo those of the Bologna Follow Up Group [59]. In Hungary and the Czech Republic, despite being committed to the use of ECTS, there are still remnants of previous national systems for educational credit, as these countries do not consider use of ECTS as a criterion in institutional evaluations, reducing the incentive to fully implement it.

Another difficulty for any initiative intending to make changes to degree programs on a larger scale are restrictions imposed by national bodies responsible for certifying programs, such as local education ministries. Participants based in three different countries described that this certification, which is intended for quality assurance [6], produces rigidity in making the small structural changes which would be necessary to establish local accreditation mechanisms, particularly **B** and **C** type courses.

“The way that masters accreditation works in this country is relatively restrictive, so you have to put a very thorough description of the programme that gets accredited by the local agency and they put minimum requirements around, for example, the number of core courses that have to be covered and the types of flexible courses you have. Asking to change a module would be difficult. It would be slow and bureaucratic.”

3.6 Strategies for successful implementation

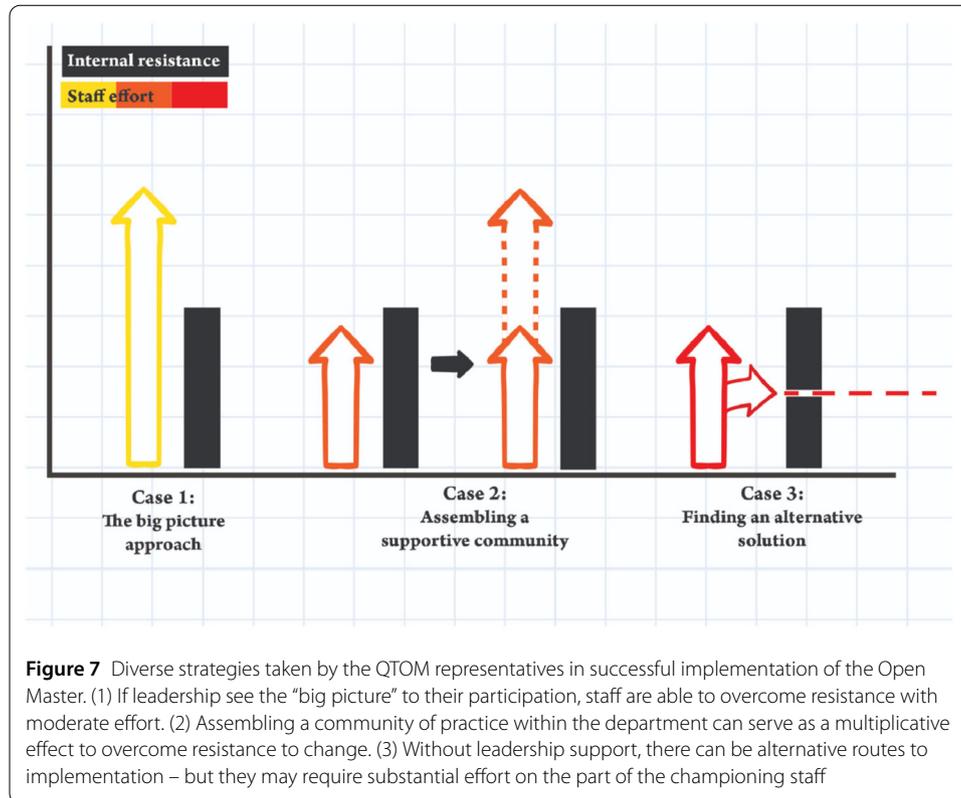
Implementation of the Open Master, and any significant educational innovation, requires organisational changes, overcoming internal resistance [60]. The “champions” [32], who believe strongly in the project’s goal and attempt to make such changes have been described as using “every means of informal sales and pressure tactics”, showing “persistence and courage of a heroic quality” [32]. Champions are particularly instrumental in implementing project and technology-based organisational transformations [34], of the kind the Open Master relies upon. We identified diversity in strategies taken and degrees of success in overcoming the departmental resistance to implementing the pilot of the Open Master. Participants that characterised their participation as productive primarily made use of one of three strategies, described below and shown below in Fig. 7.

(1) The Big Picture approach

Strategic thinking [60] led some to see the “big picture” of why their participation in the pilot was valuable, for example understanding how the Open Master model addresses the movement towards flexibility in European higher education [8, 21, 22, 59]. In these cases there was an awareness of the benefits to their institution slowly introducing novel pedagogical models, for their role in increasing attractiveness for students [61], and for the strategic value they offer in demonstrating innovation [51].

Another link demonstrated by interviewees is that graduates with specialist experience are more likely to undertake a PhD and “feed the pipeline” [50] of development of Quantum Technology. Indeed it is estimated that around one third of research outputs are attributed to PhD students [62] and this qualification is the baseline which leads to academic careers. Providing courses could therefore be seen as an investment by the department to help attract top students, who may become significant drivers of research in the future.

“Students in, say, Barcelona, might follow a course remotely in Strasbourg and think “why not choose to do the second year here or come for a PhD?”



This “big picture” is well known to be a significant driver of participation in international mobility programs [63], and was demonstrated equally in the context of the Open Master by several of the departments with the most successful implementation.

(2) Assembling a supportive community

Over the three phases of the pilot’s implementation, some participants were able to overcome what was initially an unassailable resistance by developing a support network of colleagues. These may be best described as a “community of practice” [18, 64] within their department: colleagues with a shared interest in QT education and those seeing the potential of the Open Master to benefit their organisation. This support acted as a multiplicative effect increasing the influence of the champions, who were thus able to overcome local resistance and introduce changes such as the introduction of new **B** or **C** type courses. The internal visibility afforded by participation in a pan-European initiative was cited as highly valuable in enabling this community building within the department. In the organisational change model of Kotter [65], this community is referred to as a “coalition” of supporters, instrumental in generating innovations.

“What went very well was the community. It is a bit hard to activate our colleagues sometimes, right? If it’s not obvious what the benefit is and it’s just more bureaucracy and more administration. But our experience was the opposite actually. We are kind of fortunate that we have colleagues that saw the benefit, even though it’s not their field and not their project, and we were able to get off the ground anyway.”

It is notable that on the one hand this community building may be a strong predictor of successful implementation, but it is also itself a success of participation – a kind of

“transformative value” [66], which remains even after participation, and is independent of its outcome.

“It’s only now, a year later, that we are seriously talking about how to integrate the pilot into the curriculum.”

(3) Finding an alternative solution

When unable to overcome the resistance to change, some participants found means of making the Open Master work for their students regardless, “*bending some rules*”. The A type courses, for example, were used to offer students access to online lectures without requiring any structural changes to the department or degree program.

“We cannot recognize ECTS for a course taken outside from our university, so then when chatting we decided to solve this problem in this different way. With this option, any student has to do a traineeship [A type course] for 6 ECTS and they can follow any course they want”

One participant described explicitly how they tried to “beat the system” using such a course, when the creation of a B or C type was refused by the department chair. From the student perspective, they were successful: able to receive credits for their online study. However, such a battle was a drain on the resources of the champion in question.

“The core of the problem is that he [department chair] doesn’t believe in this experience unfortunately. But that doesn’t mean that it cannot be done. If it is clear that he doesn’t believe in this experience then I will find other ways of doing it, and that it is what I am doing.”

“Maybe one solution might be having an agreement with the students, the physics students association for example.”

A lack of top-down support from leadership can be a significant impediment both to students’ flexible learning, and to the staff who endeavour to support them by whatever means necessary.

4 Discussion

Many of the success stories in all three cases, where the “champions” made genuine changes, began with what could be best described as “significant conversations” [67]. Taking place with colleagues informally, “backstage” [68], these enabled them to convey the “big picture”, generate an internal support network, or find an alternative solution, more effectively than more formal channels of discussion such as through departmental boards. In some cases, these conversations did not lead directly to successful implementation of every action required to benefit most from the Open Master. Instead they may have helped to cultivate future changes, such as the attitudinal and mechanistic.

“So now [as a result of participating in the Open Master pilot] there are colleagues that push to have some local courses on quantum technologies”

“We didn’t really have a mechanism in place for them to get credit for those courses. But in the future we can do, because we have a subject which could be adapted to that.”

This transformative development resulting from conversations can be a powerful means to engender innovations from the “middle-up” [69].

4.1 Community building is more than a means to an end

In order to successfully implement any kind of educational innovation into universities, an environment in which staff feel able to present new ideas and generate this internal community of practice [18] can be of great benefit, and we found this to be a viable strategy for implementation of the Open Master. Regardless of the outcome of the pilot, the communities built both within and between institutions have remained and will continue to do so even after the conclusion of this research. This network has already been utilised by participants to fund future educational development through the European project DigiQ, [53]. In this project, the model of the Open Master forms the backbone of a flexible education program, at once able to train hundreds of QT students per year, while also developing and transforming 16 QT Master degrees across Europe: a substantial scaling up of the present landscape. Born from the QTOM pilot, DigiQ demonstrates the transformative value of participation to the community.

[Reflecting on the benefit of internal community building for the DigiQ project] “*The foundation is from the community, generating the momentum and will. Even the financial support is really a bonus*”.

4.2 National education plans can be a help or a hindrance

Our findings demonstrate that not all countries of the European Higher Education Area are fully supporting the policy push towards flexible learning with their national education strategies. The Bologna Process is far from complete [59, 70, 71]. Restrictions imposed by local ministries of education can be a significant barrier to sustainable innovation [31] in flexible learning. Where national governance can be helpful, rather than restrictive, is to adapt to the changing landscape of higher education through “softer” coordination [72].

Steering “from the top” [73] may be beneficial in two ways. First, with recommendations for how local accreditation may be used and adapted for the Open Master model. Our research suggests that while there are benefits to more formal mechanisms, these are outweighed when the system is administratively beyond the capacity of staff to manage. Effective mechanisms seem to lie relatively centrally in formality, decoupled from bureaucracy, and with features which make scaling up accessible, such as no limitation on ECTS and straightforward integration into local learning management systems. C type courses may be the most effective in this regard. Secondly, and equally important, is a need for national recommendations to push active participation in educational experiments and pilots such as the Open Master for their role developing sustainable innovations in years to come. National and European governance may be a key driver in both of these directions.

4.3 A truly open ecosystem?

In the long term, the *Open Master* could be a first step towards a model in which an extended ecosystem of universities value flexibility for their students and offer them access to specialist courses from other institutions, overcoming the difficulty faced by many in building sufficient capacity to teach the most specialist areas of QT (or indeed other emerging technologies.) European higher education is already moving in this direction,

with the Erasmus Mundus Joint Masters programs intended to address the need for specialist training in a wide variety of technological fields [74, 75]. But these are not truly open. They are limited to selected partners (usually 3-5), and funded by competitive grants with a high barrier to entry, which can exclude those departments who do not have the expertise in accessing them [51], such as those from widening countries [76].

If it were supported from the top-down, equipped with viable accreditation mechanisms, we could envisage such an open landscape, in which participating institutions may dedicate a small fraction of staff time to provide course(s) and manage student participation. The Covid-19 pandemic has already prompted many staff to convert their courses to a hybrid format [77, 78]. Students would have access to any specialist education that they could need to take a job in the emerging QT industry. Discussing the possibility of such a “tit-for-tat” model, one interviewee, previously critical of the workload associated with the pilot, noted:

“Okay, I don’t want any money as long as everybody else provides the same.”

There is no doubt that we are still far from such a model at the present time, but note that the *Open Master* is a proof-of-concept which can help accelerate the changes required to make it possible, much like other innovations before it [20–22]. The route towards this truly open landscape requires further efforts such as this, which of course require some investment for those first-moving organisations. However, as our research demonstrates, even small investments come with a substantial “transformative value” associated with participation.

5 Conclusion

Through the conceptualisation and evaluation of the *Open Master*, we have elaborated on a new model of transnational education [16] that can allow for training STEM Master’s students in specialist areas of Quantum Technology which would not otherwise be available to them. It shows potential as a means of growing the teaching capacity of many institutions, thus helping to develop a much-needed Quantum workforce to supply the growing industry.

The Open Master relies on the mechanism of *local accreditation*, which is presently not supported with policy on either a national or European level. Nevertheless, QTOM has demonstrated that, as a proof-of-concept, the model holds great value in widening access to specialist skills, growing teaching capacity, and promoting visibility and community building in institutions. Should this instrument be further developed with recommendations for implementation and experimentation from the top-down, we may envisage a sustainable innovation in open education, where every student can access the specialist skills they need for industry.

Furthermore, a central message of the QTOM pilot is that the very process of engaging with such an international experiment generates value independent purely of its degree of success. We found that the “backstage conversations” [68] inherent in participation acted as a catalyst to kickstart a self-sustaining community within departments. This “transformative value” [66] will remain beyond the conclusion of the Open Master pilot, and continue to fuel innovations into the future.

Appendix 1: Table of codes

Code	Number of transcripts featuring code
(A) Special Course types	11
(B) Opening new courses (individual students)	2
(C) Opening new courses (all students)	10
(D) Internship/Project courses	2
(E) Other course types	1
(F) No accreditation mechanism	2
(G) Internal communication	15
(H) Change of structure or organisation, future	14
(I) Change of structure or organisation, present or past	4
(J) Feature enabling a change of any kind (e.g., participation in the pilot project leading to a new master)	20
(K) New local development, future (e.g., course, program, summer school)	12
(L) Local development, past or present (e.g., course, program, summer school)	9
(M) Participation in EU collaboration for education, future	6
(N) Participation in EU collaboration for education, past or present	18
(O) Perceived benefit of participation: staff, institution, department, faculty	16
(P) Perceived benefit of participation: students	19
(Q) Perceived challenge to participation, all kinds	20
(R) Established issue or difficulty in the organisation	15
(S) Academic administration (transcript, academic calendar, courses content, accreditation)-Generated sub-codes A, B, C, D, E, F	20

Appendix 2: C type course in the learning management system of a QTOM

partner

Title	Student Seminar Quantum Technology Open Master								
Number	13.21349								
Type	Seminar								
Semester Week Hours	2								
Offered in	Summer semester 2022								
Lecturer (Assistant)	Bluhm, Jörg Hendrik								
Organisation	Chair of Experimental Physics and Institute of Physics II (Contact information)								
Curriculum / ECTS Credits	► Compulsory subject: 0 Elective subject: 1								
Course description									
Content	Covers the breadth of the Quantum Technology Competence Framework: 1. Concepts of quantum physics 2. Physical foundations of quantum technologies 3. Enabling technologies 4. Hardware for quantum computers and sensors 5. Quantum computing and simulation 6. Quantum sensors and metrology 7. Quantum communication 8. Practical and soft skills								
Previous Knowledge Expected	Background in linear algebra, calculus, and quantum mechanics								
Objective (Expected Results of Study and Acquired Competences)	The students know the diverse topics covered in the field of Quantum Technology. The students gain thorough understanding of the foundations of quantum technologies, explore the emerging technologies including hardware for quantum computers and sensors, quantum communication, etc. to name a few. The students develop skills to think as an independent scientist by taking initiative to assemble their own program of study. The students are exposed to breadth of the Quantum Technology Competence Framework.								
Languages of Instruction	English								
Teaching and Learning Method (Transfer of Skills)	2-hour zoom seminars, each associated with:								
Workload for Students	-Pre-reading of roughly 2 hours -Exercise material of up to 4 hours -A topic area for extended projects (10-30hours) Students wishing to study for ECTS register attendance and at the completion of the course in July they write a course synopsis based on pre-reading and attendance at seminars, and may optionally complete an extended project in one of the topic areas suggested by the seminar providers. These usually take the form of a literature review.								
Scheduled Dates	13.21349 Student Seminar Quantum Technology Open Master (2SWS SE, SS 2021/22)								
Group									
Day	Date	from	to	Place	Type of Class	Date Type	Comment	CD	
Standardgruppe									
Fri	25.03.2022	14:00	16:00	Online-Veranstaltung	regular class	confirmed	Weekly Zoom link: https://aarhusuniversity.zoom.us/j/68388190701		

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Abbreviations

QT, Quantum Technology; QTedu, Quantum Technology Education community; QTOM, QTedu Open Master; PAR, Participatory Action Research; ECTS, European Credit Transfer Service; TNE, Transnational Education.

Data availability

Not applicable. Data is composed of private communication and interview transcripts, which are subject to GDPR compliance.

Declarations

Competing interests

The authors declare no competing interests.

Author contributions

J.S. initiated and coordinated the QTOM pilot. S.G. designed and conducted the research and associated interviews, and managed the operation of the QTOM pilot. M.S. transcribed the interviews and assisted with data analysis. S.G. primarily wrote the paper, with additional contributions by M.S. All authors reviewed the manuscript.

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