European Commission

2^{nd} Survey of Schools:

ICT in Education

Objective 2:

Model for a 'highly equipped and connected classroom'

FINAL REPORT

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GLOSSARY

Country codes

AT	Austria	IT	Italy
BE	Belgium	LT	Lithuania
BG	Bulgaria	LU	Luxembourg
CZ	Czech Republic	LV	Latvia
CY	Cyprus	MT	Malta
DE	Germany	NL	Netherlands
DK	Denmark	NO	Norway
EE	Estonia	PL	Poland
EL	Greece	PT	Portugal
ES	Spain	RO	Romania
FI	Finland	SE	Sweden
FR	France	SI	Slovenia
HR	Croatia	SK	Slovakia
HU	Hungary	TR	Turkey
IE	Ireland	UK	United Kingdom
IS	Iceland		

Abbreviations used

AT	Assistive technologies
BYOD	Bring your own device
CATVs	Cable TV systems
CEF	Connecting Europe facility
CPD	Continuing professional development
DigCompOrg	Digitally competent educational organisations
DigComp	Digital competence framework
DG CONNECT	Directorate General for Communications Networks, Content & Technology
DG EAC	Directorate General for Education, Youth, Sport and Culture
DOCSIS	Data over cable service interface specification
FTTC	Fibre to cabinet
HECC	Highly equipped and connected classrooms
ICT	Information and communications technology
LAN	High-speed local-area network
OTPC	One tablet per child
OER	Open educational resources
MOOCs	Massive open online courses
PCTs	Price comparison tools
WAN	High-speed district wide-area network
WLAN	High-speed wireless local-area network
SELFIE	Self-reflection tool for digitally capable schools
SITES	Second information technology in education study
VA	Voice assistant
VLEs	Virtual learning environments
VLMs	Virtual learning management system
VR	Virtual reality

Abstract

The **second objective** of the '2nd Survey of Schools: ICT in Education' designs a **conceptual model** for a **'highly equipped and connected classroom'** (HECC), defines three scenarios of a HECC and estimates the **costs** to equip and connect an average EU classroom with advanced components of the HECC model. The **entry level scenario** outlines the **minimum and essential** components of a HECC. The **advanced scenario** further advances the entry level scenario, e.g. by entailing more advanced digital equipment, as well as a greater number of teachers' professional development activities and access to paid-for contents. The **cutting-edge level** is a further advanced scenario in relation to network requirements, it also includes a greater variety of digital equipment and increased opportunities for face-to-face professional development for teachers, and leadership training.

The results show that the **average cost** per student per year to equip and **connect an average EU classroom** with advanced components of the HECC model is in the range of **224-536 EUR**. This cost range includes costs for digital technology equipment, network requirements, professional development of teachers and for access to content. Costs for setting up the physical infrastructure in terms of high-capacity networks is not included.

Résumé

Le **second objectif de la 2e Enquête sur les Technologies d'Information et de Communication (TIC) à l'école**: les TIC et l'éducation vise à définir **un modèle conceptuel de « classe hautement équipée et connectée »** (CHEC), définissant trois scénarios de CHEC et estimant les coûts pour équiper et connecter une classe moyenne de l'UE avec les **composantes avancées du modèle CHEC**. Le **scénario basique** décrit les **composantes minimales** et essentielles d'une CHEC. Le scénario avancé est une évolution du scénario de base intégrant par exemple du **matériel informatique plus avancé** ainsi qu'un plus grand nombre d'activités de développement professionnel pour les enseignants et un accès plus large à des contenus payants. Le **scénario de pointe** est encore plus perfectionné concernant les exigences de réseau, y compris une **plus grande diversité de matériel informatique et davantage d'opportunités** pour les enseignants en termes de développement professionnel et de formation à l'exercice de responsabilités.

Les résultats montrent que le coût moyen par élève pour équiper et connecter une classe moyenne de l'UE avec les **composantes avancées du modèle CHEC** est de l'ordre de **224-536 EUR**. Cette estimation inclut les **coûts du matériel digital, des exigences réseau,** du **développement professionnel des enseignants** et de **l'accès aux contenus payants**. Les coûts de mise à niveau des infrastructures de réseau en dehors des locaux de l'école ne sont pas inclus.

Summary of results and policy recommendations

The current report follows the **Digital Education Action Plan's** call to provide more data and evidence regarding digitisation in education and digital technologies in learning. The Digital Education Action Plan was adopted in January 2018 and set out how education and training systems can make better use of innovation and digital technology and support the development of relevant digital competences needed for life and work in an age of rapid digital change (European Commission, 2018)[1].

The **2nd Survey of Schools: ICT in Education** has two objectives:

1) **Objective 1: Benchmark progress in ICT in schools -** to provide detailed and up-to-date information related to access, use and attitudes towards the use of technology in education by surveying head teachers, teachers, students and parents covering the EU28, Norway, Iceland and Turkey;

2) **Objective 2: Model for a 'highly equipped and connected classroom' -** to define a conceptual model for a 'highly equipped and connected classroom' (HECC), presenting three scenarios to describe different levels of a HECC and to estimate the overall costs to equip and connect an average EU classroom with advanced components of the HECC model.

Two separate reports are published concurrently, focusing on each of the two study objectives of the '2nd Survey of Schools: ICT in Education'. The current publication refers to the **second objective** of the study, to develop a **model for a 'highly equipped and connected classroom'**. The findings on the **first study objective** ('ICT in Education: Benchmarking progress in ICT in schools') are reported in the separate publication[2].

The report is structured around the following tasks:

- Design of the conceptual model for a 'highly equipped and connected classroom' (HECC),

- Definition of three scenarios assessing what constitutes an entry level, an advanced and a cutting-edge level scenario of a HECC, and

- Estimation of the costs to equip and connect an average EU classroom with advanced components of the HECC.

Design of the conceptual model

The HECC model builds upon and complements other frameworks concerning the use of digitial technologies in education. More precisely, the HECC conceptual model of this study is based on four dimensions, covering:

- **Digital technology equipment** referring to a large number of technologies that are used in educational settings for learning and teaching purposes including both physical technologies (i.e. hardware) and educational software and services,

- **Network requirements** covering bandwidth and latency of the network providing the foundation for successful education technology implementations,

- **Professional development of teachers** referring to the teachers' continuing professional development (CPD) which focuses on teachers' capacity building for the effective use of digital technologies in teaching, learning and assessment

[1] European Commission. (2018a). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the Digital Education Action Plan. COM(2018) 22.

[2] European Commission (2019). 2nd Survey of Schools: ICT in Education – Objective 1: Benchmark progress in ICT in schools. Luxembourg: European Commission. doi: 10.2759/23401.

practices, through rapid learning cycles, fast feedback, continual reflection, collaborative coaching and other methodologies and

- **Access to digital content** reflecting the curricular requirements (i.e. different level of complexity, accuracy, correctness, authenticity, life connections, inter-disciplinary) necessary to ensure digital content's greater incorporation into the classroom and use by teachers and students.

These four dimensions are commonly outlined by numerous other studies. Moreover, the adopted HECC model also complements the European Framework for Digitally Competent Educational Organisations (**DigCompOrg**) which provides a comprehensive and generic conceptual framework that reflects on all aspects of the process of systematically integrating digital learning in educational organisations from all education sectors.

Based on desk research of existing sources, a set of categories, sub-categories and items for each of these four dimensions is proposed. These categories, sub-categories and items were discussed during stakeholder consultations with experts in the field and serve as the basis for the estimation of the average total costs to equip an average EU classroom with advanced components of the HECC.

Three scenarios were identified to describe different levels of a HECC: (i) an **entry level**; (ii) an **advanced level**; and (iii) a **cutting-edge level**. The proposed scenarios provide a general reference framework allowing the subsequent estimation of costs for the advanced level.

The developed HECC model is a **progressive model**, which implies that one school might start off with the entry level scenario in order to equip and connect a classroom, then progress to the advanced scenario and finally upgrade the classroom to the cutting-edge level scenario in order to exploit the opportunities provided by digital teaching and learning to the fullest extent. In turn, other schools could start off already with the advanced level scenario as an entry point and then eventually upgrade their classrooms to the cutting-edge level.

Opting for the most advanced cutting-edge level of a HECC might not always be feasible due to different **budget considerations** as well as **individual pedagogical and technical requirements**. As such, schools often need to trade-off between different decision criteria, including affordability, requirements and benefits that a digital classroom yields. Given that identifying different levels of a HECC is an under-studied area in the available literature, the developed scenarios aim at supporting schools in implementing one level of a HECC depending on individual needs and requirements. Thus, the three different levels represent a **continuum** of what a HECC could entail, with **multiple conceivable scenarios in between the three levels**.

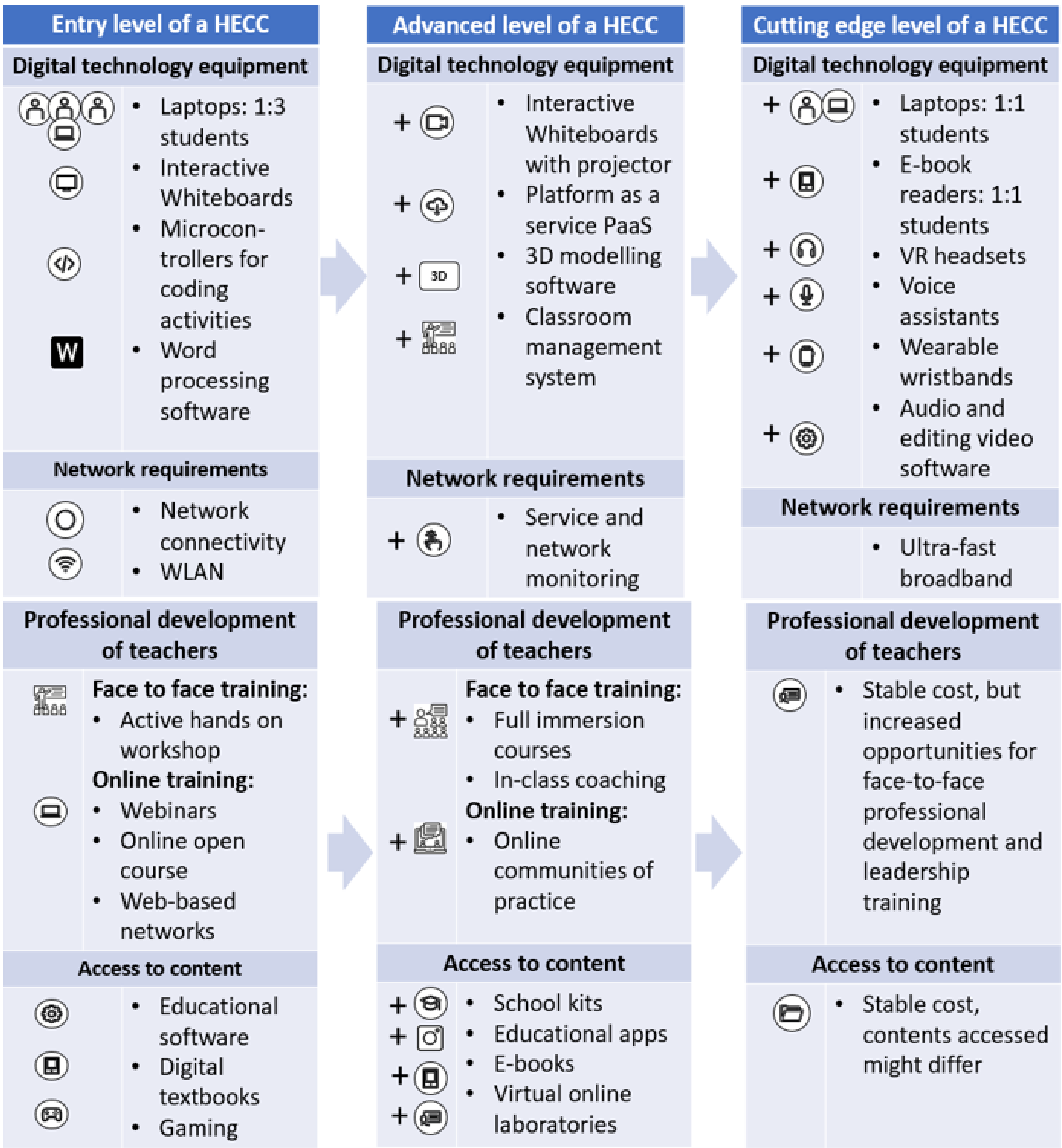
In particular, a **top-down approach** was deployed to define the three levels of a HECC. As a first step, the items that form the cutting-edge HECC scenario were determined, given that the largest evidence base, in terms of available case studies and previous research, is available to describe the ultimate categories, sub-categories and items that a cutting-edge level of a HECC would need to fulfil.

The **entry level scenario** of a HECC mainly outlines the **minimum and essential** components of a highly equipped and connected classroom. It contains essential digital technology equipment, including a limited number of components related to teachers' professional development and access to digital contents, as well as minimum network requirements needed for a functioning HECC.

The **advanced scenario** of a HECC, in turn, builds upon and **further advances** the entry level scenario, while paving the way to the cutting-edge level scenario. Differently from the entry-level, the advanced scenario entails more advanced digital equipment (e.g. 3D printers and modelling software, interactive tables), as well as a greater number of teachers' professional development activities (e.g. full immersion courses, in-class-coaching) and access to paid-for contents (e.g. makers kits, educational apps, virtual laboratories).

Finally, the **cutting-edge level scenario** of a HECC involves the ultimate categories, sub-categories and items of a highly equipped and connected classroom. This scenario further advances categories, sub-categories and items in the advanced scenario, particularly in relation to broadband connectivity (e.g. ultra-fast broadband, Virtual Private Network), a greater variety of digital equipment available to teachers and students (e.g. e-books, wristbands, audio and video software), increased opportunities for face-to-face professional development for teachers (e.g. twilight training sections, mentored action research) and leadership training.

The figure below gives a brief overview of the content of the various HECC levels across the four dimensions. Please note that the advanced level also contains the elements of the entry level and accordingly the cutting-edge level contains the elements of both advanced and entry levels.



The application of the HECC model for primary education

The three above-mentioned HECC scenarios have been built and defined based on the assumption of a classroom part of **ISCED 2** (lower secondary) education level. The distinction between primary and secondary schools varies significantly between EU Member States. In several countries in Europe (e.g. Nordic countries, Croatia, Czech Republic, Hungary, Poland), a 'single structure education' is in place and primary and lower secondary education are integrated. This integration is also reflected in the curriculum. In addition, across Europe (e.g. Italy, Spain, etc.), a school institution often includes (even in the same building or campus) primary and lower secondary levels (i.e. ISCED 1 and 2). As a consequence, the integration of primary and secondary education levels strongly impacts on the HECC four dimensions, in particular for those HECC items that apply at school (rather than a classroom) level (e.g. 3D printer, broadband connectivity, etc.). However, based on evidence from the literature and inspired by existing experiences (e.g. Future Classroom Lab), the three HECC scenarios previously described (referred to ISCED level 2) embed features that can be extended and applied across both primary (ISCED 1) and secondary education level (ISCED 2 and 3). In particular, main conditions related to dimension 1 (digital technology equipment), dimension 2 (network requirements) and dimension 3 (professional development of teachers) are common among primary and secondary education, while main differences apply in dimension 4 concerning the type of contents accessed and used by teachers and students in primary and secondary levels.

Estimation of the costs to equip and connect an average EU classroom with advanced components of the HECC

The ultimate goal of this report is to estimate the **costs for equipping and connecting an average EU classroom with advanced components of the HECC model**. The cost estimation is based on a combination of desk research, market data collection as well as stakeholder consultation with national Ministries and experts.

The results show that the **average cost per student per year** to equip and connect an average EU classroom at ISCED level 2 with advanced components of the HECC model is in the range of **224 EUR – 536 EUR**. This cost range includes costs for digital technology equipment (91 EUR – 150 EUR per student per year), network requirements (48 – 226 EUR per student per year), professional development of teachers (55 EUR – 110 EUR per student per year) and costs for access to content (30 EUR – 50 EUR per student per year). It is important to note that setting up the physical infrastructure in terms of high-capacity networks (e.g. fibre networks) is not included in this overall figure.

The cost estimation has been performed by taking the assumption that students were supplied with devices by their schools, usually at not cost to the learners or their families. One alternative model which is growing interest in, but which is not detailed in this report, is the Bring-Your-Own-Device (**BYOD**) **policy / strategy** which relies on the prevalence of learner-owned devices and where students use the mobile devices they already own. The decision to introduce BYOD to schools in Europe is overall mainly driven by a combination of social, economic, educational and technological factors which vary strongly from country to country and according to the particular contexts in which individual schools operate.

Overall, the present calculation should only serve as an orientation to the approximate costs arising from equipping schools with a HECC, but would always need to be adapted to local conditions and needs of a specific school. Moreover, this cost approximation only represents an EU average and does not consider differences in price across countries.

Key role of the EU for fostering highly equipped and connected classrooms

Even though responsibility for education lies with Member States, the European Union has an important role to play in scaling up innovation in EU Member States' education systems. Consequently, the European Commission adopted the **Digital Education Action Plan** in January 2018 (European Commission, 2018) and is currently following up on the 11 actions included in the Action Plan which are structured in three priority themes, including (1) making better **use** of **digital technology** for teaching and learning; (2) developing the

digital competences and skills needed for living and working in an age of digital transformation; and (3) improving education through **better data analysis and foresight**.

There are also several **EU funding programs** available for digital education projects in the current multifinancial annual framework running from 2014 to 2020 which complement national efforts (such as Erasmus+, European Social Funds, European Regional Development Fund, Horizon 2020, Wifi4EU through CEF, etc.). For instance, education and training is one of the eleven priorities for cohesion policy in 2014-2020 ("thematic objective 10").

There is a clear need for digital education to be further supported by the **new Multiannual Financial Framework** (2021-2027) in addition to national and regional investments as well as cooperations between private and public stakeholders. The high cost estimates reported in the study provide a clear signal to funding programmes such as the **European Social Fund** (ESF) and the **European Regional Development Fund** (ERDF) to continue supporting activities which help to modernise education and training systems, including investments in educational infrastructure. The new proposed **Research and Innovation programme** (Horizon Europe) will play a crucial role in spurring new innovation in education and also scaling up innovation activities to facilitate market entry and diffusion of innovations through large-scale piloting.

Erasmus+ including the many successfully established tools for exchanging **best practices** and **peer learning** (e.g. through tools as eTwinning, School Education Gateway, Teacher Academy, SELFIE) will need to be further scaled up to facilitate **teachers' professional development**.

The cost estimation also shows that particularly costs for **network requirements** form a significant part of the overall cost figure. Costs for setting up the physical infrastructure in terms of high-capacity networks (e.g. fibre networks) (which have not been considered in the cost estimation of this study) will have to be born on top of those reported costs. In this respect, as part of the next long-term EU budget, the European Commission proposed to renew the **Connecting Europe Facility** (CEF). The future Connected Europe Facility Programme aims to support access to Gigabit connectivity for socio-economic drivers including schools with a view to maximising their positive spill-over effects on the wider economy and society.

Moreover, the proposed **Digital Europe Programme** has been designed to support the digital transformation of the public sector and of areas of public interest by improving their digital capacities. For Digital Education, this opens up opportunities for supporting the deployment of digital capacities in schools (i.e. equipment, technologies, digital content) as well as innovative and effective teaching and learning practices at European level that have already been proven successful in smaller scale pilots.

Finally, investing in high-quality education pays long-term dividends for the European economy and for the overall prosperity of European societies. Innovation in education systems have a great potential to significantly improve learning outcomes, enhance equity and improve efficiency. Given the high overall costs to equip and connect an average EU classroom with advanced components of the HECC model, the **European Union**, **Member States**, **regions** and **municipalities** as well as **industry** and **civil society organisations** must make a concerted and coordinated effort to allow the European education sector to stay ahead of technological change.

1. Introduction and background

Digital education bears a great potential to significantly improve learning outcomes, enhance equity and improve efficiency. Digital education is most effective and sustainable when supported by the right pedagogical devices (e.g. computers, tablets, etc.), as well as embraced by teachers and embedded in clear teaching goals and sound pedagogies. Introducing new technology (hardware and software) into classrooms in the EU is not inexpensive and it is not always easy to install, use, repair, maintain, and upgrade. Moreover, teachers must be trained, motivated and engaged on how to use any new equipment and solutions that are introduced into the classroom. In addition, schools must have a robust Internet connection allowing uploading, for instance, high-definition multimedia content, to participate in an online video conference or to curate an electronic portfolio of learning, to name just a few examples. Finally, it is essential for classrooms having access to quality content including online adaptive learning paths, to stream or download video lecture sets and Open Educational Resources (OER), to name a few examples[3]. For a 21st Century digital classroom to operate at a reasonable level, all four elements (digital technology equipment, network requirements, professional development of teachers and access to content) must be addressed. This report therefore presents the deployed approach to define a conceptual model for a 'highly equipped and connected classroom' (HECC) encompassing the four above mentioned elements. In addition to that, the report will present three scenarios to describe different levels of a HECC, defined as (i) an entry level; an (ii) an advanced; and (iii) a cutting-edge level of a HECC. The following table shows all tasks and activities per task performed as part of defining a model for a 'highly equipped and connected classroom'.

Table 1: Tasks and activities per task performed as part of defining a model for a 'highly equipped and connected classroom'

Section	Task	Activities per task
1.1	**Task 1 – Design of the conceptual design model**	• Structuring of the conceptual design model consisting of four dimensions (1: digital technology equipment; 2: network requirements; 3: professional development of teachers; 4: access to content) • Definition of categories, sub-categories and items within each of the four dimensions
1.2	**Task 2 – Definition of three scenarios assessing what constitutes an entry level, an advanced and a cutting-edge level scenario of a HECC**	• Description of three different levels of a 'highly equipped and connected classroom' (HECC), including (i) an entry level scenario; (ii) an advanced level scenario and (iii) a cutting-edge level scenario along the list of items compiled in Task 1
1.3	**Task 3 – Estimation of the costs to equip and connect an average EU classroom with advanced components of the HECC model**	• Estimation of the costs to equip and connect an average EU classroom with advanced components of the HECC model through the identification of national and regional digital education initiatives and investment projects through (i) desk research, (ii) market data collection (price collection), (iii) stakeholder consultations with national Ministries and (iv) stakeholder consultations with a network of experts • Integration of the identified costs in a price collection matrix to calculate the average estimated cost for an average EU classroom with advanced components of the HECC model

[3] SETDA (2015), Højsholt-Poulsen, L. (2015), ASCD & OverDrive (2016). Please note that the full citations of the publications and reports mentioned in footnotes are reported at the end of the study in Annex 4 (Bibliography).

Task 1 – Design of the conceptual model for a 'highly equipped and connected classroom'

Box 1: Highlights Task 1

- The 'highly equipped and connected classroom' (HECC) conceptual model is aimed at providing a reference point for estimating costs of a 21st century digital classroom.
- The conceptual model of a HECC consists of four dimensions including (i) digital technology equipment; (ii) network requirements; (iii) professional development of teachers; and (iv) access to content.
- Based on desk research of existing sources, a set of categories, sub-categories and items for each of these four dimensions is proposed. These categories, sub-categories and items were discussed during stakeholder consultations with experts in the field and serve as the basis for the estimation of the average total costs to equip an average **EU classroom with advanced components of the HECC**.

1.1 Structuring of the conceptual model consisting of four dimensions

The main aim of this task is to design a conceptual model to enable the estimation of the costs to equip and connect an average EU classroom with advanced components of a **'highly equipped and connected classroom' (HECC)**.

Within the context of this study, a HECC is defined as being a:

- **Highly equipped** (i.e. refers to current and emerging technology equipment and digital content, as well as teachers' skills and confidence to effectively use technology and digital content for learning in delivering innovative pedagogies and supporting a variety of learning activities), and
- **Connected** (i.e. refers to the availability of necessary online connectivity including broadband access and WiFi connection that offers students and teaching staff the possibility to exploit the many benefits of being connected to fibre Internet, including having access to a variety of learning resources or interacting and exchanging with the outside world, to name a few examples)
- **Classroom** (i.e. refers to a learning space/room where classes are conducted).

Thus, a **highly equipped and connected classroom** does not only require a robust fibre Internet connection as well as access to digital technology equipment and digital content, but must also be embraced by digitally skilled teachers that are granted access to educational digital content.

The current report follows the **Digital Education Action Plan**'s call to provide more data and evidence regarding digitisation in education and digital technologies in learning. The Digital Education Action Plan was adopted in January 2018 and set out how education and training systems can make better use of innovation and digital technology and support the development of relevant digital competences needed for life and work in an age of rapid digital change (European Commission, 2018a). The Action Plan followed the Communication 'Strengthening European Identity through Education and Culture', the Commission's contribution to the EU Leader's Agenda discussion on education and culture at the Gothenburg Summit, which set out a vision for a European Education Area (European Commission, 2017). The Action Plan also followed the October 2017 European Council's call for training and education systems to be 'fit for the digital age' (European Council, 2017) as well as the Rome Declaration of March 2017 to provide young people with the 'best education and training' (Council of the EU, 2017). Moreover, the G-20 Digital Economy Ministerial Declaration in 2017 also shows a global recognition that 'all forms of education and lifelong learning may need to be adjusted to take advantage of new digital technologies' (Federal Ministry for Economic Affairs and Energy, 2017).

More specifically, the following political initiatives by the European Commission were considered as points of reference for building the HECC model:

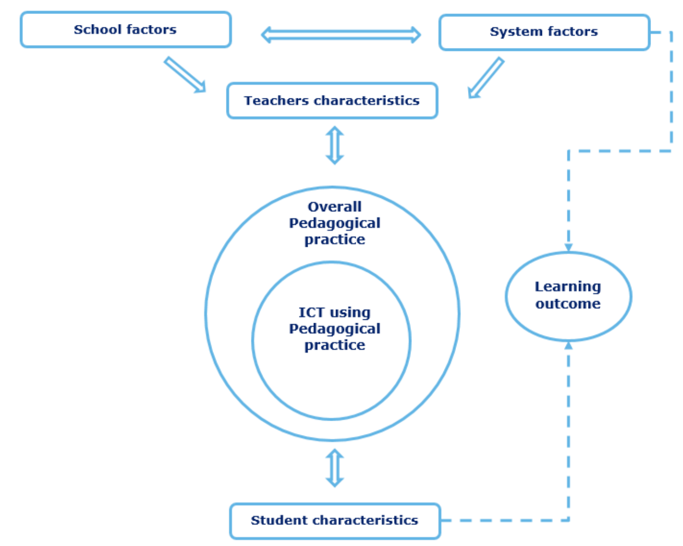
- **Communication on the Digital Education Action Plan (2018)[4]:** This Communication was adopted on the 17th of January 2018 and sets out 11 specific actions to help EU Member States to modernise their education systems by: 1) making better use of digital technology for teaching and learning; 2) developing relevant digital competences and skills for the digital transformation; and 3) improving education through better data analysis and foresight;
- **Communication on Strengthening European Identity through Education and Culture (2017)[5]:** In this Communication, intended as a contribution to the EU Leaders' meeting taking place in Gothenburg (Sweden) on 17 November 2017, the Commission highlighted that it is in the shared interest of all Member States to harness the full potential of education and culture as drivers for job creation, economic growth and social fairness as well as a means to experience European identity in all its diversity;
- **Communication on improving and modernising education (2016)[6]:** This Communication was adopted on the 6th of December 2016 whereby the Commission set out its vision for ensuring a high quality education for all. The Communication emphasises the strategic importance of education in the EU whereby the Commission recognises the achievements and progress made in education and training systems across the EU in recent years;
- **Communication on Opening Up Education: Innovative teaching and learning for all through new technologies and open educational resources (2013a)[7]:** This Communication set out a European agenda for stimulating high-quality, innovative ways of learning and teaching through new technologies and digital content. The Communication proposed actions at EU and national levels, notably helping learning institutions, teachers and learners to acquire digital skills and learning methods, supporting development and availability of open educational resources, connecting classrooms and deploying digital devices and content and mobilising all stakeholders to change the role of digital technologies at education institutions;
- **Communication on Rethinking Education (2012)[8]:** This Communication was set up in 2012 to reform education systems across the EU so as to meet growing demand for higher skills levels and reduce unemployment. The initiative focused on three areas in need of reform, including quality, accessibility and funding, in order to raise basic skill levels, promote apprenticeships, promote entrepreneurial skills and improve foreign language skills.

In addition to that, the HECC model builds upon and complements other frameworks concerning the use of digitial technologies in education. More precisely, the HECC conceptual model of this study is based on **four dimensions**, covering digital technology equipment, network requirements, professional development of teachers and access to digital content. The dimensions used for the HECC model are commonly outlined by numerous other studies, such as by the Second Information Technology in Education Study (SITES)[9] published by the international association for the evaluation of educational achievement (IEA) in 2006. The SITES study was one of the first studies to present a framework for the integration of digital technologies in education. The proposed framework (see Figure 1) considered that ICT-using pedagogical practices are part of the overall

[4] European Commission (2018a)
[5] European Commission (2017b)
[6] European Commission (2016c)
[7] European Commission (2013a)
[8] European Commission (2012)
[9] Carstens, R., & J. Pelgrum, W. (2006)

pedagogical pratices of the teacher. Hence, the framework highlighted the role of the teacher as the link between school and system factors, and aligned pedagogical practices.

Figure 1 : SITES conceptual framework



Source: SITES (2006)

Moreover, the adopted HECC model also complements the European Framework for Digitally-Competent Educational Organisations (DigCompOrg) (European Commission, 2015a). DigCompOrg provides a comprehensive and generic conceptual framework that reflects on all aspects of the process of systematically integrating digital learning in educational organisations from all education sectors. The framework has seven thematic elements and fifteen sub-elements that are common to all education sectors. Each of these seven elements reflects a different aspect of the complex process of integrating and effectively using digital learning technologies. All the elements are interconnected and interrelated. The seven elements include:

- Leadership and governance practices
- Teaching and learning practices
- Professional development of teachers
- Assessment practices
- Content and curricula
- Collaboration and networking
- Infrastructure

Furthermore, the HECC model also has a complementary perspective with regard to the Self-reflection tool for digitally capable schools (SELFIE) tool[10]. SELFIE poses questions to school leaders, teachers and students. Based on this feedback, it provides the SELFIE School Report which is a snapshot of a school's strengths and weaknesses with regard to their use of digital technologies for teaching and learning. The SELFIE School Report can subsequently be used for a dialogue within the school community, to create an action plan to improve the use of digital technologies for better learning and teaching and benchmark progress made over time.

To understand possible complimentary aspects between the HECC model and the DigCompOrg framework and SELFIE, Table 2 provides further details regarding the nature, focus, scope and target of the specific models.

[10] European Commission (2018b)

Table 2: Comparison between DigCompOrg/SELFIE and the HECC model		
	DigCompOrg/SELFIE	**HECC**
Nature	DigCompOrg refers to a comprehensive and generic conceptual framework that reflects all the aspects of the process of systematically integrating digital learning in educational organisations from all education sectors[11]. SELFIE is based on the Digitally-Competent Educational Organisations (DigCompOrg) conceptual framework and, therefore, reflects the nature of the DigCompOrg.	HECC refers to a reference framework aiming to provide the basis for estimating costs to equip and connect an average EU classroom with advanced components of the HECC model.
Focus	DigCompOrg and SELFIE focus on learning activities rather than on technology. As such, both models consider school strategies, teaching, learning and assessment practices, use of infrastructure, curricula and student experience[12].	The HECC model mainly focuses on digital infrastructure dimensions including digital technology, network requirements and access to digital contents. Nevertheless, given the crucial role of teachers to embrace new innovations including digital technology, the HECC model also takes into account teachers' professional development.
Scope	The primary purposes of DigCompOrg are: (i) to encourage self-reflection and self-assessment within educational organisations and (ii) to enable policy makers to design, implement and appraise programmes, projects and policy interventions for the integration of digital learning technologies in Education & Technology (E&T) systems. The SELFIE tool aims to provide a snapshot of schools strengths and weaknesses in their **use of digital technologies for learning.**	The purpose of the HECC model is to **enable a cost estimation** for a 'highly equipped and connected classroom'.
Target	School level (i.e. school community including school leaders, teachers and students)	Classroom level

As can be seen from Table 2, DigCompOrg and SELFIE follow a more holistic and systemic approach than the HECC model which focuses more clearly on digital infrastructure aspects (particularly on digital technology equipment and network requirements), but also takes into account teachers' professional development and access to digital content.

Although differing in terms of scope and targets of the models followed, the HECC model integrates three out of the seven elements of the DigCompOrg Framework (i.e. infrastructure, professional development and content) which are also included in SELFIE.

[11] European Commission (2017c)
[12] European Commission (2018b)

The HECC model also further integrates results from publications either endorsed by the U.N. such as 'Transforming Education: The Power of ICT Policies'[13] and other studies edited in collaboration with the European Commission's Directorate General for Education and Culture (EC DG EAC), such as the NMC 2014 school edition[14] and the EU kids' online report.

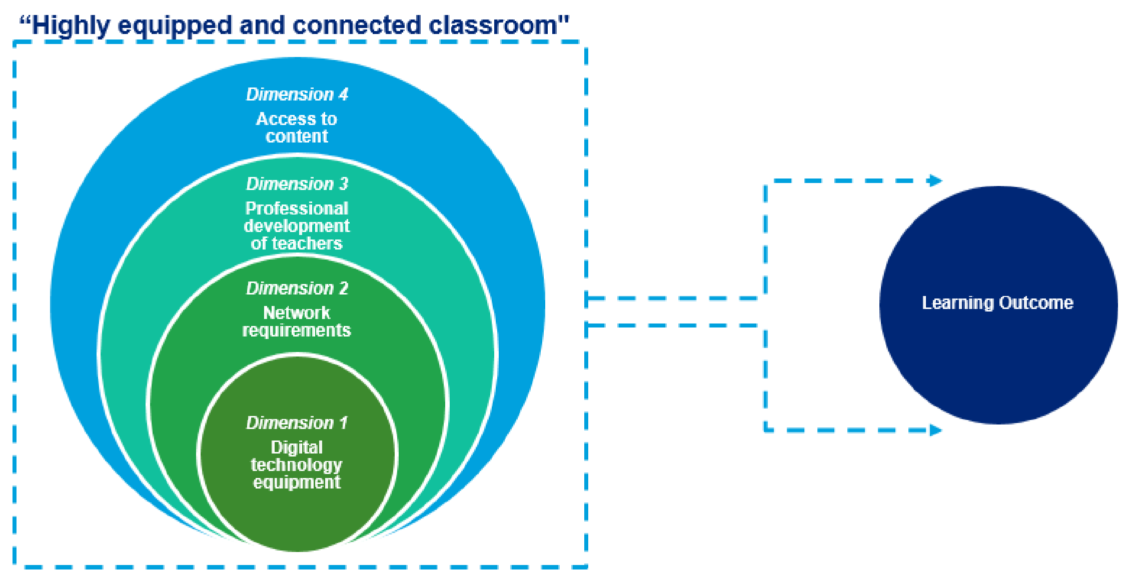
In addition, the research team consulted experts in the study area with regard to those topics for which the evidences from academic literature and publications were not sufficient. Further details about these experts' consultations are provided below in the text.

1.2 Definition of the four dimensions of the conceptual model

The dimensions of the model of a 'highly equipped and connected classroom' include the following (see Figure 2):

I. **Digital technology equipment;**
II. **Network requirements;**
III. **Professional development of teachers; and**
IV. **Access to content.**

Figure 2: Conceptual model framework



1.2.1 Dimension 1 – Digital technology equipment

Digital technology is defined as an umbrella term that refers to a large number of technologies that are used in educational settings for learning and teaching purposes. This dimension includes both physical technologies (i.e. hardware) and educational software and services. In terms of software and services, the dimension covers applications supporting a variety of activities (e.g. tracking of pupil activities, attendance and grades) and specific learning activities (e.g. learning by creating). Items part of the software include word processing software, spreadsheet systems, 3D modelling software licenses including both paid software and free alternatives, to name a few examples. This dimension also covers assistive technologies for students with special needs. Hence, 'digital

[13] UNESCO (2016)
[14] Johnson, L., Adams Becker, S., Estrada, V., Freeman, A., Kampylis, P., Vuorikari, R., & Punie, Y. (2014)

technology equipment' is a very broad dimension that encompasses many different categories of items.

In terms of structuring the different items, the study identified the following categories:

- Portable devices
- Fixed devices
- Interactive systems and devices
- Emerging technologies
- Cloud-based platforms and services
- Virtual learning environments (VLEs)
- Software and services

Rollout models like Bring Your Own Device (BYOD) policy will be discussed in Annex 3. Other possible aspects linked to this dimension (e.g. reconfigurable furniture) and impacting the costs model (e.g. funding strategies like leasing, cooperative purchase, etc.) are not discussed as they fall beyond the scope of the study and would render the approach of the study too complex.

1.2.2 Dimension 2 – Network requirements

The second dimension refers to network requirements covering bandwidth and latency requirements across different types of:

- Network connectivity
- High-speed district wide-area network (WAN)
- High-speed local-area network (LAN)
- High-speed wireless local-area network (WLAN)

A solid network infrastructure lays the foundation for successful education technology implementations. Broadband generally refers to fibre Internet access that is always on and faster than traditional dial-up access. Broadband provides higher-speed data transmission, as it allows more content to be carried through the 'pipe'[15]. Ideally, the broadband infrastructure should allow to provide a similar download and upload speed considering both speeds are optimally tested when these are symmetrical[16].

Generally, the structure of school networks varies considerably dependent upon many factors such as how recently the infrastructure was first installed, the size of the school, nature of the location of the buildings, the extent to which computers and mobile devices are used, how much cloud computing is used, etc. In addition, the bandwidth of the connectivity (the data transfer rate) achievable via routers, gateways, switches, and access points in the school's network is dependent upon the protocol they use[17].

In the context of education, several studies report that a high-speed connectivity provision makes a noticeable impact and improvement on teaching and learning processes[18]. Moreover, Internet access to every classroom and instructional space is essential to enable students to engage in multiple digital learning experiences. In particular, the high-speed connection in schools should enable students to engage in rich digital learning experiences such as streaming videos, gaming and interactive services. The planning of an IT network, fit to deliver educational outcomes for an educational institution, imposes carefully defined requirements. Planning and providing infrastructure, both Internet connectivity and devices, should stem from a clear vision for how learning and teaching will be supported. This involves understanding a variety of technical options and requirements.

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[15] U.S. Department of Education, Office of Educational Technology (2014)
[16] Download speed is the rate at which data is transferred from the Internet to the user's computer. The upload speed is the rate that data is transferred from the user's computer to the Internet. An example of symmetrical Internet connection is fibre Internet.
[17] European Schoolnet (2017a)
[18] McCoy, S., Lyons, S., Coyne, B., & Darmody, M. (2016)

In addition to that, different digital learning activities need minimum Internet bandwidth adapted for schools. New technologies such as virtual reality require high-bandwidth Internet connectivity. For other applications, such as real time gaming, a higher speed of connectivity is also needed. Reports such as by the State Educational Technology Directors Association (SETDA) recommended schools to have a minimum of 1 Mbps per student ensuring a good connectivity[19].

The current study distinguishes between three types of network connectivity, explained below, building further on the definitions included in the 2017 Report of the European Commission on 'Europe's Digital Progress'[20] and the 2016 Commission's staff working document on the Connectivity for a Digital Single Market[21]. The communication reflects on 'Common EU broadband targets for 2025'. Particularly, in order to address future broadband needs, the Commission proposes that by 2025 all schools, transport hubs and main providers of public services as well as digitally intensive enterprises should have access to Internet connections with download/upload speeds of 1 Gbps[22]. In order to achieve the 2025 target of 1 Gbps in all EU schools, fibre connectivity is today the major technology that can allow meeting the speed required. However, as it has been highlighted in the 2017 'Broadband for School[23]' report, access to fibre is not universal, and schools without fibre, mostly of them located in more remote areas, are most at risk of being left behind without the connectivity they need for quality digital learning. Therefore, satellite services can provide a solution to serve schools located in unserved or underserved areas, while waiting for a potential deployment of fibre connectivity, which may take several years. Already today, satellite connection can allow schools to reach a download speed up to 30-50 Mbps[24]. The new generations of low-Earth orbit satellite technologies may have the potential to allow also much higher bandwidth satellite Internet service in the future[25].

The three types of network connectivity distinguished in the study as well as the different digital learning activities[26] supported by each type of broadband are the following:

- **Basic connectivity network** based on a download speed lower than 30 Mbps[27]. Basic connectivity network is currently available to all in the EU, when considering all major technologies (xDsl, cable, fibre to the premises - FTTP, WiMAX, HSPA, LTE and Satellite). Examples of digital learning activities requiring 'basic connectivity network' include:
    - Browsing, social networks
    - Personal cloud
    - Gaming
    - E-learning (partially possible)
    - Etc.

- **Fast connectivity network** based on a download speed between 30 Mbps and 100 Mbps. Examples of digital learning activities requiring 'fast connectivity network' include:
    - Video streaming
    - Real time gaming
    - E-learning
    - Etc.

- **Ultra-fast connectivity network** based on a download speed faster than 100 Mbps. Internet access to every classroom and instructional space is essential to

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[19] U.S. Department of Education, Office of Educational Technology (2014)
[20] European Commission (2017d)
[21] European Commission (2016d)
[22] Idem
[23] European Commission (2017e)
[24] Idem
[25] Washington Post (2018)
[26] Idem
[27] Mbps is short for megabits per second (Megabits per second/Mbps: data transfer rate of 1,000,000 bits per second). A megabit is a data transfer rate of 1,000,000 bits per second.

enable students to engage in multiple digital learning experiences. Examples of digital learning activities requiring 'ultra-fast connectivity network':

- Cloud based office
- 3D collaboration
- Virtual reality
- Augmented reality
- Tactile Internet
- Etc.

Considering the limited learning activities allowed with basic connectivity network, the current study considers that the minimum Internet bandwitdth connectivity required for an entry-level 'highly equipped and connected classroom' is 30 Mbps[28]. Therefore, for the purpose of this study, only broadband technologies allowing to reach a download bandwidth faster than 30 Mbps (i.e. fast broadband and ultra-fast connectivity network) are taken into account.

1.2.3 Dimension 3 – Professional development of teachers

The third dimension of the HECC model is the professional development (PD) of teachers, as in line with the DigCompOrg Framework, which has been largely used for teachers' digital competence building. Such professional development refers to the teachers' continuing professional development (CPD) that focuses on teachers' capacity building for the effective use of digital technologies in teaching, learning and assessment practices, through rapid learning cycles, fast feedback, continual reflection, collaborative coaching and other methodologies.

In today's context, students and learners expect more personalisation, collaboration and better links between formal and informal learning, largely supported by digitally supported learning. However, when looking at this in practice, it appears from a 2016 UNESCO study on ICT indicators in education that schools and education systems are not yet ready to leverage on the potential of technology, considering the gaps that were noted in the digital skills of both teachers and students. In addition, the report showed that teachers and students have difficulties in locating high-quality digital learning resources from among a plethora of poor-quality ones, a lack of clarity on the learning goals, and insufficient pedagogical preparation for blending technology meaningfully into lessons and curricula[29].

Training for teachers in all areas of digital skills is a clear requirement for an effective adoption of digital technologies in classrooms. This also implies providing educators with professional learning opportunities on how to select and use (and, in the case of Open Educational Resources (OER), create and modify) digital instructional materials and integrate them into their classrooms. Hence, valuable professional learning opportunities address both technical and pedagogical knowledge and skills, nurturing teachers' (digital) competence rather than teaching how to use technologies only. Finally, PD needs to be designed on the basis of meeting teachers' individual needs as a priority. In this context, it is of uttermost importance that the school leadership supports this professional development. An inadequate support is considered as a factor undermining this development. Support for such a development can take on different forms, ranging from designating time for such opportunities to offering concrete financial or other incentives for participation.[30]

Within this dimension, the study identified the following categories:

- Face-to-face training
- Online training
- Hybrid training
- Leadership training

[28] U.S. Department of Education, Office of Educational Technology (2014)
[29] J.M. Momino, & J. Carrere (2016)
[30] OECD (2016c)

1.2.4 Dimension 4 – Access to content

The fourth dimension involves the access to quality digital contents including online adaptive learning paths, video lecture sets and Open Educational Resources (OER hereafter), to name a few examples[31].

The use of high-quality digital learning materials in classrooms creates vast opportunities for meaningful learning as well as for evaluation of the content's performance in the classroom (e.g. through feedback loops from educators), followed by timely improvement, adjustment and review before students encounter new materials.

Content elements included in this dimension reflect curricular requirements (i.e. different level of complexity, accuracy, correctness, authenticity, life connections, inter-disciplinary) necessary to ensure digital content's greater incorporation into the classroom and use by teachers and students. Schools may end up with a mixed-media approach where some content is purchased and some is OER.

Building a multi-level quality assurance system, providing incentives that encourage OER development, use and refinement, and promoting technological advances (e.g. digital data systems to more easily collect information from the field and track student progress) are not discussed as they fall beyond the scope of the study.

Within this dimension, the study identified the following categories:

- Paid for content
- Free and OER content
- Teachers' generated OER

1.3 Definition of categories, sub-categories and items within each of the four dimensions

While having defined the four dimensions of the study's model for a connected classroom, a list of **categories, sub-categories and items** is compiled as to understand what constitutes an effective HECC that allows teachers to implement and facilitate new and innovative pedagogies mediated by ICT. By 'innovative pedagogies mediated by ICT', we mean novel or changing practices of teaching, learning, and assessment enabled by technology[32]. The following three criteria underpinned the identified categories, sub-categories and items in each dimension:

- **Facilitating mobility** - i.e. devices allowing to be used in different places and settings, as well as accessing contents and services from different devices;
- **Enabling communication, collaboration and connectedness** - i.e. facilitating students and teachers working together physically and digitally, peer-to-peer collaboration and practice exchange; and
- **Boosting creativity and active learning** - i.e. digital equipment and software supporting a broad range of school activities (e.g. writing, coding, creating videos, etc.), as well as supporting teachers' confidence and digital competence.

Hence, the chosen categories, sub-categories and items prioritise educational objectives over technology per se and support students in the following:

- Active learning
- Knowledge construction
- Inquiry and exploration
- Remote communication/collaboration

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[31] SETDA (2015), Højsholt-Poulsen, L. (2015), ASCD and OverDrive (2016)
[32] Cambridge (2015), Sharples (2016), OECD (2016c)

- Data sharing
- Etc.

1.3.1 Research methodologies to define the categories, sub-categories and items per dimension

1.3.1.1 Desk research

Desk research was performed between September 2017 and November 2017. Several publications at global, EU and national level of the countries included in the scope of the study were consulted as to retain the categories, sub-categories and items per dimension.

The table below displays an overview of examples of academic publications, studies and reports which were consulted during the desk research.

Table 3: Non-exhaustive list of consulted literature

Literature type	Non-exhaustive list of consulted literature
JRC publications on ICT in Education	• Kampylis, P., Punie, Y., & Devine, J. (2015) • European Commission (2018)
Academia	• Cambridge International Examinations (2015) • Sentance, S., Humphreys, S., & Dorling, M. (2014) • Sentance, S., & Csizmadia, A. (2017) • Sentance, S., Dorling, M., McNicol, A., & Crick, T. (2012) • Fraser, C., Kennedy, A., Reid, L., & McKinney, S. (2007) • Breiter, A., Zeising, A., & Stolpmann, B. E. (2015) • Sandall, B. K. (2016)
Studies / reports	• Chesi, F., & Morelli, C. (2016) • ClassFlow (2016) • European Schoolnet (2016) • Microsoft UK schools (2012) • Future Ready Schools (2014) • Broadband Commission Working Group on Education (2017) • SETDA (2015) • OECD (2016a)
Review of data repositories and databases of publications, having access to studies in the area from the academia	• Google Scholar was used to find journal articles for ISI-listed publications, to bibliometric databases of academic publishing companies were accessed. • Web of Science • Scopus • ResearchGate • Academia

1.3.1.2 Stakeholder consultations

In order to fine-tune the list of categories, sub-categories and items, as well as to ensure their completeness and relevance, stakeholders were invited to participate to a stakeholder consultation. The consultation took place between November 2017 and December 2017.

A sample of stakeholders were identified and invited via e-mail to participate in a feedback session through phone.

In total, **five stakeholder consultation interviews** were conducted.

Table 4: Interviewed stakeholders

Organisation	Description of the organisation	Profile of the interviewed stakeholder	Provided feedback on dimension(s)

A. European Schoolnet[33]	Network of 31 European Ministries of Education	Former teacher, policy advisor and project leader involved in several initiatives on ICT in education	• Dimension 1 (Digital technology equipment) • Dimension 3 (Professional development of teachers)
B. INTEF[34] (Instituto Nacional de Tecnologías Educativas y de Formación del Profesorado)	Spanish national institute for educational technology and teachers' training	Former teacher and policy advisor in the field of ICT in education	• Dimension 3 (Professional development of teachers) • Dimension 4 (Access to content)
C. ELIG[35] (E-learning Industry group)	Open industry group with members representing the full value chain of services, products and solutions in support of knowledge and learning advancement	Senior manager and head of corporate affairs for a multinational technology company operating in the field of education	• Dimension 1 (Digital technology equipment) • Dimension 4 (Access to content)
D. Independent expert: Policy, Projects and Innovation	Independent expert in the field of educational policy development, implementation, innovation and evaluation at national and European levels	Professor, expert and advisor on educational policy development	• Dimension 3 (Professional development of teachers) • Dimension 4 (Access to content)
E. European Commission – (DG CONNECT – Communications Networks, Content & Technology)	The Directorate-General for Communications Networks, Content and Technology is the Commission department responsible to develop a digital single market[36] to generate smart, sustainable and inclusive growth in Europe	Senior policy office and expert on broadband infrastructure	• Dimension 2 (Network requirements)

1.3.2 List of categories, sub-categories and items of the HECC model

Based on the literature review and stakeholder interviews, the list of the **categories, sub-categories and items** per dimension of the model is proposed in the following tables as to understand what constitutes an effective HECC. Accordingly, **the HECC results from**

[33] European SchoolNet is the network of 31 European Ministries of Education, based in Brussels. As a not-for-profit organisation, it aims to bring innovation in teaching and learning to their key stakeholders: Ministries of Education, schools, teachers, researchers, and industry partners. More information: http://www.eun.org/about.
[34] INTEF is the National Agency for Educational Technology and Teacher Development funded by the Spanish Ministry of Education, Culture and Sport. The mission is to provide primary and secondary schools teachers with innovative resources and training opportunities to improve their competencies and acquire good practice skills, strategies and knowledge in all fields of education. More information: http://educalab.es/en/intef.
[35] Official website of ELIG (E-learning industry group) available at: https://www.elig.org/we-inspire/about/.
36 European Commission (2015b)

the combination of different items encompassing the four-interconnected dimensions.

Dimension 1 – Digital technology equipment

Table 5 : List of categories, sub-categories and items of Dimension 1 – Digital technology equipment

Category	Sub-category	Description	Items
Portable devices	Tablets & smartphones	· Mobile and tactile devices to use for all age groups and including excellent multimedia options. · Supported learning activities: viewing presentations and videos, educational apps, gameplay, creating multimedia contents (e.g. videos, audio, etc.), online learning, coding/programming, etc.	· Android tablets · iOS tablets · Smartphones · Windows tablets
	Laptops	· Devices running a full operating system (like Microsoft Windows, Apple OSX, Linux or Google Chrome) useful for specific and more complex tasks. · Supported learning activities: writing, numeracy, simulation, accessing to remote and virtual laboratories, coding/programming, etc.	· Convertible laptops · Laptops
	Other handheld devices	· Devices supporting mobile learning. · Supported learning activities: augmented reality, learning through social media, reading, etc.	· E-books readers
Fixed devices		· Devices designed for regular use at a single location or near a desk or table due to its size and requirements. These devices run a full operating system (like Microsoft Windows, Apple OSX or Linux) useful for specific and more complex tasks. · Supported learning activities: writing, numeracy, simulation, accessing to remote and virtual laboratories, coding/programming, etc.	· Desktop computers

Interactive systems and devices	· Tools facilitating whole-class and one-to-one methods, supporting group work and immersive learning · Supported learning activities: co-operative learning, presentations, simulation, peer-to-peer learning, interacting with learning contents, etc.	· Data projectors · Interactive tables with projector · Interactive Whiteboards (IWB)
Emerging technologies	· Tools supporting hands-on activities and creation · Supported learning activities: learning by doing, modelling, problem-solving, design thinking, immersive learning, simulation, etc.	· 3D printers · Microcontrollers for coding activities (i.e. Arduino, Raspberry Pi, etc.) · Virtual Reality (VR) headsets · Voice Assistants (e.g. Alexa, Siri, etc.) · Wearable wristbands
Cloud-based platforms and services	· Online platforms and services providing access to resources and data to computers and other devices on demand · Supported learning activities: leveraging digital learning materials and applications, supporting personalised and collaborative learning environments, etc.	· Platform as a Service (PaaS) · Software as a Service (SaaS)
Virtual Learning Environment (VLE)	· Online platforms allowing to share educational materials and communicate with learners via the web · Supported learning activities: online learning, blended learning, flipped classroom, project-based learning, personalized learning, and interactivity, etc.	· VLE (Virtual Learning Environment) platform

Software and services	Software and services[37]	· Applications supporting a variety of activities, such as: track of pupil activities, attendance and grades; collection and assessment of learner artefacts; creating digital contents; managing data; security services · Supported learning activities: Interacting with learning content, learning by creating, etc.	· 3D modelling software licences · Audio and video editing software licences · Classroom management system (e.g. Student Information Systems) · Data storage (e.g. Network attached storage) · Database management system · Identity management services · Presentation software (e.g. PowerPoint) · Spreadsheet software (e.g. Excel, Numbers) · Word processing software
	Assistive Technologies (AT) for students with special needs	· Software and services that help students with disability work around their challenges so they can learn, communicate or simply function better.	· Graphic organizers · Optical character recognition · Spell-checks and grammar checks · Speech-to-text tools · Text-to-speech tools

Dimension 2 – Network requirements

Table 6 : List of categories, sub-categories and items for Dimension 2 – Network requirements

Category	Sub-category	Description	Items
Network connectivity	Types of Internet:		· Infrastructure installation · Physical aspects of the network: electricity, cabling, access points, number of devices to connect · Service, maintenance and network monitoring · User help desk/technical
	1) Cable Internet / Internet over cable/ Vectoring over copper pairs	· Internet over cable (cable) is Internet provided via cable TV networks. Currently, cable can enable download speeds in excess of 300 Mbps, depending on local infrastructure.[38] · Data over cable service interface specification (DOCSIS) is an internationally recognized standard allowing high speed data transfer on existing cable TV systems (CATVSs) used by many cable operators to provide Internet access to their customers	

[37] The subcategory 'Software and services' does not include Assistive Technologies for people with special needs
[38] U.S. Department of Education, Office of Educational Technology (2014)

		through a cable modem. In 2016, DOCSIS 3.1 was released, bringing a massive leap in both up and downstream speeds. DOCSIS 3.1 allows to reach 10 Gbps for download speed and 1 Gbps for upload speed.[39] · Vectoring is an active technology that reduces crosstalk between signals travelling down nearby copper pairs. By reducing the noise, the performance of the copper is optimized towards the Shannon Limit to provide up to 100Mbps over 500 m.[40]	support · Upgrade of broadband infrastructure
	2) Fibre Internet / Internet over fibre	· Fibre-optic cable (fibre) consists of a thin cylinder of glass encased in a protective cover. It uses light rather than electrical pulses to transmit data. Each strand of the cable can pass a signal in only one direction, so fibre optic cable must have at least two strands: one for sending and one for receiving data. Unlike Data Over Cable Service, fibre-optic cables are not subject to interference, which greatly increases the transmission distance. Fibre speeds are currently limited by the abilities of the equipment on either end of the connection. Some fibre connections allow for speeds up to 100 Gbps.[41]	
	3) Fixed wireless	· Fixed wireless (sometimes called WiMAX) is an alternative to cable and can deliver data, Voice over Internet Protocol (VoIP), and Internet Protocol Television (IPTV). It requires erecting towers and installing wireless transmission/receiver platforms requiring a clear line of sight, to carry the signal from place to place. · WiMAX or Fixed wireless comes in two forms: mobile and fixed. While mobile connects buildings to user devices, fixed connects buildings together. · Fixed wireless can provide speeds up to 1 Gbps, is suitable for portable mobile broadband connectivity and cellular backbone.[42]	

[39]Technopedia, High Speed Expert (2017)
[40] Fibre to the Home, Council of Europe (2013)
[41] U.S. Department of Education, Office of Educational Technology (2014)
[42] U.S. Department of Education, Office of Educational Technology (2014)

	4) Mobile Internet	· Mobile broadband is wireless Internet access from cell towers via a mobile phone, tablet, or portable modem. Mobile broadband (also called 4G or LTE) can provide high-speed connection up to 50 Mbps (but can also go up to 1 Gbps for LTE advanced) for downloading and uploading over the same network infrastructure wireless carriers, which can partly fit in the 'ultra-fast broadband' type of broadband as identified for the study.[43]	
	5) Satellite Internet	· Satellite Internet can provide fixed, portable and mobile Internet access with data rates of up to 1 Gbps downloading and up to 10 Mbps uploading. Satellite Internet can partly fit in the 'ultra-fast broadband' type of broadband as identified for the study. Satellite broadband is also among the more expensive forms of wireless Internet access, but it can provide connectivity in the most remote areas where no other connectivity options exist.[44]	
High-speed district wide-area network (WAN)		· A Wide Area Network (WAN) provides the connection between the district office and all the schools and sites within a district. A WAN may also connect to other educational institutions (such as universities and libraries) if your district is part of a regional education network.[45]	
High-speed local-area network (LAN)		· A Local Area Network (LAN) is the network within a school or district building through which computers and devices connect to the Internet. LANs, in contrast to WANs, service much smaller geographic areas.	
High-speed wireless local-area network (WLAN)		· A WLAN (also known as WiFi or Wi-Fi) enables those using portable devices in a school to connect to the school computer network without needing a network cable. Typically, it is used to connect devices such as laptops, netbooks and tablet computers (including iPads), and other devices such as some phones and iPod devices. Desktop PCs can also have a wireless	

[43] U.S. Department of Education, Office of Educational Technology (2014)
[44] Idem
[45] Idem

	adapter added to them to enable connectivity to a WLAN.[46]	

Dimension 3 – Professional development of teachers

Table 7: List of categories, sub-categories and items for Dimension 3 – Professional development of teachers

Category	Sub-category	Description	Items
Face-to-face training	Courses and workshops	· Local, face-to-face training, conducted by experienced teachers as course leaders, promoting contextualized activities to effectively include digital technologies into teaching practices. · Training courses and workshop can take place both on-site (within the school premises) and off-site (outside the school premises).	· Active, hands on workshops (i.e. a show-case of practices, methods or digital technology uses) · Full-immersion courses · Twilight training sessions (i.e. interactive sessions combining lecture and highly practical activities)
	Coaching and peer support	· Teachers teaching and supporting other teachers, providing professional development integrated in a meaningful, concrete way that addresses specific issues teachers have in their own classroom. · Peer-group mentoring (PGM) · Coaching and peer support activities can take place both on-site (within the school premises) or off-site (outside the school premises).	· In-class coaching · Local hub meetings for groups of teachers
	Action research projects	· Teachers are presented with theoretical base (research ideas) and then invited /supported by researchers /experts to 'explore' how those ideas might be 'translated' into their classroom practice.	· Mentored action research

[46] European Schoolnet (2017)

Online training	Online courses	· By reaching many teachers at once, online professional development courses can introduce key concepts and ideas that are relevant to developing teachers' practice, discussing ideas and sharing experiences with peers, as well as providing access to course contents.	· Massive Online Open Course (MOOC) · Open Courseware · Webinars
	Online resources	· Tools, resources and portals as a training opportunity to enhance teachers' professional development.	· Resources and self-learning materials · Teachers' competence self-assessment tools
	Teachers' networks & communities of practice	· Teachers working together, sharing of good practice, professional relationships, reinforcing shared beliefs, sharing their experiences, talking the same language, and being willing to learn from one another.	· Online communities of practice · Web-based networks
Hybrid training		· Hybrid courses & workshops	· Combing both face-to-face instruction and online learning, resources online can back up first tentative steps made at F2F events.
Leadership training		· Training related to ICT for educational purposes addressed to school leaders (principals and directors) or to those who have specific responsibilities (e.g. head of a specific subject, head of laboratory).	

Dimension 4 – Access to content

Table 8 : List of categories, sub-categories and iterms of Dimension 4 – Access to content			
Category	**Sub-category**	**Description**	**Items**
Paid for content	Online courses	· Materials complementing full-course resources, including teaching materials and individual teacher resources can be combined and re-combined multiple times according to individual needs.	· Maker kits · Subscription-based materials · School kits · Science kits · Teacher guides
	Online resources	· Materials greatly expanding the possibilities for regular student application of critical thinking and problem solving skills, fostering deeper learning and allowing students to collaborate seamlessly with peers and teachers for ongoing feedback.	· Educational software · Educational apps · Gaming · Simulations · Software subscriptions · Virtual online laboratories
	Full-course resources	· Full-course resources	· Digital curriculum · Digital textbooks · E-books · Single lesson plans /units

Free and Open Educational Resources (OER) content	Online courses	· Materials complementing full-course resources, including teaching materials and individual teacher resources can be combined and re-combined multiple times according to individual needs.	· Maker kits · Subscription-based materials · School kits · Science kits · Teacher guides
	Online resources	· Materials greatly expanding the possibilities for regular student application of critical thinking and problem solving skills, fostering deeper learning and allowing students to collaborate seamlessly with peers and teachers for ongoing feedback.	· Educational software · Educational apps · Gaming · Simulations · Software subscriptions · Virtual online laboratories
	Full-course resources	· Full-course resources	· Digital curriculum · Digital textbooks · E-books · Single lesson plans /units
Teachers generated OER	Online courses	· Materials complementing full-course resources, including teaching materials and individual teacher resources can be combined and re-combined multiple times according to individual needs.	· Maker kits · Subscription-based materials · School kits · Science kits · Teacher guides
	Online resources	· Materials greatly expanding the possibilities for regular student application of critical thinking and problem solving skills, fostering deeper learning and allowing students to collaborate seamlessly with peers and teachers for ongoing feedback.	· Educational software · Educational apps · Gaming · Simulations · Software subscriptions · Virtual online laboratories
	Full-course resources	· Full-course resources	· Digital curriculum · Digital textbooks · E-books · Single lesson plans /units

2. Task 2 – Description of three different levels of a 'highly equipped and connected classroom'

Box 2: Highlights of Task 2

- Three scenarios were identified to describe different levels of a highly equipped and connected classroom (HECC). These scenarios are defined as (i) an **entry level**; (ii) an **advanced**; and (iii) a **cutting-edge level** of a HECC. The proposed scenarios provide a **general reference framework** allowing the estimation of costs for the advanced scenario.
- The HECC model is a **progressive model**, which implies that one school might start off with the entry level scenario in order to equip and connect a classroom, then progress to the advanced scenario and finally upgrade the classroom to the cutting-edge level scenario in order to exploit the opportunities provided by digital teaching and learning to the fullest extent. In turn, other schools could start off already with the advanced level scenario as an entry point and then eventually upgrade their classrooms to the cutting-edge level.
- In particular, a **top-down approach** was deployed to define the three levels of a HECC. As a first step, the items that form the cutting-edge HECC scenario were determined, given that the largest evidence base, in terms of available case studies and previous research, is available to describe the ultimate categories, sub-categories and items that a cutting-edge level of a HECC would need to fulfil. The selection and combination of the items for this scenario have been inspired by the 'Future Classroom Lab (FCL)' developed by European Schoolnet, as well as other available academic research.
- The items to be included in the entry and advanced level scenarios were then specified in a second step. Opting for the most advanced cutting-edge level of a HECC might not always be feasible due to different **budget considerations** as well as individual **pedagogical** and **technical requirements**. As such, schools often need to trade-off between different decision criteria, including affordability, requirements and benefits that a digital classroom yields. Given that identifying different levels of a HECC is an under-studied area in the available literature, the developed scenarios aim at supporting schools in implementing one level of a HECC depending on individual needs and requirements.
- Thus, the three different levels represent a **continuum** of what a HECC could entail, with **multiple conceivable scenarios in between** the three levels. In other words, many different combinations of items within the HECC scenarios would be possible. For the sake of reducing complexity, this study follows an approach of clearly defining each of the three scenarios in terms of items included or excluded. However, school leaders who wish to incorporate digital technologies in their schools are advised not to follow the strict mapping of the items within each scenario, but to select other items part of the HECC conceptual model with similar functionalities or substitute items with others, depending on their schools' individual needs and requirements.
- The items mapped in each scenario relate to the digital technology equipment, network requirements and access to digital contents available to students and teachers, as well as the professional development activities for teachers.
- The **entry level scenario** of a HECC mainly outlines the minimum and essential components of a highly equipped and connected classroom. It contains essential digital technology equipment, including a limited number of components related to teachers' professional development and access to digital contents, as well as minimum network requirements needed for a functioning HECC.
- The **advanced scenario** of a HECC builds upon and further advances the entry level scenario, while paving the way to the cutting-edge level scenario. Differently from the entry-level, the advanced scenario entails more advanced

Box 2: Highlights of Task 2
digital equipment (e.g. 3D printers and modelling software, interactive tables), as well as a greater number of teachers' professional development activities (e.g. full immersion courses, in-class-coaching) and access to paid-for contents (e.g. makers kits, educational apps, virtual laboratories). • The **cutting-edge level** scenario of a HECC involves the ultimate categories, sub-categories and items of a highly equipped and connected classroom. The cutting-edge scenario further advances categories, sub-categories and items in the advanced scenario, particularly in relation to broadband connectivity (e.g. ultra-fast broadband, Virtual Private Network), a greater variety of digital equipment available to teachers and students (e.g. e-books, wristbands, audio and video software), increased opportunities for face-to-face professional development for teachers (e.g. twilight training sections, mentored action research) and leadership training.

The richness of the conditions (i.e. categories, sub-categories and items) for each of the four dimensions part of the HECC model, as identified in Task 1, would allow the creation of a great variety of different potential HECC scenarios. For the sake of simplicity, the study defines **three scenarios only**:

I. **Entry level scenario –** including the minimum and essential components of a HECC;
II. **Advanced scenario –** including more advanced components of a HECC; and
III. **Cutting-edge level scenario –** including the ultimate categories, sub-categories and items to have an effective HECC.

It is relevant to highlight that the three different levels represent a continuum of what a HECC could entail, with multiple conceivable scenarios in between the three levels. In other words, many different other combinations of items within the HECC scenarios would be possible. For the sake of reducing complexity; it was decided to limit the analysis to three specific classification levels only.

2.1 Defining the HECC scenarios

2.1.1 Rationale of defining the HECC scenarios

The identification and selection of items to be included in each of the three scenarios is based on desk research, literature reviews and exchanges with stakeholders during the stakeholder consultation part of Task 1.

The HECC model should be seen as a progressive model, which implies that one school might start off with the entry level scenario in order to equip and connect a classroom, then progress to the advanced scenario and finally upgrade the classroom to the cutting-edge level scenario in order to exploit the opportunities provided by digital teaching and learning to the fullest extent. In turn, other schools could start off already with the advanced level scenario as an entry point and then eventually upgrade their classrooms to the cutting-edge level. The following table describes each of the three HECC scenarios.

Table 9: Description of the three HECC scenarios

Scenario	Description
Entry level scenario	The entry level scenario of a HECC mainly outlines the minimum and essential components of a highly equipped and connected classroom. It contains essential digital technology equipment, including a limited number of components related to teachers' professional development

	and access to digital contents, as well as minimum network requirements needed for a functioning HECC.
Advanced level scenario	The advanced scenario of a HECC builds upon and further advances the entry level scenario, while paving the way to the cutting-edge level scenario. Differently from the entry-level, the advanced scenario entails more advanced digital equipment (e.g. 3D printers and modelling software, interactive tables), as well as a greater number of teachers' professional development activities (e.g. full immersion courses, in-class-coaching) and access to paid-for contents (e.g. makers kits, educational apps, virtual laboratories).
Cutting-edge level scenario	The cutting-edge level scenario of a HECC involves the ultimate categories, sub-categories and items of a highly equipped and connected classroom. The cutting-edge scenario further advances categories, sub-categories and items in the advanced scenario, particularly in relation to broadband connectivity (e.g. ultra-fast broadband, Virtual Private Network), a greater variety of digital equipment available to teachers and students (e.g. e-books, wristbands, audio and video software), increased opportunities for face-to-face professional development for teachers (e.g. twilight training sections, mentored action research) and leadership training.

The performed mapping of the three levels represents, to a certain extent, a continuum of what a HECC could entail, with multiple conceivable scenarios in between of the three scenarios. Some of the items are included in all three levels, such as word processing or spreadsheet software (dimension 1) or fibre Internet (dimension 2), to name just two examples. Moreover, some of the items are included in both the cutting-edge and the advanced level, but not in the entry level scenario (e.g. platform as a service or in-class coaching). In turn, some of the items are included only in the advanced level scenario (e.g. e-book readers or VR headsets).

However, for other items, the continuum will not be built on the presence of a specific item within one of the scenarios but not within the other, but on improving **the ratio of that item per student** for a classroom. For instance, for convertible laptops, a 1 to 3 student ratio is assumed for the entry level and advanced scenario, whereas a 1 to 1 student ratio is assumed for the cutting-edge level scenario.

A top-down approach was followed to select the respective items of the four dimensions of the HECC framework for each of the three scenarios. As a first step, the items that form the cutting-edge HECC scenario were determined, given that the largest evidence base in terms of available case studies and previous research was available to substantiate the ultimate and most advanced categories, sub-categories and items that needed to be met to achieve a highly equipped and connected classroom. The selection and combination of the HECC for the cutting-edge HECC scenario have been primarily inspired by the 'Future Classroom Lab (FCL)' developed by European Schoolnet together, complemented by other available academic research.

The items to be included in the advanced and entry level scenarios were then specified in a second step. Opting for the most advanced cutting-edge level of a HECC might be not always feasible due to different budget considerations as well as individual pedagogical and technical requirements. As such, schools often need to trade-off between different decision criteria, including affordability, requirements and benefits that a digital classroom yields. Given that identifying different levels of a HECC is an understudied area in the available literature, the developed scenarios are aimed at supporting schools in implementing one level of a HECC depending on their individual needs. The three different level thus represent a continuum of what a HECC could entail.

The main criteria that guided the description of the three different scenarios reflect those laying behind the overall HECC model namely 'boosting creativity and active learning' (e.g. digital equipment and software supporting a broad range of school activities such as coding, creating videos etc.), as well as supporting teachers' confidence and digital competence. Therefore, the combination of items within each scenario creates a flexible and dynamic classroom environment, including a range of means (i.e. digital technology equipment, network requirements, professional development of teachers and access to content) which support and facilitate more personalised, collaborative, competence-based learning.

It is relevant to highlight that the three different levels represent a continuum of what a HECC could entail, with multiple conceivable scenarios in between the three levels. In other words, many different combinations of items within the HECC scenarios would be possible. For the sake of reducing complexity, this study follows an approach of clearly defining each of the three scenarios in terms of items included or excluded. However, school leaders who wish to incorporate digital technologies in their schools are advised not to follow the strict mapping of the items within each scenario, but to select other items part of the HECC conceptual model with similar functionalities or substitute items with others depending on their schools' individual requirements and needs.

2.1.2 Desk research and literature review

The following provides an overview of **the key references** (non exhaustive list) that offered guiding principles and served as a reference point to map and select items related to the entry level, advanced and cutting-edge level scenarios:

- **The European Schoolnet - Future Classroom Lab (FCL)**[47] - an innovative study developed by the European Schoolnet served as a reference point to identify key items for all scenarios. The FCL offers a comprehensive case study that describes six different zones that explore and promote the essential elements in delivering 21st century learning and teaching activities (namely interact, present, investigate, create, develop and exchange). For the purpose of this study, it was carefully analysed which elements from the FCL could be embedded in the HECC model. In addition, it was verified whether the elements were also mentioned in other relevant research[48]. In table A.1 in Annex 2, key characteristics of the Future Classroom Lab are described. Table A.2 in Annex 2 provides a mapping between the three levels of the HECC scenarios and the FLC learning zones. The proposed mapping mainly focuses on dimension 1 (digital technology equipment) and dimension 4 (access to content) of the HECC model, which entail items that directly related to the FCL learning zones; whereas dimension 2 (Network requirements) and dimension 3 (Professional development of teachers) respectively function as 'conditio sine qua non' of FCL learning zones. Although several HECC items contribute to and might be used in different FCL zones (e.g. convertible laptops support all of the six FCL zones), these items are only mentioned in relation to the main FCL learning zone to which they refer[49].

  As displayed in table A.2 in Annex 2, the items included in the HECC entry-level scenario ensure that essential categories, sub-categories and items are in place to allow students and teachers to perform learning activities in line with the FCL six learning zones. For the advanced scenario, a higher number of elements of the FCL were integrated; and for the cutting-edge scenario, all main FCL features related to different learning zones that reflect good learning and teaching (i.e. being connected, involved, and challenged) have been considered[50];

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[47] European Schoolnet (2018)
[48] Here an example of this research method: interactive tables is an element in the FCL and also in other innovative classroom settings across the EU which were described in the available literature. The approach as such was to: i) find whether an item was included in the FCL; ii) find reference regarding the availability of a specific item in an innovative classroom setting described in the available literature; and iii) when these two elements (reference from FCL and from the literature) combine, the item is added and included in the HECC scenario.
[49] European Schoolnet (2016)
[50] It should be also noted that, although FCL served as a point for reference for inspiring the definition of the three HECC scenarios, the FCL is a Lab composed by a mixed environment not aimed to be reproduced to the

- **New Media Consortium (NMC) Horizon Report**[51] - the NMC Horizon Report charts the key trends, significant challenges and important technological developments that are very likely to impact changes in the 28 Member States' primary and secondary schools over the next five years. In particular, elements regarding cloud computing and games and gamification are integrated in the mapping of the advanced and cutting-edge scenario;

- **INTEL device recommendations for learning and teaching report**[52] - this guide explores best practices for learning activities, teaching strategies, the role that technology plays, and the best device choices for lower elementary, upper elementary, middle school, and cutting-edge school students and their educators. This report mainly informed and provided evidence in relation to dimension 1 (digital technology equipment), particularly concerning the type of portable devices (i.e. comparing key features of portable devices that support main activities students perform in different educational level from primary to secondary education);

- **Chromebook research by European Schoolnet[53]** - this report outlines the processes and results of a real case study involving six schools in the Netherlands, Spain and the United Kingdom in which teachers followed a professional development programme and used Acer Chromebooks and Google Apps in the class room. This report helped mainly to define the digital equipment and ratios for the advanced and cutting-edge scenarios;

- **ASCD report[54]** - this report shows the result of a real case study that was conducted among low-reading-ability middle school students demonstrating the potential of e-book readers. It furthers proves benefits of e-readers, which were investigated to design the cutting-edge level scenario;

- **Brocade report[55]** – this informational document describes a technological solution that delivers a high-performing, scalable, and secure network infrastructure on a limited budget, supporting one-to-one initiative and BYOD mobility. The report provides input for dimension 2 (focuses on the classroom connectivity networks) in the adopted HECC model for the three scenarios;

- **Upskilling teachers to teach computer science within the secondary curriculum[56]** - this paper reports on challenges in the UK regarding upskilling teachers to teach computer science with the secondary curriculum. The report indicates how teachers should participate in many hours of training or continuing professional development (CPD) and take up external courses to improve their skills

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ideal HECC. This innovative space has indeed a specific nature and scope, namely to provide 'a flexible learning space to experiment with different styles of learning, facilitated by technology, furniture and design' as well as offering 'a space to promote discussion on future learning strategies with teachers, students and policy makers'. Thus, the FCL is an experimental space aimed at challenging visitors (policy makers, teachers, industry partners) to rethink the role of pedagogy, technology and design of the classrooms. This last consideration also reflects in the type of activities carried out in the FCL which are mainly addressed to teachers and teacher trainers (e.g. workshops and courses for continuous professional development of teachers on creative use of multimedia, 1:1 pedagogies, eSafety, etc.) and to policy-makers (e.g. tours, thematic briefings, Flemish Ministry events, events by FCL partners). All these considerations clarify that the FCL aims to depict learning scenarios that expand beyond the context of school/classroom settings (e.g. encompassing a knowledge hub space) and cannot be considered as a model for an ideal classroom as it needs to be adapted to each classroom's context.

[51] European Commission (2014b)

[52] Intel (2016a)

[53] EUN (2016)

[54] ASCD (2012)

[55] Brocade (2016)

[56] Sentance, S., Dorling, D., McNicol, A., & Crick, T. (2012)

in teaching and learning. The elements are retained for the advanced and cutting-edge scenario;

- **School Education Gateway[57] -** this article takes a look at European and national initiatives that support the development of 21st century school leadership, which is deemed relevant for the cutting-edge scenario definition; and

- **Study on mobile digital games[58]** - This paper examines core aspects of digital gaming, the benefits of digital gaming as well as its limitations such as the challenge of determining the appropriate technology to align with pedagogy and age level. Gaming is part of a more advanced online resources (paid for content) relevant for the advanced and cutting-edge scenario.

Finally, reports published by the Innovative Technologies for an Engaging Classroom (iTEC) were analysed as these provided an overall framework to define the three scenarios. iTEC was a four-year, large-scale and pan-European project which took an informed look at the potential classroom of the future. The project was running from September 2010 to August 2014. iTEC aimed at developing engaging scenarios for learning in the future classroom that could be validated in a large-scale pilot and could subsequently be scaled up. This objective was based on an increased understanding of the ways in which new and emerging technologies can support more effective forms of learner engagement[59]. In iTEC, a scenario is defined as a narrative description of teaching and learning that provides a vision for innovation and advanced pedagogical practice, making effective use of digital technologies. Moreover, the workflow proceeds through to the practical implementation of learning activities and classroom validation. The learning activities were detailed descriptions of novel teaching and learning in classrooms, describing the resources to be used, the context (e.g. the location), the roles of participants, etc.[60]

In particular, the following scenarios available by iTEC[61] provided useful indications and support to define the pedagogical implications underpinning the three scenarios and input for the narratives:

- **Our school, our environment: using technology to raise environmental awareness** - focusing on integrating all students into the larger school environment, bringing together the school community and raising awareness about low-carbon schools, carbon output and the environment[62];
- **Students creating science learning resources[63]** - focusing on students supporting one another as they learn difficult concepts in science, students collaboratively creating exhibits that can be used to teach difficult concepts learned and exhibits used to teach younger children or those in future years;
- **Developing a common understanding from multiple sources** – focusing on source evaluation, collaboration, media literacy, interactive teaching;
- **Professional development in the global classroom[64]** - covering geography, shared resources and simulations, blended learning, co-creation, professional development, virtual classrooms; and
- **Music for inclusion and integration -** covering integration, music and art, transition, collaboration, self-expression, shared understanding, 'mash-up'[65].

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[57] School Education Gateway (2016)
[58] Crompton, H., Lin, Y., Burke, D., & Block, A. (2017)
[59] iTEC (2014)
[60] Ellis, W.J.R., Blamire, R., & Van Assche, F. (2015)
[61] iTEC (2015)
62 iTEC (2015b)
63 iTEC (2015d)
64 iTEC (2015c)
65 iTEC (2015a)

2.2 Entry level scenario of a HECC

This entry level scenario of a HECC depicts **the minimum and essential components** of a highly equipped and connected classroom. The elements included in this proposed scenario concern all four dimensions of the HECC.

The setting described in this classroom is based on the following assumptions:

- A classroom composed of 23 students[66] between age 11/12 years old (ISCED 2)[67];
- The classroom is envisaged as part of a medium-sized public school (≤ 400 students)[68] located in an urban area; and
- Seven to eight teachers[69] from different subjects are responsible for the classroom.

The same educational setting (assumptions) will be taken into account while describing the advanced and cutting-edge level scenario. This provides coherence and consistency among the three scenarios. It further allows the cost estimation, which reflects the advanced scenario, to be more easily expanded to the entry level and cutting-edge level scenario; the cost estimation for these scenarios is however excluded from this study.

The following table summarises the selected items for the entry-level scenario of a HECC and whether the item is adopted at the school, classroom or student level.

[66] Eurostat (2012), OECD (2017)
[67] Eurostat (2017)
[68] OECD (2015)
[69] OECD (2014a)

Table 10: Selection of items for an entry level scenario of a HECC[70]			
HECC dimension	**HECC category/Subcategory**	**HECC item**	**Ratio per student or at classroom/school level**
Dimension 1 (Digital technology equipment)	Portable devices / Laptops	Convertible laptops	1:3 student
	Interactive systems and devices	Interactive Whiteboards (IWB)	Classroom level
	Emerging technologies	Microcontrollers for coding activities	1:3 student
	Cloud-based platforms and services	Software as a Service (SaaS)	School level
	Virtual Learning Environment (VLE)	VLE platform	School level
	Software and services	Word processing software	School level
		Spreadsheet software	School level
		Presentation software	School level
		Data storage	School level
	Assistive Technologies (AT) for people with special needs	Optical character recognition	School level
Dimension 2 (Network requirements)	Network connectivity / Fibre Internet, Satellite Internet		School level
	High-speed wireless local-area network (WLAN)		School level
Dimension 3 (Professional development of teachers)	Face-to-face training / Courses and workshop	Active, hands on workshop	Per class teacher
		In-class coaching / PGM	Per class teacher
	Online training / Online courses, Teachers' networks & communities of practice	Massive Online Open Course (MOOC)	Per class teacher
		Webinars	Per class teacher
		Web-based networks	Per class teacher
Dimension 4 (Access to content)	Paid for content / Online resources	Educational software	Per student
	Paid for content / Full-course resources	Digital textbooks	Per student
	Free and OER content	Teacher guides	Per student
		Maker kits	Per student
		Educational software	Per student
		Educational apps	Per student
		Simulations	Per student
		Gaming	Per student
		Digital textbooks	Per student
	Teachers generated OER	Teacher guide	Per student

[70] Assuming that (i) the student age is 11/12 (ISCED 2); number of students: 23; number of class teachers: 7-8

		Educational software	Per student
		Educational apps	Per student
		Simulations	Per student
		Gaming	Per student
		Digital textbooks	Per student

Dimension 1 of Scenario 1 – Digital technology equipment

In the entry level scenario of a HECC, both students and teachers have access to and use portable devices. There is a roll out of **convertible laptops**[71] in the classroom based on a **1:3 student ratio**. The adoption of convertible laptops allows students to access a variety of educational resources and data in real time, as well as to create their contents[72].

To enhance interactivity and student participation, the classroom is also equipped with an **Interactive Whiteboard (IWB)**[73]. The IWB in the entry level scenario allows teachers to create interactive exercises, to gather together and arrange ideas and student contributions. In addition, IWBs also allow students and teachers to quickly elaborate and mix existing media content, but also to incorporate external contents into teacher's own teaching materials. As compared to data projectors, the cost of an IWB may be higher. Hence, an IWB actually offers more opportunities for interactivity than the data projector, thus covering more functionalities that are essential also at entry level classroom setting[74].

As part of the emerging technologies, the entry level HECC can use **microcontrollers for coding activities** (i.e. tiny computers used to sense and control products and is mainly deployed for coding)[75] in the classroom based on a **1:3 student ratio**. Many educators believe that coding helps students to understand how computers work, to communicate their thoughts in a structured and logic way, to think critically and to succeed in the digital working place[76]. Introducing coding activities in their curricula gives students an opportunity to get first-hand experience and to work creatively, designing tangible interactive objects or systems using 'physical computing' (programmable hardware)[77].

Anytime, anywhere access to learning platforms and a pool of educational contents is secured through **cloud-based platforms and services** that are used for **data storage** (helping schools to manage and securely store higher students' data load[78]). The entry level HECC scenario, focuses on Software as a Service (SaaS); a software that is owned, delivered and managed remotely by one or more providers. These cloud-based services further improve the classroom's productivity by e.g. ensuring students' access to **productivity software** including word processing software, spreadsheet software, presentation software such as Microsoft products or Google App Education, Skype, Dropbox[79]. On the school cloud forum, teachers post important communications for classroom's parents and students regarding assignments, tests and projects, as well as keeping an archive of completed work. Parents can also log in from anywhere and instantly know how their kids are progressing.

The school cloud-based service allows to recover classroom data quickly in a 'crash' situation[80] and it hosts the school's **virtual learning management system** (VLMSs).

To support and promote inclusive education, **assistive technologies for reading purchased as the school level** are available to help students who struggle with reading skills in the classroom, both aiding in learning and increasing their motivation and

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[71] Intel (2016)
[72] European Schoolnet (2016)
[73] Idem
[74] http://files.eun.org/fcl/Learning_spaces_guidelines_Final.pdf (p.13, p.19 and the case studies from pp.30-42); http://assets.epson-europe.com/gb/en/bett2014/pdf/Epson-BETT-Why-interactive-projectors-are-great-for-education.pdf; http://www.pdsttechnologyineducation.ie/en/Technology/Advice-Sheets/Interactive-Flat-Screens-vs-Projectors.pdf; http://moe.eun.org/c/document_library/get_file?uuid=589ce404-1607-49a0-9f39-bc6b7990f30a&groupId=10620.
[75] E.g. http://microbit.org; http://www.redfernelectronics.co.uk/crumble/
[76] Freeman, A., Adams Becker, S., Cummins, M., Davis, A., & Hall Giesinger, C. (2017)
[77] Sentance, S., Waite, J., Hodges, S., MacLeod, E., & Yeomans, L. E. (2017)
[78] Intel (2016)
[79] Freeman, A., Adams Becker, S., Cummins, M., Davis, A., & Hall Giesinger, C. (2017), European Commission (2014)
[80] The Edvocate (2016)

confidence. In particular, classroom teachers use **optical character recognition** (OCR) technology to convert printed text and graphics (e.g. line art, photographs, and graphs) into a digital format that can then be converted to audio into tactile images students with learning disabilities.

Dimension 2 of Scenario 1 – Network requirements

In terms of connectivity, the classroom has a **network point[81]**, a reliable and integrated **wired and wireless network** to provide uninterrupted services[82]. The school has set up a reliable and efficient network to ensure data travels consistently from it to the broadband network, and from there to the district data centre. The school provides adequate network capacity and bandwidth speeds (between 30Mbps and 100 Mbps per classroom) to keep up with digital learning. Moreover, a robust wireless infrastructure (WLAN) is in place in the school of the entry level HECC, providing an effective means for connecting students and staff's devices to Internet and for ensuring an authenticated, reliable and secure connection[83].

Dimension 3 of Scenario 1 – Professional development of teachers

In order to effectively use and integrate digital devices and contents into teaching and learning practices, all classroom teachers **periodically** undertake and engage in a great variety of **professional development activities**. In the entry level HECC, teachers are assumed to not possess a very high level of digital competence. Face-to-face initiatives, such as a collaboration with other teachers might be most suitable at this stage. In this context, in-class coaching and peer support can be very valuable for teachers not being very digitally competent. That way, teachers can see in practice how other teachers use digital technologies in class and this could imply a lower burden to start using this themselves. The model of peer-group mentoring (PGM) which was introduced in Finland is very relevant in this context[84]. This model is not based upon the transfer of knowledge from one person to another but builds upon the ideas of dialogue and knowledge sharing in a non-hierarchical way. In addition, teachers can participate in **active hands-on workshops**, focusing on both technology use and pedagogical innovations (organised by educational institutions or private organisations). If the teachers in the entry level HECC already have some digital competence[85], they can also enrol in a number of high-quality **free online courses (e.g. Massive Online Open Courses (MOOCs)) and webinars,** covering a great variety of topics and teaching methodologies using digital technologies and featuring contents produced by teachers, teacher trainers and education experts[86]. These courses enable them to learn about innovation in the classroom and school, as well as to develop and enhance their practice. Classroom teachers in the entry level HECC also collaborate with other colleagues, by sharing knowledge, contents and practices through **teachers' web-based networks** that offer a platform for staff (teachers, head teachers, librarians, etc.) to communicate, collaborate, develop projects, share and being part of a learning community in Europe[87]. As already mentioned in the introduction of this report, support at the school leadership level for professional development is a prerequisite to the success of these activities.

Dimension 4 of Scenario 1 – Access to content

The high-speed connectivity adopted at the school level further allows students to **access a great variety of multi-media contents, apps and interactive resources**. For

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[81] Satellite-based broadband services should be acknowledged as an efficient option for poorly connected schools (cf. https://ec.europa.eu/digital-single-market/en/news/results-satellite-broadband-schools-study)
[82] Brocade (2016)
[83] COSN (2015)

[84] Geeraerts,K, Tynjala, P , Heikkinen, H, Markkanen, I, Pennanen,M, Gijbels, D (2015)
[85] Muñoz, C., Punie, Y., Inamorato, A. (2016)
[86] European Schoolnet (2017c)
[87] More information about eTwinning available at: https://www.etwinning.net/en/pub/index.htm

example, teachers use **simulations**[88] that allow students to test, design, experiment and explore science concepts and ideas. Students use an electronic sensor (included in the **makers kits** available in the classroom), plugged into a tablet computer, to record the data. Teachers also use mobile **digital games,** which motivate and engage students and help their success in different subjects[89]. **Teachers' guides**[90] are also used to guide teachers through the steps of planning and conducting an online, collaborative project in this classroom setting. These can be generated by the teachers themselves as part of the OER.

2.3 Advanced level scenario of a HECC

The second scenario depicts **more advanced components** than the ones included in the entry level scenario. It builds upon and further advances the entry level scenario, while paving the way to the cutting-edge level scenario. This advanced scenario, compared to the entry level scenario, includes a higher number of components related to professional development of teachers and access to paid/free and OER contents. Faster broadband connectivity also constitutes the advanced scenario.

The setting described in this classroom is based on the same assumptions as set for the entry level scenario.

In line with the entry level scenario, the FCL[91] served as a relevant source to build the scenario and to select and combine the items. The main FCL features related to different learning zones were selected and carefully adapted to the specific objectives of the advanced level scenario of a HECC. The following table summarises the selected items for the advanced scenario of a HECC.

[88] E.g. https://phet.colorado.edu
[89] Crompton, H., Lin, Y., Burke, D., & Block, A. (2017)
[90] https://www.teachervision.com/search/Teachers%20guide
[91] European Schoolnet (2017c)

Table 11: Selection of items for an advanced scenario of a HECC[92]				
HECC dimension	**HECC category/Subcategory**	**HECC item**	**Ratio per student or at classroom/school levels**	**Deviation from entry-level scenario**
Dimension 1 (Digital technology equipment)	Portable devices / Laptops	Convertible laptops	1:3 student	No difference
	Interactive systems and devices	Interactive Whiteboards (IWB)	Classroom level	No difference
		4 interactive tables with projector	Classroom level	Added to the entry-level scenario
	Emerging technologies	Microcontrollers for coding activities	1:3 student	No difference
		3D printers	School level	Added to the entry-level scenario
	Cloud-based platforms and services	Platform as a Service (PaaS)	School level	Added to the entry-level scenario
	Virtual Learning Environment (VLE)	VLE platform	School level	No difference
	Software and services	Word processing software	School level	No difference
		Spreadsheet software	School level	No difference
		Presentation software	School level	No difference
		3D modelling software	School level	Added to the entry-level scenario
		Data storage	School level	No difference
		Classroom management system	School level	Added to the entry-level scenario
	Assistive Technologies (AT) for people with special needs	Optical character recognition	School level	No difference
Dimension 2 (Network requirements)	Network connectivity / Fibre Internet, Satellite Internet		School level	No difference
	High-speed wireless local-area network (WLAN)		School level	No difference
	Service, maintenance and network monitoring		School level	Added to the entry-level scenario
Dimension 3 (Professional development of teachers)	Face-to-face training / Courses and workshops, Coaching and peer support	Full immersion courses	Per class teacher	Added to the entry-level scenario
		In-class coaching / PGM	Per class teacher	No difference
	Online training / Online courses, Teachers' networks & communities of practice	Massive Online Open Course (MOOC)	Per class teacher	No difference
		Webinars	Per class teacher	No difference
		Web-based networks	Per class teacher	No difference
		Online communities of practice	Per class teacher	Added to the entry-level scenario

[92] Assuming that (i) the student age is 11/12 (ISCED 2); number of students: 23; number of class teachers: 7-8

	Leadership training	Training related to digital technologies for educational purposes	Per head teacher / teacher with special responsibilities	No difference
Dimension 4 (Access to content)	Paid for content / Online courses, Online resources, Full-course resources	School kits	Per student	Added to the entry-level scenario
		Makers kits	Per student	Added to the entry-level scenario
		Educational apps	Per student	Added to the entry-level scenario
		Virtual online laboratories	Per student	Added to the entry-level scenario
		E-books	Per student	Added to the entry-level scenario
	Free and OER content / Online courses, Online resources, Full-course resources	Teachers Guide	Per student	No difference
		Maker kits	Per student	No difference
		Educational software	Per student	No difference
		Educational apps	Per student	No difference
		Simulations	Per student	No difference
		Gaming	Per student	No difference
		Virtual online laboratories	Per student	Added to the entry-level scenario
		Digital textbooks	Per student	No difference
	Teachers generated OER / Online courses, Online resources, Full-course resources	Teachers guide	Per student	No difference
		Educational software	Per student	No difference
		Educational apps	Per student	No difference
		Simulations	Per student	No difference
		Gaming	Per student	No difference
		Digital textbooks	Per student	No difference

Dimension 1 of Scenario 2 – Digital technology equipment

In the advanced level scenario, convertible laptops are rolled out based on a **1:3 student ratio**.

In the advanced scenario, students' interaction is enhanced by interactive tables with projectors. The advanced classroom is indeed equipped **with four networked interactive tables** controlled by a tablet and that can be projected to the **classroom's multi-touch interactive whiteboard**. This stimulates the interactivity and student participation in the classroom. As the tables are networked, digital resources and information can be shared easily between group members and between tables, as well as with the teacher to support peer collaboration and interaction in groups[93]. The design and features of the interactive tables provide new opportunities for collaboration and interaction, which are complementary to other portable and interactive devices (e.g. tablets) supporting diverse and complex teaching methodologies. The combination of the interactive tables with the IWB in the advanced level HECC will further allow teachers to create interactive exercises, to gather together and arrange ideas and student contributions. In addition, IWBs also allow students and teachers to quickly elaborate and mix existing media content, but also to incorporate external contents into teacher's own teaching materials.

Classroom students and teachers will as well have access to **three-dimensional (3D) printing technology** available in the school that allows them to produce a physical object. By using **the 3D printer,** which is an item that was not included in the entry-level HECC scenario, students observe features on 3D objects that are more difficult to visualise on paper or other 2D formats and examine replicas of artefacts otherwise inaccessible.[94] By developing their own models, students also cultivate their creative thinking and problem-solving skills. Teachers can use **3D modelling software** as a powerful tool to engage students in learning and experimenting design methods that integrate engineering design core ideas and practice in a multidisciplinary learning environment. By designing and developing their own models, students also cultivate their creative thinking and problem-solving skills[95].

As part of the emerging technologies, the advanced level HECC scenario includes **microcontroller devices for coding activities** based on **a 1:3 student ratio**. Classroom teachers can further use **optical character recognition** (OCR) technology as part of the assistive technologies, which will be purchased at the school level.

The advanced HECC scenario secures access to learning platforms and a pool of educational contents through **cloud-based platforms and services**. In specific, whereas in the entry-level HECC the learning contents are conveyed through Software as a Service (SaaS), the advanced scenario focuses on Platform as a Service (PaaS). As far as SaaS is concerned, the software is hosted on a remote server and is always accessible over Internet. On the other hand, PaaS, instead of delivering the software over the web, offers a platform for the creation of the software. PaaS is therefore a cloud-based computing environment designed to support the rapid development, running and management of applications. It is integrated and abstracted from the lower-level infrastructure components[96]. The platforms and services are used for **data storage** and for improving classroom productivity (e.g. ensuring students' access to **productivity software** such as Microsoft products or Google App Education)[97].

[93] E.g. Mercier, E.M. & Higgins, S. (2013)
[94] E.g.: Yale (2018)
[95] E.g.: Montironi, M.H., Eliahu, D. & H Cheng, H. (2015)
[96] Definition retrieved from: https://www.ibm.com/blogs/cloud-computing/2014/02/what-is-platform-as-a-service-paas/
[97] Freeman, A., Adams Becker, S., Cummins, M., Davis, A., & Hall Giesinger, C. (2017)

On the school cloud forum, teachers post important communications for classroom's parents and students regarding assignments, tests and projects, as well as are able to keep an archive of completed work. Parents can also log in from anywhere and instantly know how their kids are progressing. The school cloud-based service allows to recover classroom data quickly in a 'crash' situation[98] and it hosts the school's **virtual learning management system** (VLMSs) e.g. Moodle and Blackboard[99], that allows to make learning goals visible to parents, as well as supporting students' self-evaluation and access to assessment tasks. Pedagogical data hosted on the VLM are tied together with administrative data via a **student information system**[100] (e.g. Quickschool, Gradelink, etc.). This system, integrated in the advanced level HECC scenario, is a digital solution that allows to note students' personal details, attendance, marks etc. and other relevant staff parameters. Such a system is a crucial hub in the workflow of teachers and administration and, by integrating administrative and pedagogical data, presents rich prediction and school progress models. Moreover, in the advanced level HECC scenario, there are no textbooks in this classroom. Having **e-books and coursework**, students can add their own contribution, research, pictures and annotations. Students can work together in a **virtual space** set up for their classroom within the school's Learning Management System.

Dimension 2 of Scenario 2 – Network requirements

In addition to that, the classroom also has a **network point**, a reliable and integrated **wired and wireless network** to provide uninterrupted services[101]. The school has set up a reliable and efficient network to ensure data travels consistently from it to the broadband network, and from there to the district data center. The school provides adequate network capacity and bandwidth speeds (between 30Mbps and 100 Mbps per classroom) to keep up with digital learning. Moreover, a robust wireless infrastructure (WLAN) is in place at the school level, providing an effective means for connecting students and staff's devices to the Internet and for ensuring an authenticated, reliable and secure connection[102]. In order to guarantee reliable and continuous operations of the school network infrastructure, the network is regularly maintained and monitored by an in-house or external responsible team.

Dimension 3 of Scenario 2 – Professional development of teachers

In order to effectively use and integrate digital devices and contents into teaching and learning practices, all classroom teachers periodically undertake and engage in a great variety of professional development activities. However, compared to the entry-level scenario, the advanced HECC foresees more intense and collaborative type of face-to-face teachers' training activities. Among face-to-face initiatives, teachers participate in **full immersion courses**[103] focusing on both technology use and pedagogical innovations and are organised by educational institutions or private organisations. In class **coaching and peer support**[104] also allows teachers to try out new strategies learned during the training workshop and get feedback on how these strategies worked in the classroom.

To learn about innovation in the classroom and school, as well as to develop and enhance their practice, classroom teachers also enrol in a number of high-quality free **online courses (MOOCs) and webinars,** covering a great variety of topics and teaching methodologies using digital technologies and featuring contents produced by teachers, teacher trainers and education experts[105]. In the advanced HECC scenario more collaborative forms of training, which were not included in the entry-level scenario, are offered to teachers. In specific, classroom teachers collaborate with other colleagues, by

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[98] The Edvocate (2016)

[99] Mohammedameen Almajalid, R. (2017)
[100] Crowd (2018)
[101] Brocade (2016)
[102] COSN (2015)
[103] E.g. Sue Sentence (2012)
[104] Chun Lee, S., Nugent, G., & Kunz, G. (2014)
[105] European Schoolnet (2017c)

sharing knowledge, contents and practices through **teachers' networks and communities of practice** that offer a platform for staff (teachers, head teachers, librarians, etc.) to communicate, collaborate, develop projects, share and being part of a learning community in Europe[106].

As for the entry-level scenario, the above-mentioned professional development activites necessitate a strong support of the school leadership.

Dimension 4 of Scenario 2 – Access to content

The adopted high-speed connectivity further allows students to **access a great variety of multi-media contents, apps and interactive resources**. For example, in the advanced HECC, students can connect to **remotely-operated laboratories** (**virtual online labs**)[107] that offer an opportunity to conduct scientific experiments with real equipment from remote locations. Teachers can also use **simulations**[108] that allow students to test, design, experiment and explore science concepts and ideas. Students use an electronic sensor (included in the **makers kits** available in the classroom), plugged into a tablet computer, to record the data. Also, school kits are available at the student level to support school leaders, teachers and the whole school community to implement innovative practices. These resources provide a model to experiment and change pedagogies, translating from theory to classroom e.g. how to conduct cooperative learning activity, how to design and run a creative atelier, how to create a digital content repository, etc.[109]. Teachers also use mobile **digital games,** which motivate and engage students and help their success in different subjects[110]. **Teachers' guides**[111] are also used to guide teachers through the steps of planning and conducting an online, collaborative project in this classroom setting.

2.4 Cutting-edge level scenario of a HECC

The third scenario refers to the cutting-edge level scenario which depicts **the most advanced components** of a highly equipped and connected classroom. This scenario involves a solid, high-performance technological infrastructure that allows students and teachers to carry out a multiplicity of innovative teaching and learning activities.

This scenario embeds most elements inspired from the FCL[112].

The following table summarises the selected items for the cutting-edge level scenario of a HECC as well as the information at which level the item is adopted. The classroom setting is based on the same assumptions as adopted for the entry level and advanced scenarios.

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[106] More information about eTwinning available at: https://www.etwinning.net/en/pub/index.htm
[107] E.g. Go-Lab (n.d.), TeachThought (2017)
[108] E.g. https://phet.colorado.edu
[109] Definition retrieved from: http://resources.schoolkit.co.nz/article/575-our-pedagogical-model; http://schoolkit.istruzione.it/schoolkit/
[110] Crompton, H., Lin, Y., Burke, D., & Block, A. (2017)
[111] E.g. https://www.teachervision.com/search/Teachers%20guide
[112] European Schoolnet (2017b)

Table 12: Selection of items for the cutting-edge scenario of a HECC[113]				
HECC Dimension	**HECC Category/Subcategory**	**HECC Item**	**Ratio per student or at classroom/school levels**	**Deviation from advanced scenario**
Dimension 1 (Digital technology equipment)	Portable devices / Laptops	Convertible laptops	1:1 student	Changed ratio
	Portable devices / Other handheld devices	E-book readers	1:1 student	Added to the advanced scenario
	Interactive systems and devices	Interactive Whiteboards (IWB)	Classroom level	No difference
		4 interactive tables with projector	Classroom level	No difference
	Emerging technologies	3D printer	School level	No difference
		Microcontrollers for coding activities	1:1 student	Changed ratio
		VR headsets	1:1 student	Added to the advanced scenario
		Wearable wristbands	1:1 student	Added to the advanced scenario
		Voice assistants (i.e. Alexa, Siri, etc.)	1:1 student	Added to the advanced scenario
	Cloud-based platforms and services	Platform as a Service (PaaS)	School level	No difference
	Virtual Learning Environment (VLE)	VLE platform	School level	No difference
	Services and software	Word processing software	School level	No difference
		Spreadsheet software	School level	No difference
		Presentation software	School level	No difference
		3D modelling software	School level	No difference
		Data Storage	School level	No difference
		Audio and video editing software	School level	Added to the advanced scenario
	Assistive technologies	Optical character recognition	School level	No difference
Dimension 2 (Network requirements)	Network connectivity / Fibre Internet, Satellite Internet		School level	Increased internet speed (>100 Mbps)

[113] Assuming that (i) the student age is 11/12 (ISCED 2); number of students: 23; number of class teachers: 7-8

	High-speed wireless local-area network (WLAN)		School level	No difference
	Service, maintenance and network monitoring		School level	No difference
Dimension 3 (Professional development of teachers)	Face-to-face training / Courses and workshop, Coaching and peer support	Full immersion courses	Per class teacher	Stable costs but increased opportunities to the advanced level scenario
		In class coaching / PGM	Per class teacher	Stable costs but increased opportunities to the advanced level scenario
	Online training / Online courses, Online resources, Teachers' networks & communities of practice	Massive Online Open Course (MOOC)	Per class teacher	No difference
		Webinars	Per class teacher	No difference
		Web-based networks	Per class teacher	No difference
		Online communities of practice	Per class teacher	No difference
	Leadership training	Training related to digital technologies for educational purposes	Per head teacher / teacher with special responsibilities	Added to the advanced scenario Stable costs but increased opportunities to the advanced level scenario
Dimension 4 (Access to content)	Paid for content / Online courses, Online resources, Full-course resources	School kits	Per student	No difference
		Makers kits	Per student	No difference
		Educational apps	Per student	No difference
		Virtual online laboratories	Per student	No difference
		E-books	Per student	No difference
	Free and OER content / Online courses, Online resources, Full-course resources	Teachers guide	Per student	No difference
		Maker kits	Per student	No difference
		Educational software	Per student	No difference
		Educational apps	Per student	No difference
		Simulations	Per student	No difference
		Gaming	Per student	No difference
		Virtual online laboratories	Per student	No difference
		Digital textbooks	Per student	No difference
	Teachers generated OER / Online courses, Online resources, Full-course resources	Teachers guide	Per student	No difference
		Educational Software	Per student	No difference
		Educational apps	Per student	No difference
		Simulations	Per student	No difference
		Gaming	Per student	No difference
		Digital textbooks	Per student	No difference

Dimension 1 – Digital technology equipment

In the cutting-edge level scenario of a HECC, students and teachers have access to and use portable devices. As compared to the entry level and advanced scenarios, convertible laptops are rolled out on a **1:1 student ratio**, meaning that each student in the classroom has access to a personal convertible laptop.

Compared to the entry-level and advanced scenarios, in the cutting-edge level scenario of a HECC, **e-book readers** are deployed and used to support literacy learning[114], boosting students' reading comprehension as well as increase their motivation to read[115].

Interactivity and student participation in the classroom is stimulated through interactive systems. The classroom in the cutting-edge level scenario is equipped **with four networked interactive tables** controlled by a tablet and at least **one multi-touch interactive whiteboard**.

Students and teachers will also have access to **three-dimensional (3D) printing technology** available in the school that allows them to produce a physical object.

The cutting-edge HECC also integrates emerging technologies in the classroom. To illustrate, **microcontroller devices** are purchased assisting students in their coding activities. Each student will have access to one device (**1:1 student ratio**). Classroom teachers can further use **optical character recognition** (OCR) technology as part of the assistive technologies and integrate this at the school level.

Compared to the entry-level and advanced scenarios, the cutting-edge HECC will adopt new technologies, such as Virtual Reality (VR), wearable technologies and Artificial Intelligence (AI), to involve students in innovative and experimental learning opportunities. In particular, classroom teachers play with Virtual Reality by providing students access to **Virtual Reality (VR)**[116] **devices** that enable more experiential learning opportunities, taking students to outer space, back in time, inside a molecule, or instilling empathy and teaching global awareness[117]. VR headsets are integrated in the classroom based on a 1:1 student ratio.

To optimise the learning environment (e.g. allowing both students and teachers to deal consciously with the individual's physiological conditions and varying levels of concentration throughout the day), each student wears an activity tracker (such as **wristbands** and smartwatches)[118]. Through these wearable technologies, students receive alerts to take a break, eat the right food or take physical exercise before going to class, measuring objectively students' physical activity/inactivity that is linked to cognitive performance, academic achievement and mental well-being[119].

In order to meet the needs of all students, when the teacher is working with a small group, a **voice digital assistant** (e.g. Alexa, Chatbot, etc.)[120] is used in the classroom to support the other students. Through a smart speaker, the voice assistant set reminders, read an audio book or play tranquil music. Students can ask for a random number in a range of numbers, or request information about a famous person, a historical event and for words to be spelled or translated from other languages, hence supporting also migrant students in the classroom to acquire the new language[121].

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[114] ASCD (2012)
[115] Graham Parker (2017)
[116] NMC Horizon Report (2017)
[117] K12 Blueprint (2018)
[118] Kennisnet (2017)
[119] Van Dijk, M. L., De Groot, R. H. M., Savelberg, H. C. M., Van Acker, F. & Kirschner, P. A. (2014), De Groot, R.H.M., Van Dijk, M. L. & Kirschner, P.A. (2015)
[120] More information available at: https://www.technologyreview.com/s/608430/growing-up-with-alexa/
[121] The CLIPSO project is developing a chatboat-based storyworld to foster basic language skills of hospitalised migrant learners https://www.itd.cnr.it/Progetti_Rispo1.php?PROGETTO=1185&FlagSelected=en

The **cloud-based platforms and services** used for **data storage** and for improving classroom productivity as defined in the advanced scenario are also integrated in the cutting-edge scenario of a HECC (i.e. PaaS). The school cloud-based service also hosts the school's **virtual learning management system** (VLMSs). Moreover, similar to the advanced scenario, there are no textbooks in this classroom. Having **e-books and coursework**, students add their own contribution, research, pictures and annotations. Classroom students work together in a **virtual space** set up for their classroom within the school's Learning Management System.

In the classroom, teachers promote and encourage students to create videos and media to deeply engage them in learning experiences and to help them understand more complex concepts[122]. During these activities (e.g. filmmaking, stop motion animation), students usually collaborate on a storyboard that displays the sequence for a story or a physical event. Afterwards, students create props using modelling clay or other models and take photographs of the sequence which are uploaded into audio and video editing software to generate their own digital product that could be built upon, and that ultimately can be used to explain such complex concepts to other middle school students. Hence, through investigation, storytelling and media production, teachers empower learners as creators allowing them to also demonstrate their mastery in forms that surpass traditional assessment format (e.g. tests and worksheets).

Dimension 2 of Scenario 3 – Network requirements

The classroom additionally has a **network point**, a reliable and integrated **wired and wireless network** to provide uninterrupted services[123]. The school has set up a reliable and efficient network to ensure data travels consistently from it to the broadband network, and from there to the district data center. The school provides ultra-fast network capacity and bandwidth speeds (at least 100 Mbps per classroom) to keep up with the needs of the cutting-edge technology equipment described above . WLAN is in place at a school level, providing an effective means for connecting students and staff's devices to Internet and for ensuring an authenticated, reliable and secure connection[124]. As for the advanced level scenario, the network is regularly maintained and monitored by an in-house or external responsible team.

Dimension 3 of Scenario 3 – Professional development of teachers

In order to effectively use and integrate digital devices and contents into teaching and learning practices, all classroom teachers periodically undertake and engage in a great variety of professional development activities. Among face-to-face initiatives, teachers participate in **full immersion courses**[125] that focus on both technology use and pedagogical innovations and are organised by educational institutions or private organisations. **In class coaching and peer support[126]** also allows teachers to try out new strategies learned during the training workshop and get feedback on how these strategies worked in the classroom.

To learn about innovation in the classroom and school, as well as to develop and enhance their practice, classroom teachers also enrol in a number of high-quality free **online courses (MOOCs),** covering a great variety of topics and teaching methodologies using digital technologies and featuring contents produced by teachers, teacher trainers and education experts[127]. Classroom teachers also collaborate with other colleagues, by sharing knowledge, contents and practices through **teachers' networks and communities of practice** that offer a platform for staff (teachers, head teachers, librarians, etc.) to

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[122] Using stop-motion animation in organic chemestry https://eic.rsc.org/ideas/stop-motion-animation-to-facilitate-group-discussion/2010073.article
[123] Brocade (2016)
[124] COSN (2015)
[125] Sue Sentence (2012)
[126] Lee, S.C., Nugent, G., & Kunz, G. (2014)
[127] European Schoolnet (2017c)

communicate, collaborate, develop projects, share and being part of a learning community in Europe[128]. Both web-based networks as well as online communities of practice are embedded in this scenario.

Those teachers who have leadership roles within the school also take part in **leadership training[129]** initiatives addressing key aspects of Educational Management, Quality Assurance and Curriculum Development, as well as contributing to the school's digital readiness[130]. Related to this leadership role, it remains important that school leaders actively support professional development of teachers not having this role. Compared to the advanced scenario, opportunities for leadership training for teachers increase in the cutting edge scenario, however, the overall costs for professional development remain stable.

As for both preceeding scenarios, professional development relies on a strong support of the school leadership.

Dimension 4 of Scenario 3 – Access to content

The adopted high-speed connectivity allows students to **access a great variety of multi-media, interactive resources**, to collaborate remotely and to create their own contents. For example, students can connect to **remotely-operated laboratories** (virtual online labs)[131] that offer an opportunity to conduct scientific experiments with real equipment from remote locations. Students use an electronic sensor (included in the **makers kits** available in the classroom), plugged into a tablet computer, to record the data. School kits are available at the student level to support school leaders, teachers and the whole school community to implement innovative practices. These resources provide a model to experiment and change pedagogies, translating from theory to classroom e.g. how to conduct cooperative learning activity, how to design and run a creative atelier, how to create a digital content repository, etc.)[132]. Teachers also uses mobile **digital games,** which motivate and engage students and help their success in different subjects[133]. **Teachers' guides**[134] are also used to guide teachers through the steps of planning and conducting an online, collaborative project in this classroom setting.

3. Task 3 – Estimation of the costs to equip and connect an average EU classroom with advanced components of the HECC

Box 3: Highlights Task 3

- This task aims to identify the associated costs of digital education initiatives at the national and/or regional level along the four dimensions of the HECC model (i.e., digital technology equipment, network requirements, professional development of teachers and access to content).
- The main goal of Task 3 is to estimate the costs to equip and connect an average EU classroom with advanced components of the HECC model.
- Cost data were collected via the use of (i) desk research; (ii) online market data/price lists; (iii) stakeholder consultations with national Ministries; and (iv) stakeholder consultations with a network of experts.

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[128] More information about eTwinning available at: https://www.etwinning.net/en/pub/index.htm
[129] School Education Gateway (2016)
[130] European Commission (2018a)
[131] E.g. https://www.golabz.eu/lab/wave-on-a-string; https://www.teachthought.com/learning-models/6-characteristics-of-tomorrows-classroom-technology/
[132] Definition retrieved from http://resources.schoolkit.co.nz/article/575-our-pedagogical-model; http://schoolkit.istruzione.it/schoolkit/
[133] Crompton, H., Lin, Y., Burke, D., & Block, A. (2017)
[134] E.g. https://www.teachervision.com/search/Teachers%20guide

Box 3: Highlights Task 3

- Cost data for the advanced HECC was then presented and expressed at the student level. In specific, the average cost per student per year to equip and connect an average EU classroom with advanced components of the HECC model is the following:
    - Dimension 1 (Digital technology equipment): 91 EUR – 150 EUR;
    - Dimension 2 (Network requirements): 48 EUR – 226 EUR;
    - Dimension 3 (Professional development of teachers): 55 EUR – 110 EUR;
    - Dimension 4 (Access to content): 30 EUR – 50 EUR
    - **Total cost per student per year (all dimensions): ~224 EUR – ~536 EUR**

Task 3 aims to identify the associated costs and scale of digital education initiatives at the national and/or regional level along the four dimensions of the HECC model (i.e., digital technology equipment, network requirements, professional development of teachers and access to content). Hence, the main goal of Task 3 is to **estimate the costs to equip and connect an average EU classroom with advanced components of the HECC model**.

More precisely, Task 3 consists of the following activities:

1. **Data collection**: Identification of the associated costs reviewing initiatives and investments undertaken in the field of digital education at the national and/or regional level in relation along the four dimensions of the HECC. The data was collected via the use of (i) desk research; (ii) online market data/ price lists; (iii) stakeholder consultations with national Ministries; and (iv) stakeholder consultations with a network of experts.
2. **Data analysis**: In depth analysis of the identified cost data per dimension of the HECC model; and
3. **Data consolidation:** Integration of the collected cost data into a price collection matrix in order to estimate the cost to equip and connect an average EU classroom with advanced components of the HECC model.

3.1 Data collection

Desk research

A desk research was performed between November 2017 and January 2018, aimed at identifying publications that report on recent investments undertaken at the national and/or regional level in primary and secondary education. The desk reserched focused on investments performed in the field of digital technology equipment, network requirements, professional development of teachers and access to content in line with the four dimensions HECC model.

Table 13: Desk research sources[135]

Desk research sources	Examples
Studies / reports	• Agasisti T., Hippe R., & Munda G. (2017) • Camilleri A., Ehlers U., & Pawlowski J. (2014) • European Commission (2014b) • Johnson, L., Adams Becker, S., Estrada, V., & Freeman, A. (2015) • Adams Becker, S., Freeman, A., Giesinger Hall, C., Cummins, M., & Yuhnke, B. (2016) • Freeman, A., Adams Becker, S., Cummins, M., Davis, A., & Hall Giesinger, C. (2017) • Licht, A.H, Tasiopoulou, E., & Wastiau, P. (2017) • TNTP (The new teacher project) (2015) • UK Department for Education (2013) • U.S. Department of Education, Office of Educational Technology (2014) • OECD (2016a) • Eleonora Villegas-Reimers (2003) • Miao, F., Mishra, S., & McGreal R. (2016) • European Commission (2017) • European Schoolnet (2017d) • Google (2013) • Camacho M. (2017)
Academia	• Breiter, A., Zeising, A., & Stolpmann, B. (2015) • Levi Hilton III, J., Robinson, T., Wiley, D., & Ackerman, J. (2014) • Wiley, D., Green, C., & Soares, I. (2012)
Review of data repositories and databases of publications, having access to studies in the area from the academia	• Web of Science • Scopus • ResearchGate • Academia

Market data collection (price collection)

The desk research was supported by an online market data collection exercise in which prices were gathered for the items for which no cost information was obtained through the other data collection methods. The price collection demonstrated large variations depending on the specific provider, the performance of the item and the degree of novelty of the specific version of the product. Furthermore, it seems reasonable to expect a substantial reduction in cost when ordering items in large numbers. As a result, we preferably choose prices at the lower end of the identified price range to inform the later cost calculation.

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[135] Data was mainly collected for the countries in scope of study, but, if deemed relevant for the purpose of the cost estimation exercise, the scope of the desk research was extended to non-European countries.

The research team consulted Price Comparison Tools (PCTs) and websites of digital equipment manufacturers and other providers of technologies and equipment to gather the associated costs per item. The table below shows the items for which either price information was obtained through consulting a) PCT websites or b) websites of digital equipment manufacturers and providers.

Table 14: Overview market data collection approach

Items for which price information was obtained through consulting PCT websites	Items for which price information was obtained through consulting websites of digital equipment manufacturers and providers
1. Smartphones	1. Wearable wristbands
2. E-book readers	2. VR headsets
3. 3D printers	3. VLE platform
4. Microcontrollers for coding activities	4. Assistive Technologies (AT) for student with special needs
5. Convertible laptops	5. Cloud-based platforms and services
6. Tablets	6. Interactive tables with projector
	7. Software and services (i.e. database management system, classroom management system, audio and video editing software licences, 3D modelling software licences, identity management services, data storage)
	8. Voice Assistant (VA)

Price Comparison Tools

PCTs are websites and search engines featuring price comparison and user-generated online reviews. They include all digital content and applications developed to be used by consumers to compare products and services online in terms of prices and functionalities. PCTs are considered as crucial instruments to provide clear and transparent pricing information.

The research team selected **a sample of 8 PCTs** displaying prices for various types of digital equipment. These PCTs are active in Belgium, France, Germany, Italy Spain and/or the UK.

Table 15: Consulted PCTs

Consulted PCT	Description of the organisation and PCT	PCT country origin
Test-Achat[136]	Non-profit organisation that promotes consumer protection by informing, defending and representing consumers. It offers consumers the possibility to compare online prices for different types of products and services	Belgium
Which.co.uk[137]	Consumer organisation that promotes consumer protection by providing unbiased advice to consumers, testing goods and services for consumers and publishing the results	UK
Pricespy[138]	Compares prices on thousands of and services and provides user and expert reviews allowing the consumer to make the best purchase decisions	UK

[136] Website of Test-Achat available at: https://www.test-achats.be
[137] Website of Which.co.uk available at: https://www.which.co.uk
[138] Website of Pricespy available at: https://pricespy.co.uk

OCU[139]	Consumers' protection organisation that runs comparative tests on behalf of consumers and offer the results on their website	Spain
123comparer.fr[140]	Independent French PCT	France
Idealo[141]	PCT owned by the German group Axel Springer active in several EU countries and providing price and products information on their website	France, Italy, Germany
Robot Shop[142]	Leading robot store for domestic and professional robot technology that allows comparison between prices and products	France, UK, Germany
Trovaprezzi[143]	Generalist PCT on the Italian market	Italy

The research team randomly **consulted 3 out of these 8 PCTs operating in a different country** as to collect the prices for the items indicated in the table below. Collecting price data from different PCTs and countries enables to calculate an average cost across the three countries for that item, allowing a more adequate cost estimation for the average level of a HECC.

The team browsed for each item on the three selected PCT websites and entered the description of the item in the search box of the website. In turn, all available products on the PCT website that matched that item were displayed. Out of that list, the research team filtered on the price so that the lowest prices for the item were shown. From that list, the team selected the three cheapest products and collected each time the price of that product. To illustrate: the item 'smartphone' was inserted in the search box of the PCTs '123comparer.fr', 'Which.co.uk' and 'Test-Achat'. Collected prices were integrated in an Excel file; the average prices (range value) retrieved from the 3 PCTs for the cheapest version of each item was calculated and served as the final price range for the item in the HECC model.

Table 16 : Collected data through PCTs

Items for which price information was obtained through the PCT	Three PCTs consulted per item	Countries for which the prices were collected	Date when price data was collected
Smartphone	123comparer.fr	France	23/02/2018
	Which.co.uk	UK	
	Test-Achat	Belgium	
E-book reader	123comparer.fr	France	06/03/2018
	Which.co.uk	UK	
	OCU	Spain	
3D printer	Idealo	France	06/03/2018
	Pricespy	UK	
	Trovaprezzi	Italy	
Microcontroller	Robot Shop[144]	France	23/02/2018
		UK	
		Germany	
Convertible laptops		Italy	23/02/2018

[139] Website of OCU available at: https://www.ocu.org
[140] Website of 123comparare.fr available at: https://www.123comparer.fr/
[141] Website of Idealo Germany, France and Italy available at: https://www.idealo.de/ https://www.idealo.fr/ https://www.idealo.it/
[142] Website of Robot Shop available at: https://www.robotshop.com/
[143] Website of Trovaprezzi available at: https://www.trovaprezzi.it/
[144] For the item microcontroller the specialised PCT 'Robot Shop' was used. 'Robot Shop' has country-specific websites allowing prices comparison across countries. Prices for microcontroller were collected for France, UK and Germany.

	Idealo[145]	Germany	
	Pricespy	UK	
Tablet	123comparer.fr	France	06/03/2018
	Which.co.uk	UK	
	Test-Achat	Belgium	

Website of digital equipment manufacturers and providers

For the remaining 8 items (i.e. wearable wristbands, VR headsets, VLE platform, Assistive Technologies (AT) for student with special needs, cloud-based platforms and services, interactive tables with projector, software and services, Voice Assistant) whose prices were not found through the PCTs, prices were directly extracted from price lists published on websites of specific technology manufacturers and providers of technologies and equipment. Websites of both EU and non-EU based companies were consulted taking into account the lack of publicly available pricing data for a limited number of items. Collected prices were integrated in a separate Excel spreadsheet, and if needed, were converted to EUR.

Stakeholder consultation with national Ministries

The third data collection method covers a stakeholder consultation with national Ministries which was carried out between January and February 2018. The 31 national Ministries for the countries in scope of the study were invited via e-mail to participate to the consultation through phone interviews.

The national Ministries were asked to participate in a phone interview in order to provide their input regarding:

1) Recent initiatives / investments undertaken at the national or regional level in primary and secondary education to upgrade the digital technology equipment, network requirements, professional development of teachers and access to content;
2) The costs related to these initiatives / investments in education; and
3) Planned initiatives / investments related to digital education investments in primary and secondary education within the next 3 years and the associated costs.

In total, **eight phone interviews** were organised with national Ministries. **Three national Ministries additionally provided feedback in writing**. The table below provides an overview of the Ministries that participated to the study.

Table 17: Output stakeholder consultations with national Ministries

Country	National Ministry	Phone interview	Feedback in writing
Belgium	Department for Education and Training – Ministry of Education and Training for the Flemish community in Belgium		✓
Belgium	General Administration for Education – Federation Wallonie-Bruxelles	✓	
Cyprus	Ministry of Education and Culture of Cyprus	✓	
Denmark	Ministry of Education of Denmark		✓
Estonia	Estonian Ministry of Education and Research		✓

[145] Similarly to 'Robot Shop', 'Idealo' is a PCT that has country-specific websites allowing prices comparison across countries. Prices for chromebooks using 'Idealo' were collected for France and Italy.

Finland	Finnish National Agency for Education[146]	✓	
France	French Ministry of Education		✓
Lithuania	Ministry of Education and Science of Lithuania	✓	
Netherlands	Kennisnet[147]	✓	
Norway	Norwegian Directorate for Education and Training[148]	✓	
Slovenia	Ministry of Education, Science and Sport of Slovenia	✓	
Spain	INTEF (Instituto Nacional de Tecnologias Educativas y de Formacion del Profesorado)[149]	✓	

Stakeholder consultation with a network of experts

In addition, experts were requested to also provide, to the extent feasible, qualitative and quantitative information on recent investments in the study area undertaken in Member States. In specific, the experts provided information on the following projects:

- The 'Samsung Smart School' project in Germany[150] and in Spain[151];
- The 2012 'School Broadband Programme'[152] project in Ireland;
- The 2015 'Escuelas Conectadas'[153] project in Spain; and
- The 2016 initiative 'NOOCs (Nano Online Open Courses)'[154] in Spain.

These initiatives are analysed in the data analysis section.

3.2 Data consolidation and analysis

The data collection activities allowed to identify information on a wide range of investments that have been undertaken and/or are foreseen by Member States (MS), regional and/ or local administrations to finance the development and upgrading of connected classrooms in their region/ country.

The following paragraphs provide a consolidation of the identified projects and costs presented per dimension of the HECC model. The costs are presented for all scenarios of a HECC, thus for both the entry level, advanced level and cutting-edge level of a HECC. This not only gives a complete overview of the costs of all categories and subcategories, but also allows schools to calculate their proper HECC model. As already mentioned before, the presented scenarios are a continuum and depend upon a number of external factors,

[146] The Finnish National Agency for Education is the national development agency responsible for early childhood education and care, pre-primary, basic, general and vocational upper secondary education as well as for adult education and training. Website of the agency available at: http://www.oph.fi/english/

[147] Kennisnet is the public organization for Education & ICT in Netherlands. They provide a national ICT-infrastructure, advise the sector councils and share knowledge with the primary education, secondary education and vocational education and training. Together with the sector counsels Kennisnet enable the educational sector to realize their ambitions with ICT. Kennisnet is funded by the Dutch Ministry of Education, Culture and Science More. More information available at https://www.kennisnet.nl

[148] The Norwegian Directorate for Education and Training is the agency under the Ministry of Education and Research responsible for kindergartens, primary schools and secondary schools. More information available at https://www.regjeringen.no/en/dep/kd/organisation/kunnskapsdepartementets-etater-og-virksomheter/Subordinate-agencies-2/norwegian-directorate-for-education-and-/id426533/

[149] (INTEF) is the National Agency for Educational Technology and Teacher Development funded by the Spanish Ministry of Education, Culture and Sport. The mission is to provide primary and secondary schools teachers with innovative resources and training opportunities to improve their competencies and acquire good practice skills, strategies and knowledge in all fields of education. More information available at http://educalab.es/en/intef

[150] Samsung (2016)

[151] Samsung (2015, 2016, 2017)

[152] Heanet (2010)

[153] Spanish Ministry of Education and Culture (2015)

[154] INTEF (2016)

not only at the school, but also at the country level. The presented scenarios could thus be completely individualized based upon the presented data below.

Dimension 1 - Digital technology equipment

Category	Subcategory	Items
Portable devices	Tablets & Smartphones	Android tablets, Window tablets, iOS tablets
	Laptops	Laptops, convertible laptops
	Other handheld devices	E-books readers
Fixed devices		Desktop computers

One initiative related to portable devices is the **'One Tablet Per Child' (OTPC)** scheme[155] launched in Malta in 2014, where all pupils in the 4th year of primary school, across all schools in Malta, were given a LearnPad Workbook 10.1 tablet. The project beneficiary, the Directorate for Quality Standards in Education, aimed with the project to provide a technical and pedagogical framework for the tablet to be effectively used in a teaching and learning environment. The OTPC is intended to support Malta's efforts to reach the EU 2020 goals in Early School Leaving and Further and Higher Education. The project cost approximately 11.9 million EUR[156]. About 80% of the project was financed through the European Social Fund (ESF); the residual part was funded by national funds[157]. In 2018, the project will be extended to include also children in the fifth year of primary schools[158].

In the Netherlands, a similar project was launched by the Tabor College d'Ampte (secondary education). The school provides the parents with the option to purchase an iPad for their children themselves or to lease it through the school. In the case of buying the iPad, the school provides the parents with a financial support of 120 EUR per student and additionally covers the insurance of the device[159].

With regard to **convertible laptops**, the average cost was obtained from the market data collection exercise via price collection tools which showed that **a basic convertible laptop** suited for educational activities costs approximately 200 EUR.

Cost figures for laptos and tablets were provided by the 2015 Bertelsmann Stiftung Study[160], which estimated the total cost of equipping a primary and secondary school in Germany with learning-friendly IT infrastructure, equipment and training for teachers. The cost estimation is supported by scenarios and sub-scenarios[161]. The study shows that the cost for one **laptop** amounts to about 500 EUR per device per student which has a lifetime of approximately five years. **Tablets** cost approximately 300 EUR per student. Cost information on tablets was also obtained through the market data collection method via PCTs which showed that on average, basic tablets costs around 50 – 100 EUR per student.

In addition to that, the Government of Cyprus (Ministry of Education and Culture) launched different initiatives between 2015 and 2017 to equip schools with various digital technology equipment with a total cost of approximately 4.9 million EUR. In total, 8,444 devices were purchased to be used in primary and secondary education. The cost estimated per device

[155] Ministry of Education and Employment in Malta (2017)
[156] EU Funds (2017)
[157] Idem
[158] Ecovis (2017)
[159] KennisNet (2017)
[160] Breiter, A., Zeising, A., & Stolpmann, B. E. (2015)

was estimated at: 585 EUR per **desktop computer**, 740 EUR per **laptop PC**, 331 EUR per **video projector** and 213 EUR per **printer or multi-function printers**. In addition to that, the Ministry of Education and Science of Lithuania provided cost information regarding the purchase of computers for schools. Amongst others, in 2017, 300 **desktop computers** were purchased at a price of about 654 EUR per device; 200 Samsung Galaxy Tab A 2016 were purchased at a price of 277 EUR per device; and a total of 500 Lenovo ThinkPad E570 were purchased at 658 EUR per device.

In addition, the availability of **e-book readers** in classrooms is expanding fast, especially in the last ten years[162]. The price range depends on the quality portrayed by the e-book readers. Cost-related data for the item e-book reader were additionally collected via market data collection using PCTs. On average, e-book reader costs between 50 – 100 EUR.

Category	Subcategory	Items
Interactive systems and devices		Interactive whiteboards, Data projectors, Interactive tables with projector

Data from the 2015 Bertelsmann Stiftung Study[163] showed that **interactive whiteboards** offer a good alternative as compared to conventional whiteboards and are more favoured by many schools in Germany. Prices for IWBs vary considerably in the market. A complete IWB costs on average 3,500 EUR and may have additional costs for its assembly. The device additionally requires a software, which is usually free of charge in the basic version, however, a full range of functions needs to be licensed. Such school licenses can cost up to 2,000 EUR per year. Other schools might opt for acquiring conventional and cheaper projectors. Due to the fact that these projectors are without interactive functionalities, schools generally need to buy additional accessories such as speakers and cameras to make the device more interactive. The cost of equipping a classroom with an **IWB** including the assembly, accessories and spare parts amounts to **26.67 EUR per student per year.** Traditional **beamers with projection screens** are cheaper than interactive whiteboards and cost according to the study **6.67 EUR per student per year[164].**

Finally, prices for **interactive tables with projector** were retrieved from the online market on the websites of specialised providers and they cost around 4,000 – 5,000 EUR.

Category	Subcategory	Items
Emerging technologies		3D printers, VR headsets, Wearable wristbands, Microcontrollers for coding activities (i.e. Arduino, Raspberry Pi, etc.), Voice Assistants (i.e. Alexa, Siri, etc.)

In 2013, the **UK Department for Education**[165] launched a programme to 3D printers into state-school classrooms to boost the teaching of science, technology, engineering, maths (STEM) as well as of design and technology. This initiative followed the 2012 pilot project under which the Department for Education allowed 21 secondary schools to trial the use of the printers in STEM and design and technology classes. Following the success of that

[162] Embong, A. M., Noor, A. M., Hashim, H. M., Ali, R. M. & Shaari, Z. H. (2012)
[163] Breiter, A., Zeising, A., & Stolpmann, B. E. (2015)
[164] Idem
[165] UK Department of Education (2013)

trial, the Department for Education decided to bring the technology into more schools and set up a fund of £500,000[166] (approx. 560,000 EUR[167]) so up to 60 teaching schools could buy 3D printers and train teachers to use them effectively.

With regard to the cost of this technology, prices of entry-level 3D printers adapted for educational purposes dropped to affordable levels, mainly thanks to the benefits from the open-source movement and to the expiration of previous patents[168]. Looking at the costs collected through market research, entry-level consumer 3D printers are available for £300 (approx. 336 EUR[169]) on the market at the time of conducting the price comparision exercise. More premium 3D printers, which allow to create a huge number of designs, cost around £1,000[170] (approx. 1,120 EUR[171]).

Wearable technologies are also becoming more and more present in primary and secondary classrooms. For instance, **Virtual Reality (VR) headsets** have become accessible to students in schools mainly thanks to the decreased price of the VR glasses. There are two ways of using virtual reality in the classroom. The first set-up involves a traditional desktop set-up in which the student explores a virtual environment using a computer, keyboard and mouse, or uses some other input device such as a controller. The second is fully immersive and requires the student to wear a head mounted display (HMD) and data gloves to interact within a virtual environment. This environment may take the form of a series of large screens or a complete CAVE virtual reality system[172].

The main drawback of VR is the cost of the headset. Nevertheless, progress has been seen in the economic scaling of the technology. In particular, a low-cost solution that boosted the spread of VR in education is Google Cardboard, a headset made of inexpensive materials. Google Cardboard gives students the possibility to build their own VR content in an accessible and flexible way[173]. Google Cardboard for example can be bought online by the customer for 6.30 EUR[174]. In addition, further cost information for the VR headsets was collected through the market data collection method from websites of market specialists. In particular, from the online market basic VR headsets cost between 50 – 100 EUR.

Another wearable technology which is progressively being used and introduced in schools is a **wearable wristband**. Some cheap solutions of wearable wristbands are available on the market[175]. For example, KidFit by X-Doria [176] is a wearable wristband fitness and sleep tracker for pupils aged 5-11, able to capture and respond to children's physical activity. The price for this device amounts to 32.99 EUR[177]. Alternatively, other more advanced solutions suitable for the educational context have been implemented. For instance, 'Heart Zones System[178]' is a fitness technology software and data driven programmes that engage, assess and motivate physical activity using wearables to empower students to pursue safe and healthy active lifestyles. This system is generally used within physical education classrooms by enhancing a new teaching method that utilizes wearables with real-time data feedback. The price for the classroom pack (30 students) for this 'Heart

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[166] Idem
[167] Conversion rate £/EUR: 1.1207 on 06/03/2018 from http://www.xe.com
[168] Canessa, E., Fonda, C., & Zennaro, M. (2013)
[169] Conversion rate £/EUR: 1.1207 on 06/03/2018 from http://www.xe.com
[170] Idem
[171] Conversion rate £/EUR: 1.1207 on 06/03/2018 from http://www.xe.com
[172] Virtual Reality Society (2017)
[173] Idem
[174] Price retrieved on 07/03/2018 referred to the product 'Knox V2' from Google Cardboard website: https://vr.google.com/intl/it_it/cardboard/get-cardboard/
[175] The article 'Top 10 fitness trackers for kids 2018' compares different fitness tracker tools available on the market. Available at: http://gadgetsandwearables.com/2017/12/25/fitness-trackers-kids
[176] More information on the product KidFit by X-Doria available at: http://gadgetsandwearables.com/2015/11/29/activity-tracker-for-kids-kidfit/
[177] Price for the product KidFit by X-Doria was retrieved on 06/03/2018 from: https://www.beslist.nl/products/sport_outdoor_vrije-tijd/sport_outdoor_vrije-tijd_484412/r/voor_kinderen/c/merk~10340870#/modal=browse/mcatid=206/mitemid=8599934/mshopid=1/mshopitemid=952671672/
[178] Official website of 'Heart Zones System' available at: https://heartzones.com/heart-zones-system/

Zones System' device amounts to 7,026.37 USD[179] (approx. 5,670 EUR[180]) which means 234 USD per students[181] (approx. 189 EUR[182]).

Many educators believe that coding helps students to understand how computers work, to communicate their thoughts in a structured and logic way, to think critically and to succeed in the digital working place[183]. As such, **microcontrollers for coding activities** were included in the HECC model which is defined as a computer present in a single integrated circuit that is dedicated to perform basic coding activities[184]. The cost information for microcontrollers was collected through the market data collection method via Price Comparison Tools. In terms of pricing, this technology ranges between 20 – 40 EUR per device.

The last emerging technology analysed refers to **Voice Assistant (VA).** Price data for the item 'Voice Assistant' has been retrieved by consulting the price lists provided online by specialised providers. On average, VA technologies cost between 0 – 60 EUR (free solutions also available on the market).

Category	Subcategory	Items
Cloud-based platform and services		Platform as a Service (PaaS), Software as a Service (SaaS)

Based on the lack of data publically available, no pricing information has been gathered on cloud-based platforms.

Category	Subcategory	Items
Virtual Learning Environment (VLE)		VLE platform

The VLE market is composed of a huge number of products, some of which are complimentary and others which are not aimed at the education field. When a school needs a VLE solution, the first priority is to identify the main players available on the market. In addition, schools can rely on free open-source solutions or, alternatively, purchase a ready-to-use product from market providers. With regard to the cost side, when setting up a VLE solution, there are two main cost elements that schools need to take into account. In particular: (i) one-off set up cost needed to build the inclusive learning environment; and (ii) licenses cost for all the students who are using the learning environment. As such, the cost for VLEs heavily depends on how many licenses are needed in the school. When schools however opt for using a free to download VLE, they need for example to take into account the substantial cost of setting up, customising and managing the platform effectively[185]. In addition, extra time and effort is required to create content and materials to be shared on the platform. One of the most popular open-source VLE is Moodle[186] which

179 Price for the product 'Heart Zones System' was retrieved on 06/03/2018 from: https://store.schoolspecialty.com/OA_HTML/ibeCCtpItmDspRte.jsp?minisite=10206&item=5825195&utm_referrer=https%3A%2F%2Fwww.google.lu%2Furl%3Fsa%3Dt%26rct%3Dj%26q%3D%26esrc%3Ds%26source%3Dweb%26cd%3D5%26ved%3D0ahUKEwjNwsWk99fZAhUQfFAKHVbPDdkQFghFMAQ%26url%3Dhttps%253A%252F%252Fm.store.schoolspecialty.com%252FOA_HTML%252FibeCCtpItmDspRte.jsp%253Fminisite%253D10206%2526item%253D5825195%26usg%3DAOvVaw07HB95obNkcWCwx8CexJjn
180 Conversion rate USD/EUR on 06/03/2018 : 0.807. From http://www.xe.com/
181 Each set of the product Heart Zones System is composed by 30 wristabands
182 Conversion rate USD/EUR on 06/03/2018 : 0.807. From http://www.xe.com/
183 Freeman, A., Adams Becker, S., Cummins, M., Davis, A., & Hall Giesinger, C. (2017)
184 Definition of microcontroller was retrieved from: https://www.techopedia.com/definition/3641/microcontroller
185 Gallacher, C. (2015)
186 Moodle is a Learning Platform or course management system (CMS) - a free Open Source software package designed to help educators create effective online courses based on sound pedagogical principles. More information on Moodle available at: https://moodle.org/

is a software using a mixed payment model: the users can access to basic elements of the platform for free whereas extra options are paid[187].

A meaningful comparison between different VLEs has been done at Taunton School[188] (UK). The comparison study showed that the market for VLEs at that time in the UK provided dozen of commercial VLEs, such as, Frog, LP+, SLG (SIMS Learning Gateway), Blackboard, Fronter, StudyWiz, SharePoint and Firefly. The market data collection exercise confirmed that almost all the above-mentioned VLE providers are still active on the market, however, there is generally few publicly available information on the prices for commercial VLEs. Pricing data was only collected for the installation and utilisation of 'StudyWiz'[189] VLE in an Australian high school. One-off set-up cost for installing StudyWiz VLE amounts to 3,125 USD[190] (approx. 2,522[191] EUR) per school or, assuming a school of 430 students, 7.26 USD per student (approx. 5.86[192] EUR). VLE license costs are 4,837.50 USD (approx. 3,904[193] EUR) per school per year or, with the same assumption previously taken about 11.25 USD (approx. 9.07[194] EUR) per student per year.

Category	Subcategory	Items
Software and services	Software and services	Word processing software, Spreadsheet software, Presentation software

Software distributors generally offer special educational contracts to schools under two models: the subscription model and the buying license. Both the cases apply to upgrade-licenses, meaning that older operating systems need to be installed already. On one hand, the rental/subsciption model has the particularity that licensing costs are calculated based on the number of people working full time at the school and that the products will be running on all computers. In terms of cost, for a subscription model there are yearly recurring costs. On the other hand, when the school is looking for a more long term solution (software usage is intended for more than 5 years), the buying option becomes a more economically viable solution than the subscription model. The 2015 Bertelsmann Stiftung Study[195] estimates that the cost for **basic software package under the subscription model**, including the operating systems as well as the Microsoft Office software, amounts to 4.56 EUR[196] per student per year.

A 2010 study from Kennisnet[197] in turn provides costs for software for a school who aims to become fully digitalised over the next coming years. Costs for software expressed per student per year cover those for **Microsoft and Adobe licenses** at 25.09 EUR per student per year, **software service desk application** at 0.37 EUR per student per year, **ghost reader** at 4.80 EUR per student per year and **Sophos antivirus** at 14.87 EUR per student per year.

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[187] iSpring (2015)
[188] Andy Kemp (2012)
[189] Studywiz Pty Ltd. provided learning software solutions to schools and school districts internationally. However, this provider is not operating anymore on the market of VLE.
[190] The reported pricing information refers to the implementation of 'Studywiz' VLE in high school. The price data are relatively outdated (September 2011) and, therefore, price fluctuations might have occurred. Price data retrieved from: https://pbhstechnology.wikispaces.com/file/view/Studywiz_Purchasing_Guide_Punchbowl_Boys_High_School_09092011%5B1%5D.pdf
[191] Conversion rate USD/EUR on 06/03/2018 : 0.807. From http://www.xe.com/
[192] Idem
[193] Idem
[194] Idem
[195] Breiter, A., Zeising, A., & Stolpmann, B. E. (2015)
[196] The cost is calculated based on the assumption of a school with 60 full time employees. In addition, it is relevant to highlight that the cost referred to basic software package also includes the cost for access to digital content from FWU. FWU is the media institute of all the German federal states together and Germany's leading producer of media used at schools and in further education. This specific cost item (FWU) is further analysed later in this chapter in dimension 4 (Access to content).
[197] Kennisnet (2010)

As an alternative to the paid software reported above, the software market also offers **free and open source solutions**. In particular, several alternatives to Microsoft's suite and programmes are available on the online market and compatible with different operating systems. For instance, programmes such as SoftMaker's FreeOffice, LibreOffice, WPS office and Google Suite offer very similar features to the traditional Microsoft Office and are generally compatible with all Microsoft document formats.

Category	Subcategory	Items
Software and services	Assistive technologies (AT)	Optical character recognition, Dictation tools (speech-to-text), Graphic organizers, Spell-checks and grammar checks

Information on AT and pricing data used in this section are mainly retrieved from the publication from ICT 4IAL and SENnet about 'Access for all to the classroom of the future: a basic toolkit for teachers to improve access to digital technologies for students with disabilities[198]'.

A first type of AT is **optical character recognition** (OCR) **technology**[199] that offers blind and visually impaired learners the capacity to scan printed text and then speak it back in synthetic speech through text-to-speech technology. The online market offers several free solutions of basic OCR that simply convert printed text into digital format (scanning and recognition phases). One of the most popular OCR apps, thanks to its easy to use functionality, is the 'PDF Scanner: Document Scan+ OCR'. Another simple and easy to use solution is 'Free Online OCR[200]' that supports 46 languages. For those users who are looking for more advanced OCR the 'OmniPage Standard 18[201]' costs 72.90 EUR[202]. These above-mentioned OCT software and apps need to be combined with text-to-speech technology. Once the OCR technology converted the written document into digital format, the text-to-speech technologies speak the digital version and make the document accessible to blind learners. Also the market of text-to-speech tools is rich of free to download solutions such as, for example, Balabolka[203], Natural Reader[204] and Panopretor Basic[205].

A second type of AT included in the HECC model is **speech-to-text tool**. The online market of speech-to-text tools is rich and varies from free tools to paid-for-software and apps. An example of free speech-to-text app available on the online market is Dragon Natural Speaking[206] which is a free app for the iPad, or as PC software. Alternatively, users might opt for paid tools such as Captura talk[207] that costs 16.99 EUR on Itunes Apple Store[208]. In addition, schools might rely on more advanced solutions which can be used for the overall

[198] ICT4IAL and SENnet (2014)
[199] American Foundation for the Blind (AFB) (n.d.)
[200] Website of Free Online OCR available at: http://www.onlineocr.net/
[201] More information on OmniPage Standard 18 available at https://www.nuance.com/print-capture-and-pdf-solutions/optical-character-recognition/omnipage/omnipag
[202] Price for the software OmniPage Standard 18 retrieved on 23/02/2018 from: https://shop.nuance.fr/store/nuanceeu/fr_FR/pd/productID.229630600/pgm.95401200/OfferID.42233879309/Currency.EUR?utm_source=google&utm_medium=emea-cpc&utm_campaign=IBU+%2F+OmniPage+Standard+%2F+Product+%2F+EU+-+FR+%2F+FR+%2F+None+%2F+Broad&keyword=%2Bomnipage+%2B18-b
[203] Website of the software Balabolka available at: http://www.cross-plus-a.com/balabolka.htm
[204] Website of the software Natural Reader available at: https://www.naturalreaders.com/
[205] Website of the software Panopretor Basic availale at: http://www.panopreter.com/en/products/pb/index.php
[206] More information on the software Dragon Natural Speaking is available at: http://www.nuance.fr/for-individuals/by-product/dragon-for-pc/index.htm
[207] Capturatalk is an all-in-one assistive technology app that has a range of features to assist with the accessibility of text, literacy and communication support on smartphones and tablets. More information available at: http://www.iansyst.co.uk/technology/iansyst%27s-product-innovations/capturatalk-app
[208] Price retrieved on 07/03/2018 from Apple App Store: https://itunes.apple.com/lu/app/capturatalk/id785701867?mt=8&ign-itsct=785701867-785701867&ign-itscg=0176&ign-mpt=uo%3D4

organisation. For instance, Read&Write[209] from TextHelp provides speech to text software at £800[210] (approx. 897 EUR[211]) per annum per school.

Students with ADHD, autism, dyslexia, aphasia, or who struggle with organizing their thoughts into written words might benefit from **graphic organizer tools**. An example of graphic organizer solution available on the market is 'Inspiration[212]' which is a software allowing kids to engage in the writing process through diagrams, outlines, graphics, video, and sound. 'Inspiration' is available on Amazon market place at 24 USD[213] (approx. 27 EUR[214]).

The last items analysed as part of the AT are **spell and grammar checks.** These Writing Assistive Technologies (WAT) come to assist people that have special writing disabilities. Regular spell checkers available on the markets and/or automatically installed in word processing software usually have some grammar checking capabilities. Ghotit[215] is a dyslexia writing and reading assistant that corrects grammar errors uncorrectable by regular spell checkers. Ghotit can be acquired via a pay-once perpetual license at 199 USD[216] (approx. 160.59 EUR[217]) for the full software for Windows or Mac and, alternatively, via a recurrent monthly subscription at 29 USD/month (approx. 23.40 EUR[218]).

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209 Read&Write literacy software makes the web and documents more accessible for children, students and employees with dyslexia and reading difficulties. More information on Read&Write software available at: https://www.texthelp.com/en-us/products/read-write/
210 Price retrieved on 07/03/2018 from the official website: https://www.texthelp.com/en-gb/pricing/
211 Conversion rate £/EUR on 08/03/2018: 1.1207. From http://www.xe.com/
212 Website of the software Inspiration available at: http://www.inspiration.com/Curriculum-Integration/special-needs
213 Price for the software Inspiration retrieved on 23/02/2018 from: https://www.amazon.com/s/ref=nb_sb_noss_2?url=search-alias%3Dsoftware&field-keywords=inspiration+
214 Conversion rate £/EUR on 08/03/2018: 1.1207. From http://www.xe.com/
215 Ghotit is a dyslexia writing and reading assistant. It is available both as a software and as a mobile apps. More information available at: https://www.ghotit.com/
216 The full price list of Ghotit solutions is available online at the following link: https://www.ghotit.com/get_it_now
217 Conversion rate USD/EUR on 06/03/2018: 0.807. From http://www.xe.com/
218 Conversion rate USD/EUR on 06/03/2018: 0.807. From http://www.xe.com/

Summary collected cost information Dimension 1 (Digital technology equipment)

The table below presents a summary of the costs for the categories, sub-categories and items part of Dimension 1. The costs were identified, where feasible, through analysis of the initiatives, stakeholder consultations and collected market data as described above.

Table 18: Collected cost information for Dimension 1

Category	Sub-category	Items	Cost in EUR	Cost expressed per
Portable devices	Tablets & Smartphones	Tablets (iOS, Android, Windows)	50 – 100 EUR	Per device
		Smartphones	50 – 100 EUR	Per device
	Laptops	Convertible laptops	200 – 300 EUR	Per device
		Laptops	300 – 700 EUR	Per device
	Other handled devices	E-book readers	50 – 100 EUR	Per device
Fixed devices		Desktop computers	550 – 700 EUR	Per device
Interactive systems and devices		Interactive Whiteboards (IWB)	• 30 – 40 EUR • 5,000 – 6,000 EUR	• Per student per year (lifetime of 8 years) • Per device (including software licenses for advanced functions)
		Data projectors	• 10 – 15 EUR • 200 – 300 EUR	• Per student per year (lifetime of 8 years) • Per device
		Interactive tables with projector	4,000 – 5,000 EUR	Per device
Emerging technologies		3D printers	150 – 300 EUR	Per device
		VR headsets	50 – 100 EUR	Per device
		Wearable wristband	100 – 200 EUR	Per device
		Microcontroller for coding activities	20 – 40 EUR	Per device
		Voice Assistant (VA)	0 – 60 EUR *(free solutions available)*	Per device
Cloud-based platform and services		Platform as a Service (PaaS)	N/A	
		Software as a Service (SaaS)	N/A	
Virtual Learning Environment (VLE)		VLE platform	• One-off cost: 7 – 10 EUR • Recurring cost (license): 8 – 10 EUR	• Per student • Per student per year
Software and services	Software and services	Classroom management system	• 1,500 – 2,500 EUR • 15 – 20 EUR • 1 – 5 EUR	• Per school per year • Per student per year • Per student per month
		Word processing software Spreadsheet system Presentation programme Database management system	• 3 – 7 EUR • 20 – 30 EUR (including Adobe software)	• Per student per year • Per student per year
		Audio and video editing software licences	• 15 – 20 EUR • 50 – 80 EUR	• Per license per month • Per perpetual license
		3D modelling software licences	20 – 140 EUR	Per license per year
		Identity management services	0.50 – 4 EUR	Per month per user
		Data Storage (e.g. Network Attached Storage)	80 – 300 EUR	Per year per school
	Assistive Technologies (AT) for people with special needs	Text-to-speech tools	*Free solutions available*	
		Optical character recognition	0 - 75 EUR (*free solutions available)*	Per software
		Dictation tools (speech-to-text)	0 - 20 EUR (*free solutions available)*	Per software
		Graphic organizers	20 – 40 EUR	Per software
		Spell-checks and grammar checks	• 150 – 170 EUR • 20 – 30 EUR	• Per software (perpetual license) • Per software per month (recurrent monthly subscription)

Dimension 2 – Network requirement

Costs related to network requirements cover: high-speed network connectivity (i.e. cable Internet, fibre Internet, fixed wireless, mobile broadband, satellite Internet), Wide-Area Network (WAN), High-speed local-area network (LAN), High-speed wireless local-area network (WLAN), maintenance and network monitoring.

The costs for network requirements may widely vary from country to country and region to region based on local circumstances.

The following factors most likely to have a large impact on the cost of a network infrastructure in schools[219]:

- Number of devices and type of digital learning sources the network should support and, hence, the resulting bandwidth requirements;
- Capacity and age of the physical infrastructure, including conduits, cables, network equipment and wireless access points;
- How much of the existing equipment can be re-used in a new network (in the case of upgrading a network / changing to another network);
- Location of the school and available paths for connecting the school to the Internet; and
- Level and type of security measures the school needs to provide.

Category	Subcategory
Network connectivity	Cable Internet, Fibre Internet, Fixed wireless, Mobile Internet, Satellite Internet

The need for a network infrastructure, especially at renewal of schools, derives from the fact that the digital tools used by today's students require a superior and faster bandwidth compared with previous online tools such as email and static materials. To allow students to access cutting-edge digital learning tools, an upgraded technical infrastructure is required in every classroom. Broadband roll-out in Europe has been accelerating in recent years and at present Internet access in some form – fixed or wireless – is an infrastructure that is expected to be available in schools, even in the most rural areas[220].

In Spain, the '**Escuelas Conectadas[221]'** project aims to equip national schools with high-speed Internet connectivity of at least 100 Mbit/second in accordance with the objectives of the 'Digital Culture Plan in the School' and the 'Digital Agenda'[222]. As part of specific plans of the Digital Agenda for Spain, the government approved an investment of 63.5 million EUR to provide ultrafast access to schools, which are part of the larger investments of 330 million EUR for the Connected Schools Programme. The project is co-financed by the EU through the European Regional Development Fund (ERDF). In total, 6.5 million Spanish students received benefits from this initiative, involving more than 16,500 Spanish non-university teaching centres[223].

Under the '**School Broadband Programme[224]'** launched in 2012, all the Irish 780 post-primary schools were connected by a high-speed 100 Mbit/second connection. The overall investment for this initiative was 30 million EUR, along a three-year programme rolled out on behalf of the Irish Government by HEAnet, Ireland's National Education and Research Network. Schools were not just provided with a high-speed 100 Mbit/second connection, but also with a managed school router, centralised content filtering, centralised firewalling, anti-virus and associated services.

[219] U.S. Department of Education, Office of Educational Technology (2014)
[220] Forzati, M., Cavenius, H., Salvatori, A., Agnelli, S., & Ciani L. (2017)
[221] Spanish Ministry of Education and Culture (2015)
222 European Commission (2014a)
[223] Idem
[224] Heanet (2010)

The first study shows the costs for implementing a network infrastructure presented for different types of Internet connection (i.e. (V)DSL/cable network (asymmetric), broadband connection (symmetrical), LAN, WLAN). The costs are expressed for one school per year as well as for one student per year. The cost of equipping a school with a (V)DSL/**cable network (asymmetric)** accessible to all the students amounts to a total of 600 EUR for the school per year or an average of 0.80 EUR per student per year. If schools are provided with a subscription for a **symmetrical broadband Internet access (e.g. based on fibre internet),** which allows more possibilities in terms of uploading and downloading data at the same time, the cost sharply increases to 12,000 EUR for the school per year or 16 EUR per student per year. The above data clearly highlights the difference in terms of pricing between an asymmetric Internet connection and a faster symmetrical broadband connection. Whilst connection speeds of cable Internet connections typically range between 20 Mbps and 100 Mbps (with actual data rates highly variable, depending on the provider and network conditions)[225], some fibre connections allow for speeds up to 100 Gbps[226]. However with the start of the proprietary data communication standards (such as Data Over Cable Service Interface Specification - DOCSIS) that permits the addition of high-bandwidth data transfer to an existing cable system, the cable industry targets to increase the transferable maximum data capacity[227]. With the upgrade to DOCSIS 3.1 (released in 2016), cable operators are able to deliver data up to download speeds as high as 10 Gbps and upload speeds as high as 2 Gbps over their existing hybrid fibre/coax lines[228]. In addition, also Vectoring technology has emerged as a means of increasing broadband speeds without investing in an extensive fibre roll-out. The technology uses noise cancellation[229], in a similar way to noise-cancelling headphones, to increase data speeds on existing copper infrastructure[230]. In order to get more bandwidth to each user group (including schools), typically a network segmentation has to be performed. Ideally this is done by using fibre trunks from the head-end to the respective network segment node. From this node the rest of the network segment is built with classic coaxial cable infrastructure which, thanks to DOCSIS 3.1 and Vectoring, is more powerful and allows access speeds up to Gbit level. In order to achieve the 2025 target[231] set by the European Commission of 1 Gigabit per second to all EU schools, network segmentation can be a viable solution to meet the speed required. Furthermore, investment costs for setting up the physical infrastructure in terms of high-capacity broadband networks (e.g. fibre networks, laying cables, etc.) would occur on top of these yearly costs.

The 2010 study from Kennisnet[232] shows the costs for infrastructure for an average digitalised school with 1,500 pupils and 100 teachers. The data of this study indicated that the total infrastructure costs have generally a strong relationship with the use of digital learning material. Nevertheless, costs for infrastructure cannot be one-to-one attributed to the use of digital learning material considering that computers are also used for other purposes (e.g. teachers use computers for administration). The school in the study assumed that 70% of the infrastructure costs occur in the framework of the use of digital learning materials. The total infrastructure costs for one school for the use of digital learning materials amounts to 64,680 EUR. The costs for physical aspects of the network are further detailed in the report (e.g. cabling total cost of approx. 4,000 EUR per year). The cost to have access to **fixed wireless** amounts to 8,000 EUR/year[233].

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225 Lifewire (2018)
226 U.S. Department of Education, Office of Educational Technology (2014)
227 DELTA Electronics (2015)
228 Heavy Reading (2016)
229 The concept of noise cancellation refers to the technology that analyses noise conditions on copper lines and creates a cancelling anti-noise. Definition retrieved from:
http://www.circleid.com/posts/20130606_the_pros_and_cons_of_vectoring/
230 Capacity Media (2012)
231 European Commission (2016e)
232 Kennisnet (2010)
233 Kennisnet (2010)

Mobile Internet connection[234] (4G/LTE[235]) can be a valid solution for network access for those schools that have not have an Internet connection. In the areas with 4G/LTE networks, schools can expect data download speeds of approximately 5 to 12 Mbps and upload speeds of approximately 2 to 5 Mbps per connection shared by all users. This means their performance and reliability rivals WLANs, especially those without pervasive coverage throughout the school. No studies nor market data were found supporting the estimation of costs for mobile Internet.

Satellite-based broadband can be used to access to Internet for those schools who cannot get online via the means described above (i.e. cable Internet, fibre Internet, wireless fixed and mobile), due to the fact that they are located in more rural areas. Satellite communications offer indeed a stable quality of service everywhere, regardless of geographic location[236]. In addition, satellite technology is considered the most cost-effective solution for broadband in remote areas with a low population density of typically less than 150 inhabitants[237]. A 2017 study[238] from the European Commission estimates the cost of building up a satellite network infrastructure that can be used to connect schools. When a school considers to set up a satellite broadband infrastructure, it should take into account both fixed and recurring costs. The fixed cost of equipping a school with fast Internet access with a standard solution allowing a speed up to 22 Mbps with 10-40 GB of monthly volume allowance per site amounts to 450-600 EUR per kit (including transport, installation, activation and VAT). The recurring costs for the same type of satellite connectivity network solutions are **between 35 EUR and 90 EUR per month per school[239].**

Category
Wide-area network (WAN)

A Wide Area Network (WAN) is a geographically distributed private telecommunications network that interconnects multiple local area networks[240]. In the education context, WAN provides connectivity between all the schools and sites within a region or country. A WAN may also connect to other educational institutions (such as universities and libraries) if the district is part of a regional education network[241].

The cost data referring to WAN networks is retrieved from the 2014 study from Education Superhighway[242]. This study developed a model that identifies the key equipment and services typically used to deploy and maintain a robust LAN, Wi-Fi, and core WAN network and estimates the aggregate cost of the equipment and services for the US' K-12 public schools. With regard to WAN networks, the cost estimation has been performed assuming different sizes of districts. In particular districts have been classified in tiny (1 school), small (2-5 schools), medium (6-15 schools), large (16-50 schools) and very large-sized (51-2.000 schools) districts. Per each district, the study identified the equipment/devices required to set-up a WAN network, the quantity of equipment/devices needed, the cost of the equipment and the replacement life for the specific equipment. In particular, with reference to a medium district (6-15 schools), the following elements are shown:

[234] Information referred to mobile broadband have been retrieved from: Center for digital education (2014)
[235] 4G is a family of mobile telecommunications protocols that delivers speeds up to 10 times faster than its predecessor, 3G. The major carriers now use a type of 4G network known as LTE. Definition retrieved from: Center for digital education (2014)
[236] Forzati, M., Cavenius, H., Salvatori, A., Agnelli, S., & Ciani L. (2017)
[237] Idem
[238] Idem
[239] Idem
[240] TechTarget. WAN (wide area network). Available at: https://searchenterprisewan.techtarget.com/definition/WAN
[241] U.S. Department of Education, Office of Educational Technology (2014)
[242] Education Superhighway (2014)

Table 19[243]: Equipment and cost for the setup of a WAN network in medium district				
Equipment[244]	**Quantity**	**Cost in USD[245]**	**Cost in EUR[246]**	**Lifetime (to replace the equipment)**
District Internal Core Switch/Router (Capex)	1	12,500	10,000	6
Firewall (Capex)	1	10,000	800	4
Content Filter (Capex)	1	10,000	800	4
Data Center Racks and Accessories (Capex)	1	5,000	4,000	12
Annual maintenance and support expenses	NA	7,875	6,350	NA

Based on the above cost-data, the overall cost for equipping a medium district with a WAN network amounts to **37,500 USD (approx. 30,300 EUR[247]) for the capital expenses[248]** and to **7,875 UDS (approx. 6,400 EUR[249]) for the annual maintenance and support expenses**.

Category
High-speed local-area network (LAN)

The wired local-area network (LAN) is the network within a school or district building through which computers and devices connect to the Internet. Compared to wireless technology, the wired LAN offers significantly higher transfer rates[250]. To support next-generation applications, most schools need indeed to upgrade their LANs. The Government of Cyprus, Ministry of Education and Culture, for example, has launched a project to upgrade the ICT infrastructure and structured cabling of 42 schools for secondary general education, technical and vocational education. The rest of the 78 schools that belong to this group have already implemented the upgrades in the period between 2007 and 2011. The design of the structured cabling uses a set of unified standards for all schools to provide both data and voice communication for the whole school (both administrative offices and classrooms). The structured cabling system of the school network is implemented using fibre optics and high-speed network equipment (router and switches) to facilitate high-speed network connections throughout the school. The project has already started and is scheduled to finish for all schools by June 2020 with an estimated cost of 1.6 million EUR. The project is subsidised by the EU. The cost involves the services of consulting engineers to prepare the design plans and afterwards to supervise the installation as well as the services of an electrical and mechanical contracting company to implement the design plans.

The Bertelsmann Stiftung[251] indicated that expanding the LAN network includes the installation of a double junction box in each classroom which is estimated to cost 4,725 EUR per school per year in the 5:1 model (i.e. one Internet-connected device shared by 5 students) or, considering an average school of 750 students about **6.30 EUR per student**

243 Education Superhighway (2014)
244 The definitions of the below equipment are reported in Annex 1 (Glossary): Education Superhighway (2014)
245 When relying on this study results and particularly on the costs, it should be taken into account that equipment prices have been collected from the US market and may be subject to fluctuations
246 Conversion rate USD/EUR on 06/03/2018: 0.807. From http://www.xe.com/
247 Conversion rate USD/EUR on 06/03/2018: 0.807. From http://www.xe.com/
248 Capital expenses include district internal core switch/router, firewall, content filter and data center racks and accessories
249 Conversion rate USD/EUR on 06/03/2018: 0.807. From http://www.xe.com/
250 Cisco (n.d.)
251 Breiter, A., Zeising, A., & Stolpmann, B. E. (2015)

per year. The expansion of the LAN network in the 1:1 model also costs 6.30 EUR per student per year.

High-speed wireless local-area network (WLAN)

Category
High-speed wireless local-area network (WLAN)

Schools might also opt for upgrading their LAN to a network where the data is not transmitted via cables but over the air through the use of wireless transmitters and receivers (Wireless Local Area Network – WLAN). The estimated cost of **upgrading an existing LAN infrastructure to WLAN** ranges from 3.00 to 6.00 EUR per sqm area[252]. Taking into account the assumptions for the model school such as the fact it comprehends a school size of 7,500 square meters, the upgrade cost ranges between 2,250 EUR and 4,500 EUR per school per year or, considering an average school of 750 students[253], between 3.00 EUR and 6.00 EUR per student per year.

The 2014 study from Center for digital education[254] takes into account relevant infrastructure elements which are required to upgrade an existing LAN network to a WLAN connection. In particular, two redundant master WLAN controllers (one as a failover) are needed so as to manage the WiFi-access point. The cost of one WLAN controller amounts on average to 45,000 USD as one-time charge (approx. 36,315 EUR[255]). In addition, access point and related licenses are required in order to allow a WiFi device to connect to a wired network. The cost of the WLAN access point and licenses is 55,000 USD as one-time charge (approx. 44,385 EUR[256]) and assumes that the access points would need to be renewed after 5 years.

Finally, a 2014 study[257] from Education Superhighway developed an interesting mixed model of Internet network for schools in the United States, called LAN/ WiFi, that incorporates features and characteristics of both LAN and WiFi networks (i.e. wired and wireless network). In specific, the study indicates a list of the required equipment and services, on a per-school and per-classroom basis, along with the quantities and costs represented in the LAN / WiFi cost model. In specific, the following elements are needed to equip an average US school with the LAN / WiFi network:

Table 20[258]: Equipment and cost for the setup of LAN / WiFi network

Equipment (school-level)[259]	Quantity	Equipment cost in USD[260]	Equipment cost in EUR[261]	Equipment installation cost in USD	Equipment installation cost in EUR[262]
Core Switching/Routing	1	10,000 – 12,000	7,000 - 9,000	-	-
Access Points	4	500 - 600	400 - 500	20 - 30	15 - 25

[252] Breiter, A., Zeising, A., & Stolpmann, B. E. (2015)
[253] This assumption comes from the Breiter, A., Zeising, A., & Stolpmann, B. E. (2015).
[254] Center for digital education (2014)
[255] Conversion rate USD/EUR on 06/03/2018: 0.807. From http://www.xe.com/
[256] Conversion rate USD/EUR on 06/03/2018: 0.807. From http://www.xe.com/
[257] Education Superhighway (2014)
[258] Idem
[259] The definitions of the below equipment are reported in Annex 1 (Glossary): Education Superhighway (2014)
[260] When relying on this study results and particularly on the costs, it should be taken into account that equipment prices have been collected from the US market and may be subject to fluctuations
[261] Conversion rate USD/EUR on 06/03/2018: 0.807. From http://www.xe.com/
[262] Conversion rate USD/EUR on 06/03/2018: 0.807. From http://www.xe.com/

WiFi Site Survey	1	-	-	3,200 – 4,000	2,500 – 3,300
Power distribution unit	1	1,400 – 1,500	1,100 – 1,200	-	-
Rack and Accessories	1	4,000 – 5,000	3,200 – 4,200	200 - 300	150 - 250
Annual maintenance and support expenses	NA	1,500 – 1,600	1,200 – 1,300	NA	NA

Equipment (classroom-level)[263]	**Quantity**	**Equipment cost in USD**	**Equipment cost in EUR[264]**	**Equipment installation cost in USD**	**Equipment installation cost in EUR[265]**
Wireless Access Points	1.2	500 - 600	400 - 500	20 - 30	15 - 25
Wireless Management	1.2	100 - 200	80 - 180	-	-
Wired Drops	6	15 - 20	10 - 15	200 - 300	150 - 250
Access Switch Ports	6	50 - 100	40 - 80	-	-
Switch-switch fibre	0.1	2,000 – 2,500	1,600 – 2,100	8,000 – 9,000	6,400 – 7,400
Power distribution unit	0.1	300 - 400	250 - 350	-	-
Rack and accessories	0.1	2,000 - 3000	1,600 – 2,600	200 - 300	150 - 250
Annual maintenance and support expenses	NA	100 - 200	60 - 160	NA	NA

From the above data it results that, overall, the cost of equipping a school with the mixed network model of LAN / WiFi amounts to 23,000[266] USD (approx. 19,000 EUR) of capital expenses[267] (one-off cost) and to 1,152 USD (approx. 900 EUR) of annual maintenance and support expenses. In turn, the cost of equipping each classroom part of the school with the same network infrastructure amounts to 3,722[268] USD (approx. 3,000 EUR) of capital expenses[269] (one-off cost) and to 1,152 USD (approx. 900 EUR) of annual maintenance.

Category	**Subcategory**	**Items**
Network connectivity	Cable Internet, Fibre Internet, Fixed wireless, Mobile Internet, Satellite Internet	Service, maintenance and network monitoring, User help desk/technical support

[263] The equipment referred to classroom level includes all the devices to be installed in each classroom. Therefore the number of devices (and, as a consequence, the costs) depend on the number of classroom in each school.
[264] Conversion rate USD/EUR on 06/03/2018: 0.807. From http://www.xe.com/
[265] Conversion rate USD/EUR on 06/03/2018: 0.807. From http://www.xe.com/
[266] This cost figure considers the overall cost of the following equipment: core switching/routing, core access points, Wi-Fi site survey, power distribution unit and rack and accessories. For each equipment the following calculation was done: (equipment cost in USD + equipment installation cost in USD) * quantities. Finally, all the costs of the above-mentioned equipment were summed.
[267] Capital expenses include: core switching/routing, core access points, WiFi site survey, power distribution unit and rack and accessories.
[268] This cost figure considers the overall cost of the following equipment: wireless access points, wireless management, wired drops, access switch ports, switch-switch fibre, power distribition unit, rack and accessories. For each equipment the following calculation was done: (equipment cost in USD + equipment installation cost in USD) * quantities. Finally, all the costs of the above-mentioned equipment were summed.
[269] Capital expenses include: wireless access points, wireless management, wired drops, access switch ports, switch-switch fibre, power distribution unit, rack and accessories

When setting up a broadband infrastructure in schools, many schools underestimate the cost drivers for ongoing service, maintenance and network monitoring as well as for human capital. Human capital costs include the time, personnel, sustained professional development and expertise to manage the network and provide technical support for teachers, staff and students. Staff can include consultants to assist with technology planning, set-up, and testing; in some cases, a full-time ICT coordinator can be assigned.

The **maintenance and upgrade of devices and equipment** is key to guarantee reliable and continuous operations of the school ICT infrastructure. Therefore, schools should allocate some budget to cover this cost. The estimated cost for infrastructure maintenance for a 5:1 model (ratio of 5 pupils per computer) is approx. 27,000 EUR per year per school or 36 EUR per student per year. For a 1:1 model (ratio of 1 school pupil per computer) the cost is approx. 135,000 EUR per year per school or 180 EUR per student per year[270].

As noted above, another type of cost driver deals with the personnel costs for user help desk/technical support. Such human capital costs include the time, personnel, sustained professional development and expertise to manage and monitor the network as well as provide technical support for teachers, staff, and students[271]. Usually, schools with an extensive broadband network opt for creating **a dedicated permanent IT position** who can support the planning, the implementation and the control of a development planning process. On average, the estimated staff costs for one FTE managing 300 IT terminals is about 15 EUR per computer per month or 180 EUR per computer per year in (in the case of the 1:1 model) and 36 EUR per computer per year in the case of the 5:1 model. Schools that do not assign a position of a dedicated IT position can transfer some of the services to other service providers which would usually lead to a similar cost[272].

[270] Idem
[271] U.S. Department of Education, Office of Educational Technology (2014)
[272] Idem

Summary collected cost information Dimension 2 (Network requirements)

The table below presents a summary of the costs for the categories, sub-categories and items part of Dimension 2. The costs were identified, where feasible, through analysis of the initiatives, stakeholder consultations and collected market data as described above.

Table 21: Collected cost information for Dimension 2

Category	Sub-category	Items	Cost in EUR	Cost expressed per
Network connectivity	Cable Internet / Internet over cable		• 500 – 2,000 • 0.80 – 1	• Per school per year • Per student per year
	Fibre Internet		• 15 - 20 for Internet package allowing symmetrical broadband access[273]	• Per student per year
	Fixed wireless		• 3,000 – 9,000	• Per school per year
	Mobile Internet		• N/A	
	Satellite Internet		• 450 – 600 • 50 - 100	• Per school per kit (fixed cost) • Per month per school (recurring cost)
High-speed district wide-area network (WAN)			• 25,000 – 35,000 • 5,000 – 6,000	• Per school (one-off capital expenses) • Per schools per year (maintenance and support)
High-speed local-area network (LAN)			• 0.80 - 16 • 6 - 10 • 4,000 – 5,000	• Per student per year (5:1 model) • Per student per year (1:1 model) • Per school per year
High-speed wireless local-area network (WLAN)			• 3 - 6 • 2,250 – 4,500	• Per student per year (5:1 model and 1:1 model) • Per school per year (5:1 model and 1:1 model)
Maintenance and network monitoring		Service, maintenance and network monitoring	• 27,000 – 30,000 • 30 - 40 • 120,000 – 140,000 • 180 - 200	• Per year per school (5:1 model) • Per student per year (5:1 model) • Per year per school (1:1 model) • Per student per year (1:1 model)
		User help desk/technical support	• 15 - 30 • 180 - 200 • 35 - 45	• Per computer per month (1:1 model) • Per computer per year (1:1 model) • Per computer per year (5:1 model)

[273] These costs refer to the yearly subscription costs per student for an Internet package allowing a symmetrical broadband Internet access. Investment costs for setting up the physical infrastructure in terms of high-capacity broadband networks (e.g. fibre networks, laying cables, etc.) would occur on top of these yearly costs.

Dimension 3 – Professional development of teachers

In this framework, investments in education and training systems are becoming increasingly crucial in order to improve the effectiveness and efficiency in raising the skills and digital competence of teachers. Following that, dimension 3 focuses on assessing the level and costs of the professional development that teachers should receive who use digital equipment and infrastructure in the organisation and administration of their school. In the following section, we will elaborate on the various elements of such professional development of staff through the use of face-to-face training, workshops, seminar, courses, etc.

From the data collection activities, it emerged the complexity and the limitations of obtaining publicly available information to estimate the cost of professional development of teachers related to ICT training as well as of implementing training programmes on the correct use of digital technologies for pedagogical purposes in schools.

Category	Subcategory
Face-to-face training	Courses and workshop, Coaching and peer support
Online training	Online courses, Online resources, Teachers' networks & communities of practice
Hybrid training	

The Norwegian government invested 1.2 billion NOK (approx. 125 million EUR[274]) in further and continuing education for teachers in 2015 with the 2015 strategy **'Promotion of the status and quality of teachers – a joint effort for a modern school of knowledge'**[275]. Approx. 5,050 teachers were offered places on courses in continuing education in order to help them to obtain the qualifications they need. In particular, courses on the **pedagogical use of digital technologies** were available both as learning/blended learning courses and as traditional courses.

In 2016, the Finnish National Agency for Education launched **a national tutor teacher programme**[276], aimed at training a tutor teacher for each Finnish school. The EUR 90 million programme (2016 figures) aims to make Finland the leading country for modern learning and inspiring education by 2020. The programme covers three strands: teacher education, innovative pedagogy and local experimentation. All comprehensive schools will be given tutor teachers to support their peers in new (digital) learning methods and collaborative teaching. The tutor teacher's task is to support and train their colleagues locally, with a specific focus on **how to use ICT pedagogically**. About 7.5 million EUR has been earmarked in 2016 to train and support 2,500 tutor teachers.

In 2014, the Estonian Ministry of Education and Research started promoting and coordinating via HITSA[277] (Information Technology Foundation for Education); a network of educational technologists who are teachers supporting other teachers in using digital technologies in teaching in a methodological and pedagogical correct way. The investment on the network of educational technologists amounts to 40,000 EUR per year.

In the 2010 study from Kennisnet[278] however, cost information is presented related to the training of personnel. Nevertheless, no details on the scope of the training is provided. Examples of trainings provided at a school level in the Netherlands and the associated costs are:

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[274] Conversion rate NOK/EUR on 13/03/2018: 0.104. From http://www.xe.com/
[275] European Schoolnet (2015b)
[276] European Commission (2016e)
[277] The Information Technology Foundation for Education (HITSA) is a non-profit association established by the Republic of Estonia, the University of Tartu, Tallinn University of Technology, Eesti Telekom and the Estonian Association of Information Technology and Telecommunications. Website of the association available at: http://www.hitsa.ee/about-us
[278] Kennisnet (2010)

- Digital skilled teachers and coordinators (e.g. training in relation to managing tasks, managing curriculum, optimising processes, etc.) which costs about 335.77 EUR/student per year;
- Training / workshop to work with MacBooks which costs about 5.85 EUR/student per year; and
- Training ICT staff regarding the Apple platform which costs about 5.78 EUR/student per year.

Also in a 2006 report by Becta ICT Research on 'Managing ICT costs in schools'[279], findings are shown related to costs for **user self-support, formal support, training, consumables, network, software and hardware**. The results are based on a sample of 43 surveyed schools in 2002-2005 in the United Kingdom in both primary, secondary and special schools in a variety of settings from rural to inner city and also included large and small schools which are varied in their level of ICT provision. The indicated average costs for training related to ICT per year are:

- User self-support related to ICT: 12,116 £/year (approx. 13,634 EUR[280]) for a primary school and 74,183 £/year (approx. 88,136 EUR[281]) for a secondary school;
- Formal support related to ICT: 16,784 £/year (approx. 18,809 EUR[282]) for a primary school and 95,159 £/year (approx. 106,644 EUR[283]) for a secondary school; and
- Training related to ICT: 2,113 £/year (approx. 2,368 EUR[284]) for a primary school and 2,769 £/year (approx. 3,103 EUR[285]) for a secondary school.

As an alternative to the more traditional face-to-face training sessions, teachers can also participate to **online training and courses** as well as to online community of practices and web-based networks. The innovative formats of teachers' training through ICT (e.g. MOOCs, OpenCourseware, webinars, web-based networks) help reduce the cost of training. For instance, MOOCs, Open Courseware and Webinars are online distance courses that are free of charge and that can be accessed by everyone without entry requirements[286]. As such, the participants do not have to pay for a full course experience: all the resources and most of the course services (e.g. feedback, tests, quizzes, exam and some limited tutoring).

Online communities of practice also offer great potential for teachers, in helping them to create and sustain networks of mutual support. There are already a wide range of online communities that aim to help teachers to support one another. These communities range from groups within large corporate providers (e.g. Facebook, EdModo, etc) and government sites (e.g. Scootle) to institutional (e.g. individual university-provided sites) and researcher-led platforms. Also in this case, online communities of practices are generally open freely to all teachers and educators who are interested in joining the online community.

Some EU Member States have opted to offer teachers **hybrid training** solutions. Hybrid traing combines both traditional training courses with online training. For example, over the years 2009 to 2013, the Slovenian Ministry of Education developed and financed a training programme[287] to strengthen teachers' ICT skills. Teachers were provided with two types of training as part of a single course. In particular: (i) traditional courses (top-down

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[279] Becta ICT Research (2006)
[280] Conversion rate £/EUR: 1.1207 on 06/03/2018 from http://www.xe.com
[281] Idem
[282] Idem
[283] Idem
[284] Idem
[285] Idem
[286] OECD (2016b)
[287] The information on this initiative as well as the related cost data have been collected during the consultation with the Slovenian National Ministry of Education. Further information on the initiative to be consulted via: Republic of Slovenia, Ministry of Education, Science and Sport (2016). Strategic guidelines for further implementation of ICT in the Slovenian education until 2020. Retrieved from http://www.mizs.gov.si/fileadmin/mizs.gov.si/pageuploads/URI/Slovenian_Strategic_Guidelines_ICT_in_education.pdf

approach) taken both face-to-face and online via distance-learning workshop; and (ii) peer-to-peer training. Half of the training programme was offered online, using 'Moodle[288]'. More than 36,000 teachers (annually roughly 8,000) participated to this training session. This training course is a typical example of a hybrid training which combines both face-to-face instructions with online learning. The duration of the course was set to 3 days. In total, the cost of **20 hours (3 days) training was 195 EUR[289] per teacher** for the whole course.

A final element that should be taken into account when performing an estimation on the cost for teachers' training refers to the **reduced teaching load**, meaning the hourly costs of the teacher (i.e. costs through allocation of teachers' time) dedicated to the training. The Bertelsmann Stiftung[290] study also reports that the cost per student (secondary education) for the reduced teaching load ranges between 5 – 10 EUR.

Category	Subcategory
Leadership training	

School leaders or those who have specific responsibilities (e.g. head of a specific subject), might also need specific ICT training in order to know how to put the desired/requested ICT change into practice in their school. In addition, school leaders should be skilled on how to define an action plan for the digital transformation in their schools and on how to organise the digital domain within their institutions. Finally, school leaders should be able to evaluate the situation and developmental needs of the digital infrastructure in accordance with the institution's needs.

Some national Ministries have promoted and developed training programmes with the objective of improving ICT skills of school leaders. For instance, the Estonian Ministry of Education and Research launched in 2015 the programme 'Educational Leader in a Digital Age[291]'. The program supports leaders at all educational levels to lead the learning process in the digital age purposefully and to create, as a team, an ICT vision and action plan for their institution. This training aims to develop teachers' professional (job-specific) digital competence and their skills to develop students' digital skills. From the data collected during the stakeholder consultation with the Estonian Ministry, approx. 400,000 EUR are invested every year to support this programme. In particular, in 2017, 3,788 education leaders participated in these training courses which are organised by HITSA[292] (Information Technology Foundation for Education). Based on the above cost data from the Ministry, the research team calculated that the cost of this programme amounts to **approx. 106 EUR per school leader for the whole training**.

[288] Moodle is a Learning Platform or course management system (CMS) - a free Open Source software package designed to help educators create effective online courses based on sound pedagogical principles. Website of Moodle available at: https://moodle.org/
[289] This cost information was shared by the Slovenian Ministry of Education during the consultation with Ministry performed as part of Task 3.
[290] Breiter, A., Zeising, A., & Stolpmann, B. E. (2015), Breiter, A., Zeising, A., & Stolpmann, B. E. (2017)
[291] European Schoolnet (2015a)
[292] The Information Technology Foundation for Education (HITSA) is a non-profit association established by the Republic of Estonia, the University of Tartu, Tallinn University of Technology, Eesti Telekom and the Estonian Association of Information Technology and Telecommunications. Website of the association available at: http://www.hitsa.ee/about-us

Summary collected cost information Dimension 3 (Professional development of teachers)

The table below presents a summary of the costs for the categories, sub-categories and items part of Dimension 3. The costs were identified, where feasible, through analysis of the initiatives, stakeholder consultations and collected market data as described above.

Table 22: Collected cost information for Dimension 3

Category	Sub-category	Items	Cost in EUR	Cost expressed per
Teachers' professional development on ICT skills (reduced teaching load)			1,500 – 2,500	• Per primary school per year (two to four hours per
Hybrid training			150 - 250	• Per teacher per course (20 hours - 3 days)
Leadership training			100 – 500	• Per school leader per training course

Dimension 4 - Access to content

In order to create new opportunities for students for meaningful learning, digital content and resources are more and more available in schools and accessible to students and teachers. Open online learning as an access tool is becoming increasingly popular in Europe and elsewhere, with the rise of Open Educational Resources (OER), Massive Open Online Courses (MOOCs) and other forms of non-formal and informal learning that emerge from opening up educational processes through the use of digital technologies [293].

Open online learning can be provided in different formats ranging from paid content offered by e-learning centers or online media distributors (e.g. online courses, online resources and full-course resources), free Open Educational Resources (OER) content and teachers generated OER, which may be accessible through the server of the school. The distinguishing feature of OER when compared to other resources refers to the freedom with which it may be used, reused and repurposed thanks to its open licence[294].

The data collection for dimension 4 focuses on the costs to access to digital educational content, excluding the costs related to the technologies and platforms linked to the creation, collection and dissemination of digital resources. In addition, also the technical infrastructure (i.e. hardware) needed to be installed in schools to allow students to access to digital content (i.e. computers, laptops, etc.) is not included in this section as it was previously reported in Dimension 1.

Category
Paid for content

Software applications for educational purposes (pedagogic content) are usually locally installed on the computers of schools or via an appropriate online software. Digital learning materials can also be accessed via online media distributors; the user is often required to pay for the access to these materials. In Germany for example, digital learning materials can be accessed via the Media centers of Merlin, BMOD, EDMOND, etc. Users are required to pay a flat-rate license fee to access the library with content including more than 4,000 media. An average primary school pays approx. 360 EUR per year to access media from the FWU[295]; an average secondary school pays approx. 600 EUR per year[296].

According to Ekelund (2018), schools' purchasing of physical and digital teaching materials continues to decline. In 2017, schools in Sweden in total purchased analogue and digital teaching materials for an average of 50 EUR per pupil. The sale of analogue learning material declined significantly, while the schools' purchase of digital teaching aids increased by around 35 per cent, though from a very low level. Of the total sales of teaching materials, the digital teaching materials make up only 10 percent. Estimations show that a complete set of digital teaching material (all subjects) coud amount up to 70 Euro per pupil and school year[297].

Other National Ministries opt for acquiring digital materials and contents from external publishers. The Lithuanian Ministry of Education acquired, for instance, digital materials through a public tender in 2014. The Ministry particularly acquired digital resources for

[293] Camilleri A., Ehlers U., & Pawlowski J. (2014)
[294] Idem
[295] FWU is the media institute of all the German federal states together and Germany's leading producer of media used at schools and in further education. Every year, the Institute produces about 130 new titles. Its range includes didactic DVDs, interactive multimedia software, CD-ROMs and nationwide video curricula for all grades and types of schools. The digital material is accompanied by additional information to assist teachers in designing their lessons.
[296] Breiter, A., Zeising, A., & Stolpmann, B. E. (2015)
297 Ekelund, R. (2018)

specific subjects. The cost of the digital contents amounted to approx. 140,000 EUR per subject[298].

Category
Free OER content

One of the potential benefits of the digital revolution in education, as outlined in the 2013 European Commission's Communication 'Opening up education'[299], implies that individuals can easily seek and acquire knowledge from sources other than their teachers and institutions. Learning is no longer confined to specific classroom timetables or methods, new education providers have emerged and teachers can more easily share and create content with colleagues and learners from different countries. In addition to broadening access to education, wider use of new technology and open educational resources contributed to alleviate costs for educational institutions and for students. Consequently, besides the access to paid content, learners have more and more access to a large range of educational resources provided in **a free format** (i.e. Open Educational Resources - OER). Although OER are educational resources which are freely accessible and openly licensed, there are still relevant permission barriers which may result in costs. On the one hand, OER can be reused and shared, producing substantial cost savings. On the other hand, there are some costs in the assembly and adaptation process[300], which have to be carefully considered. OERs need to be created by some publishers or authors before being distributed across the online network. These costs include the time of people in creating curricula and materials, adapting existing OER, obtaining copyright licensing, etc. In addition, other associated costs have to be taken into account such as the cost to build the ICT infrastructure that allows the distribution of OER contents. However, an estimation of the costs associated to the creation of OER would be complicated due to the level of complexity of the specific conditions / assumptions to be taken into account. Thus, within the framework of our study, OER are considered as free of charge for the final user (i.e. students and/or teachers) and they do not affect the classroom's cost model.

Category
Teachers generated OER

Due to the growth of OER, creative teachers started not only creating their own materials, but also sharing and distributing these contents among the community as OER. Teachers who are ready and willing to create and share educational materials as OER, they need access to technologies and tools to support these activities. However, similarly to the approach adopted in the above section on 'free OER content', access technologies and tools to support OER creation are not considered as items part of dimension 4 of the HECC model. Thefore, no cost estimation is performed with regard to access technologies and tools. Consequently, teachers' generated OER are deemed as free of charge and they do not have direct impact on the classroom's cost model.

[298] An example of digital resources acquired by the Lithuanian Ministry related to artistic education subject (music, dance, theatre) is available at the following link: https://smp2014me.ugdome.lt/
[299] European Commission (2013a)
[300] Miao, F., Mishra, S., & McGreal, R. (2016)

Summary collected cost information Dimension 4 (Access to content)

The table below presents a summary of the costs for the categories, sub-categories and items part of Dimension 4. The costs were identified, where feasible, through analysis of the initiatives, stakeholder consultations and collected market data as described above.

Table 23: Collected cost information for Dimension 4

Category	Sub-category	Items	Cost in EUR	Cost expressed per
Paid for content			• 12.0000 – 20.000 EUR	• Per year and per school (estimated upon FWU[301] media and information from Sweden and Lithuania)
Free and OER content			*Free of charge*	
Teachers generated OER			*Free of charge*	

[301] FWU is the media institute of all the German federal states together and Germany's leading producer of media used at schools and in further education. Every year, the Institute produces about 130 new titles. Its range includes didactic DVDs, interactive multimedia software, CD-ROMs and nationwide video curricula for all grades and types of schools. The digital material is accompanied by additional information to assist teachers in designing their lessons.

3.3 Cost per student for an advanced HECC

This section presents the estimated costs to equip and connect an average EU classroom with advanced components of the HECC model. Costs are presented **at student level** based on the following assumptions:

- A classroom composed of 23 students[302] between age 11/12 years old (ISCED 2)[303];
- The classroom is envisaged as part of a medium-sized public school (= 400 students)[304] located in an urban area; and
- Seven to eight teachers[305] from different subjects are responsible for the classroom.

The following table summarises the selected items for the advanced scenario of a HECC as well as the related costs per student.

[302] Eurostat (2012), OECD. (2017a)
[303] Idem
[304] OECD (2015)
[305]OECD (2014b)

Table 24: Summary of selected items for the advanced scenario of a HECC and related costs per student			
HECC Dimension	HECC Category/Subcategory	HECC Item	Cost per student per year in EUR
Dimension 1 (Digital technology equipment)	Portable devices	Convertible laptops (1:3 student)	14 - 20 EUR[306]
	Interactive systems and devices	Interactive Whiteboards (IWB) (one per classroom)	30 - 40 EUR[307]
		Interactive tables with projector (one per classroom)	20 - 27 EUR[308]
	Emerging technologies	Microcontrollers for coding (1:3 student)	0.9 – 1.7 EUR[309]
		3D printers (one per school)	0.08 – 0.16 EUR[310]
	Cloud-based platforms and services	Platform as a Service (PaaS)	N/A
	Virtual Learning Environment (VLE)	VLE Platform	One-off cost : 7 - 10 EUR Recurring cost (license) : 8 - 10 EUR
	Software and services	Word processing software	3 - 30 EUR
		Spreadsheet software	
		Presentation software	
		3D modelling software	0.05 – 0.35 EUR[311]
		Data Storage	0.20 – 0.75 EUR[312]
		Classroom management system (e.g. student information system)	15 - 20 EUR
	Assistive Technologies	Optical character recognition	*Free solutions available*
	Total estimated costs for dimension 1		**91 EUR – 150 EUR**

[306] Assuming 23 students per classroom, 8 devices are needed to comply with the 1:3 model (1 device for 3 students). Considering that the cost for a Chromebooks was estimated between 200-300 EUR per device (5 year lifetime), the cost of Chromebooks per student is between 14 - 20 EUR.
[307] Cost for the item ‘Interactive whiteboard’ (8 year of lifetime) was retrieved from: Breiter, A., Zeising, A., & Stolpmann, B. E. (2015)
[308] Assuming 23 students per classroom, the cost per student of an interactive table with projector (8 years of lifetime) available in each classroom is between 20 – 27 EUR.
[309] Assuming 23 students per classroom, 8 microcontrollers are needed to comply with the 1:3 model (1 device for 3 students). Considering that the cost for a microcontroller (8 years of lifetime) was estimated between 20-40 EUR per device, the cost of microcontrollers per student is estimated between 0.9 – 1.7 EUR.
[310] Assuming 400 students per school, the cost per student of one 3D printer (5 years of lifetime) available in the school is between 0.08 – 0.16 EUR.
[311] Assuming 400 students per school, the cost per student for the item ‘3D modelling software licenses’ is between 0.05 – 0.35 EUR
[312] Assuming 400 students per school, the cost per student for the item ‘Data storage’ is 0.20 – 0.75 EUR.

Dimension 2 (Network requirements)	Network connectivity (between 30 and 100 Mbps)	Fibre Internet / Satellite	15 - 20 EUR[313]
	High-speed wireless local-area network (WLAN)		3 EUR – 6 EUR
	Service, maintenance and network monitoring		30 EUR – 200 EUR
	Total estimated costs for dimension 2		**48 EUR – 226 EUR**
Dimension 3 (Professional development of teachers)	Face-to-face training	Full immersion courses	5 - 10 EUR (Reduced teaching load) 50 – 100 (hybrid course)[314]
		In-class coaching	
	Online training	Massive Online Open Course (MOOC)	
		Webinars	
		Web-based networks	
		Online communities of practice	
	Leadership Training		
	Total estimated costs for dimension 3		**55 – 110 EUR**
Dimension 4 (Access to content)	Paid for content	School kits	30 - 50 EUR
		Makers kits	
		Educational Apps	
		Virtual Online Laboratories	
		E-books	
	Free and OER content		*Free of charge*
	Teachers generated OER		*Free of charge*
	Total estimated costs for dimension 4		**30 EUR – 50 EUR**
Total estimated costs to equip and connect an average EU classroom with advanced components of the HECC model			**~224 EUR – ~536 EUR**

313 These costs refer to the yearly subscription costs per student for an Internet package allowing a symmetrical broadband Internet access. Investment costs for setting up the physical infrastructure in terms of high-capacity broadband networks (e.g. fibre networks, laying cables, etc.) would occur on top of these yearly costs.

314 To compute the cost for the teachers training per student, the research team took into account the hybrid training (150 – 250 EUR per teacher per course). Considering an average of 8 teachers per classroom (23 students) undertaking one course per year, the cost per student for teachers' training ranges between 50 – 100 EUR annually.

4. Conclusions

4.1 Summary of results

The objective of this report is to define a conceptual model for a 'highly equipped and connected classroom' (HECC), presenting three scenarios to describe different levels of a HECC and to estimate the overall costs to equip and connect an average EU classroom with advanced components of the HECC model.

The developed HECC model is a progressive model, which implies that one school might start off with the entry level scenario in order to equip and connect a classroom, then progress to the advanced scenario and finally upgrade the classroom to the cutting-edge level scenario in order to exploit the opportunities provided by digital teaching and learning to the fullest extent. In turn, other schools could start off already with the advanced level scenario as an entry point and then eventually upgrade their classrooms to the cutting-edge level. Thus, the three different levels represent a continuum of what a HECC could entail, with multiple conceivable scenarios in between the three levels.

The entry level scenario of a HECC mainly outlines the minimum and essential components of a highly equipped and connected classroom. It contains essential digital technology equipment, including a limited number of components related to teachers' professional development and access to digital contents, as well as minimum network requirements needed for a functioning HECC. The advanced scenario of a HECC, in turn, builds upon and further advances the entry level scenario, while paving the way to the cutting-edge level scenario. Differently from the entry-level, the advanced scenario entails more advanced digital equipment (e.g. 3D printers and modelling software, interactive tables), as well as a greater number of teachers' professional development activities (e.g. full immersion courses, in-class-coaching) and access to paid-for contents (e.g. makers kits, educational apps, virtual laboratories). Finally, the cutting-edge level scenario of a HECC involves the ultimate categories, sub-categories and items of a highly equipped and connected classroom. This scenario further advances categories, sub-categories and items in the advanced scenario, particularly in relation to broadband connectivity (e.g. ultra-fast broadband, Virtual Private Network), a greater variety of digital equipment available to teachers and students (e.g. e-books, wristbands, audio and video software), increased opportunities for face-to-face professional development for teachers (e.g. twilight training sections, mentored action research) and leadership training.

The ultimate goal of this report is to estimate the costs for equipping and connecting an average EU classroom with advanced components of the HECC model. The results show that the average cost per student per year to equip and connect an average EU classroom with advanced components of the HECC model results is in the range of 224-536 EUR. This cost range includes costs for digital technology equipment (91 EUR – 150 EUR per student per year), network requirements (48 – 226 EUR per student per year), professional development of teachers (55 EUR – 110 EUR per student per year) and costs for access to content (30 EUR – 50 EUR per student per year). It is important to note that setting up the physical infrastructure in terms of high-capacity networks (e.g. fibre networks) is not included in this overall figure (see 4.5 for a more detailed discussion on this point).

Overall, it should be noted that the present calculation only serves as an orientation to the approximate costs arising from equipping schools with a HECC, but would always need to be adapted to local conditions and needs of a specific school. Moreover, this cost approximation only represents an EU average and does not consider differences in price across countries.

4.2 Key role of the EU for fostering highly equipped and connected classrooms

Even though responsibility for education lies with Member States, the European Union has an important role to play in scaling up innovation in EU Member States' education systems. Consequently, the European Commission adopted the Digital Education Action Plan in January 2018 (European Commission, 2018)[315] and is currently following up on the 11 actions included in the Action Plan which are structured in three priority themes, including (1) making better use of digital technology for teaching and learning; (2) developing the digital competences and skills needed for living and working in an age of digital transformation; and (3) improving education through better data analysis and foresight.

There are also several EU funding programs available for digital education projects in the current multifinancial annual framework running from 2014 to 2020 which complement national efforts (such as Erasmus+, European Social Funds, European Regional Development Fund, Horizon 2020, Wifi4EU through CEF, etc.). For instance, education and training is one of the eleven priorities for cohesion policy in 2014-2020 ("thematic objective 10").

There is a clear need for digital education to be further supported by the new Multiannual Financial Framework (2021-2027) in addition to national and regional investments as well as cooperations between private and public stakeholders. The high cost estimates reported in the study provide a clear signal to funding programmes such as the European Social Fund (ESF) and the European Regional Development Fund (ERDF) to continue supporting activities which help to modernise education and training systems, including investments in educational infrastructure. The new proposed Research and Innovation programme (Horizon Europe) will play a crucial role in spurring new innovation in education and also scaling up innovation activities to facilitate market entry and diffusion of innovations through large-scale piloting.

Erasmus+ including the many successfully established tools for exchanging best practices and peer learning (e.g. through tools as eTwinning, School Education Gateway, Teacher Academy) will need to be further scaled up to facilitate teachers' professional development.

The cost estimation also shows that particularly costs for network requirements form a significant part of the overall cost figure. Costs for setting up the physical infrastructure in terms of high-capacity networks (e.g. fibre networks) (which have not been considered in the cost estimation of this study) will have to be born on top of those reported costs. In this respect, as part of the next long-term EU budget, the European Commission proposed to renew the Connecting Europe Facility (CEF). The future Connected Europe Facility Programme aims to support access to Gigabit connectivity for socio-economic drivers including schools with a view to maximising their positive spill-over effects on the wider economy and society.

Moreover, the proposed Digital Europe Programme has been designed to support the digital transformation of the public sector and of areas of public interest by improving their digital capacities. For Digital Education, this opens up opportunities for supporting the deployment of digital capacities in schools (i.e. equipment, technologies, digital content) as well as innovative and effective teaching and learning practices at European level that have already been proven successful in smaller scale pilots.

Finally, investing in high-quality education pays long-term dividends for the European economy and for the overall prosperity of European societies. Innovation in education systems have a great potential to significantly improve learning outcomes, enhance equity and improve efficiency. Given the high overall costs to equip and connect an average EU

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315 European Commission. (2018a). Communication from the commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the Digital Education Action Plan. COM(2018) 22

classroom with advanced components of the HECC model, the European Union, Member States, regions and municipalities as well as industry and civil society organisations must make a concerted and coordinated effort to allow the European education sector to stay ahead of technological change.

4.3 The application of the HECC model for primary education

As explained in the above chapter on Task 2, the three HECC scenarios have been built and defined based on the assumption of a classroom composed of 23 students[316] between age 11/12 years old, part of **ISCED 2** (lower secondary) education level[317]. This assumption was taken with the goal of reducing the complexity of building the three HECC scenarios. Therefore, the total estimated cost to equip and connect an average EU classroom with advanced components of the HECC model refers to an ISCED 2 classroom. The distinction between primary and secondary schools varies significantly between EU Member States. In several countries in Europe (e.g. Nordic countries, Croatia, Czech Republic, Hungary, Poland)[318], a 'single structure education' is in place and primary and lower secondary education are integrated. This integration is also reflected in the curriculum. In addition, across Europe (e.g. Italy, Spain, etc.), a school institution often includes (even in the same building or campus) primary and lower secondary levels (i.e. ISCED 1 and 2). As a consequence, the integration of primary and secondary education levels strongly impacts on the HECC four dimensions, in particular for those HECC items that apply at school (rather than a classroom) level (e.g. 3D printer, broadband connectivity, etc.). However, based on evidences from the literature and inspired by existing experiences (e.g. Future Classroom Lab), the three HECC scenarios previously described (referred to ISCED level 2) embed features that can be extended and applied across both primary (ISCED 1) and secondary education level (ISCED 2 and 3). In particular, main conditions related to dimension 1 (digital technology equipment), dimension 2 (network requirements) and dimension 3 (professional development of teachers) are common among primary and secondary education, while main differences apply in dimension 4 concerning the type of contents accessed and used by teachers and students in primary and secondary levels.

In specific, dimension 2 (network connectivity) and dimension 3 (professional development of teachers) play a crucial role in defining the HECC, encompassing items that mostly apply at school level/district. Concerning dimension 2, a recent report[319] prepared for the European Commission pointed out that in 2016 many schools in the EU still lack broadband access (especially in primary schools, where 25% lack broadband), suggesting that satellite broadband could be an efficient option for poorly connected schools. Similarly, other studies[320] and initiatives[321] at country level are developing broadband initiatives that tackle both primary and secondary levels through a unified approach. Although teachers' professional development (dimension 3) initiatives vary between primary and secondary education, within the scope of this study, the focus is on the type of training opportunities for supporting teachers' capacity building for the effective use of digital technologies in teaching, learning and assessment practices. Hence, the suggested approaches included in this dimension (e.g. formal courses, seminars and workshops, online training, mentoring and supervision) commonly apply to professional development programmes/initiatives promoted at school/district level for both primary and secondary teachers.

[316] Eurostat (2012), OECD (2017a)
[317] Eurostat (2017)
[318] European Commission/EACEA/Eurydice (2017)
[319] European Commission (2017e)
[320] GEANT (2017)
[321] Heanet (2014)

With regard to dimension 1 (digital technology equipment), as pointed out in several studies and reports (e.g. NMC Horizon reports[322], INTEL report[323], Kennisnet report[324], OECD innovative learning environments[325]) main conditions related to this dimension are common among primary and secondary education.

Concerning the digital contents (dimension 4), differences apply mainly in the resources used by teachers and students in primary and secondary education. While the type of contents (i.e. paid-for/free and OER/ teachers' generated OER, as well as makers kits, simulations, etc.) depicted in the HECC model apply across all education levels, the kind (and the level of complexity) of activities facilitated by these contents strongly depends on the students' age and thus vary across primary and secondary levels. For instance, the HECC item 'makers kit' can be applied across different education levels but, however, it is deployed differently in each ISCED level. In specific, in primary classrooms, students might use products such as Cubetto[326] or Bee-Bots[327] to introduce basic programming concepts and the fundamentals of computational thinking. Students attending lower secondary education may use MICRO: bit[328] which is a pocket-sized code-able physical computing device that was designed to be visually appealing and tactile, affordable, easy to use, interactive and extensible. Finally, in upper secondary classrooms, student can develop engineering skills and being introduced to cybersecurity concepts through Arduino kits[329]. Similarly, Virtual Online Laboratories allow to carry out exploratory activities for primary[330] and secondary students[331] at different levels of complexity.

In conclusion, the impact of the differences between a primary and secondary HECC on the cost estimation performed as part of Task 3 can be considered as rather low. As explained above, the main conditions related to dimension 1, dimension 2 and dimension 3 are common among primary and secondary education and, therefore, would not significantly impact the cost analysis. Finally, also the HECC items referred to dimension 4 do not vastly vary in primary or secondary education. As previously explained, what changes between primary and secondary levels with regard to dimension 4 is the kind (and the level of complexity) of pedagogical activities facilitated by the digital contents.

4.4 Bring Your Own Device (BYOD)

The cost estimation has been performed by taking the assumption that students were supplied with devices by their schools, usually at not cost to the learners or their families. Such use of one portable ICT device per learner is rapidly becoming the norm in many education and training contexts around the world. However, one alternative model which is growing interest in, and debated around, is the BYOD policy / strategy which relies on the prevalence of learner-owned devices and where students use the mobile devices they already own[332]. Under the BYOD policy, the cost of providing a device for personal educational use is transferred to families or students. These may bring a device they already own to their school, or select and purchase a new device, or pay for a device chosen by the school or local authority. The decision to introduce BYOD to schools in Europe is overall mainly driven by a combination of social, economic, educational and technological factors. The relative importance of these factors varies from country to country and according to the particular contexts in which individual schools operate[333]. An elaborated analysis on the applications of BYOD policy across EU Member States, on the perceived

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[322] European Commission (2014)
[323] Intel (2016)
[324] Kennisnet (2017)
[325] OECD (2017b)
[326] Primo (2016)
[327] Teaching in the primary years (2018)
[328] King's College London (2017)
[329] American Society for Engineering Education (2015)
[330] PHET (n.d.)
[331] Go-Lab (n.d.)
[332] UNESCO (2013).
[333] EUN (2015).

benefits and risks of the policy as well as on the impact of BYOD on the HECC model is presented in Annex 3.

4.5 Limitations

As with any study, the current study is subject to some limitations. Generally, it was difficult to find public consolidated data on costs according to the 4 dimensions detailed beforehand. Also, the resources and costs shown at a student level for an advanced HECC provide a first starting point for discussion for policy-makers and would need a much more thorough cost analysis adapted to the specific setting. The definitions of the HECC scenarios will also need to be carefully adapted to the existing setting in place and thus will have an impact on the cost estimations. Resources needed for schools to operate in an equipped and connected classroom are very different in nature and consequently, are different across countries and within countries. In particular, countries that are in the early stages of introducing ICT in schools have different needs than countries that have longer experience with the technology and content and therefore may need to focus on investing in specific items per each of the four dimensions of our model. Second, the cost estimation was performed through data collection during the period January 2018 - March 2018. Thus, it should be taken into account that prices may be subject to fluctuations by the time this report has been published. Third, collection of costs was based on costs of individual items, thus not taking into account any discounts that might be obtained by national Ministries when purchasing e.g. digital technologies in bulk. Fourth, costs for Dimension 2 (Network Requirements) only include the equipment/subscription costs for broadband services at school level whereas the costs for setting up the physical infrastructure in terms of high-capacity broadband networks (e.g. fibre networks) is not taken into consideration in the cost analysis as this is very much depending on the specific school setting and due to significant differences between Member States and between regions within Member States. The cost estimation related to dimension 2 (professional development of teachers) focusses only on the continuous professional development of teachers (after their studies have been finished) and does not cover the initial teacher training. Furthermore, costs associated with content and access to content were very difficult to estimate due to a lack of public consolidated data across Europe.

Annex 1 Glossary HECC Model (categories, sub-categories and items)

Dimension 1 (Digital technology equipment)

3D modelling software licenses – licenses which allow the use of computer programs used for developing a mathematical representation of any three-dimensional surface of objects[334].

3D printers - computer-aided manufacturing (CAM) devices that create three-dimensional objects. Like a traditional printer, a 3D printer receives digital data from a computer as input. However, instead of printing the output on paper, a 3D printer builds a three-dimensional model out of a custom material[335].

Android tablets - are tablet-sized PCs that run on Google's Android operating system (OS). Android tablets include almost all the key features found in a regular tablet PC, including office applications, games, Web browsers and many other programs[336].

Assistive technologies (AT) for people with special needs - are the software and services that help students with disability work around their challenges so they can learn, communicate or simply function better[337]. The benefits of these technologies on children with disabilities are in the terms of improved learning outcomes, increased students' involvement in classroom as well as their independence.

Audio and video editing software - Audio editing software is software which allows editing and generating of audio data. Video editing software is an application program which handles the post-production video editing of digital video sequences on a computer non-linear editing system[338].

Classroom management system (e.g. Student Information System)[339] - software designed to assist teachers in classrooms where students predominantly work on connected devices such as computers, laptops or tablets. Classroom Management Software can be used to:

- Monitor the screens of an entire class from a single desktop;
- Monitor pupil Internet activity in real time;
- Access a pupil's Internet history;
- Automatically capture screenshots from a device whilst in use; and
- Monitor keyboard strokes and create alerts if pupils type inappropriate or flagged words.

Database management system - is system software for creating and managing databases. The database management system provides users and programmers with a systematic way to create, retrieve, update and manage data[340].

[334] Definition retrieved from: https://en.wikipedia.org/wiki/List_of_3D_modeling_software
[335] Definition retrieved from: https://techterms.com/definition/3d_printer
[336] Definition retrieved from: https://www.techopedia.com/definition/25194/android-tablets
[337] Definition available at: https://www.understood.org/en/school-learning/assistive-technology/assistive-technologies-basics/assistive-technology-what-it-is-and-how-it-works
[338] Definition retrieved from: https://en.wikipedia.org/wiki/Video_editing_software https://en.wikipedia.org/wiki/Video_editing_software
[339] Definition retrieved from: https://www.bigbrotherwatch.org.uk/wp-content/uploads/2016/11/Classroom-Management-Software-Another-Brick-in-the-Wall.pdf
[340] Definition retrieved from: https://searchsqlserver.techtarget.com/definition/database-management-system

Data storage - a type of dedicated file / data storage device that provides local-area network local area network (LAN) nodes with file-based shared storage through a standard Ethernet connection[341].

Data projectors - a device that projects a computer output onto a white or silver fabric screen that is wall-, ceiling- or tripod-mounted. It is widely used in classrooms and auditoriums for instruction and slide presentations[342].

Desktop computers - personal computers that are designed to fit conveniently on top of a typical office desk[343].

Dictation tools (speech-to-text) - allows kids to write by using their voice. As they speak, their words appear on the screen[344].

E-books readers – are deployed and used to support literacy learning[345], boosting students' reading comprehension as well as increase their motivation to read[346]. In particular, these portable devices allow students to personalise the font size and page orientation to suit their individual needs and preferences, highlight text to mark key passages, insert notes in response to the text, search for word definitions in the built-in dictionary, and use a text-to-speech feature to practice reading fluency. By recording and reviewing the students' use of these tools and features, teachers can monitor students' skills and progress as readers, as well as suggesting new reading strategies[347].

Graphic organizers - visual tools that can help to break down ideas and projects into smaller parts. Kids can use these tools to brainstorm and plan what they want to write[348].

Identity management services - systems and software that allow identifying, authenticating and authorizing individuals or groups of people to have access to applications, systems or networks by associating user rights and restrictions with established identities. The managed identities can also refer to software processes that need access to organizational systems[349].

Interactive tables with projector - multi-touch tables that combine micro technology with the concept of design and usability[350].

Interactive Whiteboards (IWB) - are a large display that connects to a computer and a projector. It projects the computer's desktop onto the board's surface, where users control the computer with a pen, finger, or other device. The board is typically mounted to a wall or floor stand. Various accessories, such as student response systems, enable interactivity[351]. Users can interact with the content on the board using fingers or a stylus[352].

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[341] Definition retrieved from: http://searchstorage.techtarget.com/definition/network-attached-storage
[342] Definition retrieved from: https://www.pcmag.com/encyclopedia/term/40830/data-projector
[343] Definition retrieved from: https://searchenterprisedesktop.techtarget.com/definition/desktop-computer
[344] Definition retrieved from: https://www.understood.org/en/school-learning/assistive-technology/assistive-technologies-basics/assistive-technology-for-writing
[345] ASCD (2012)
[346] Graham Parker (2017)
[347] Union, C. D., Union, L. W., & Green, T. D. (2015), Gardener, L. (2011)
[348] Definition retrieved from: https://www.understood.org/en/school-learning/assistive-technology/assistive-technologies-basics/assistive-technology-for-writing
[349] Definition retrieved from: http://searchsecurity.techtarget.com/definition/identity-management-ID-management
[350] Definition retrieved from: http://www.mastervision-products.com/en/products/interactive-solutions/table/interactive-tables/
[351] Educational Leadership (2009)
[352] Definition retrieved from: E.g. Cambridge International Examinations (2015)

iOS tablets - tablet PCs designed by Apple Inc. The iOS mobile operating system is a Unix-like OS that is made up of four abstraction layers: the core OS layer, the core services layer, the media layer and the cocoa touch layer[353].

Laptops - portable and compact personal computers with the same capabilities as a desktop computer[354].

Microcontrollers for coding activities (i.e. Arduino, Raspberry Pi, etc.) - a computer present in a single integrated circuit that is dedicated to perform coding activities[355]. The microcontroller is the essential and required element to perform basic coding tasks. Examples of microcontrollers as shared by the stakeholder are 'Arduino' and 'Raspberry Pi', which are educational open-source computing platforms, which contain several types of microcontrollers in the platforms for physical computing[356]. Many educators believe that coding helps students to understand how computers work, to communicate their thoughts in a structured and logic way, to think critically and to succeed in the digital working place[357]. As such, microcontrollers were included in the HECC model which is defined as a computer present in a single integrated circuit that is dedicated to perform basic coding activities[358]. More and more schools are introducing coding activities in their curricula. As an example, in 2013, the secondary school 'Ponte dos Brozon at Coruna' (Spain) developed the project 'Recreo con Codigo'[359] with the aim of gradually introducing programming so that students between 6-12 years are able to understand algorithms and find out how to use them in their daily lives. Coding is used transversally, across various subjects and ages, starting from early primary students. Similar to the Spanish initiative, the Government of the Wallonie-Bruxelles federation in Belgium promoted in 2011 the 'Learn to program[360]' project. This initiative aims to provide learners with the tools to become active creators and participants in the digital world. Pupils learn how to use 'Scratch[361]' program, 'Raspberry Pi[362]' microcontroller and 'Makey Makey'[363], an electronic invention tool and toy that allows users to connect everyday objects to computer programmes. Using these tools, pupils learn how to program, create and use technology

Optical character recognition - an assistive technology that reads aloud text from images and pictures[364]. Optical character recognition (OCR) technology offers blind and visually impaired learners the capacity to scan printed text and then speak it back in synthetic speech through text-to-speech technology[365]. This tool works in three phases: scanning, recognition and reading text. Initially, a printed document is scanned by a camera. OCR software then converts the images into recognized characters and words. The synthesizer then speaks the recognized text by using text-to-speech technology. Finally, the information is stored in an electronic form, either on a PC or in the memory of the OCR system itself[366].

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[353] Definition retrieved from: https://www.techopedia.com/definition/758/ipad
[354] Definition retrieved from: www.businessdictionary.com/definition/laptop.html
[355] Definition retrieved from: https://www.techopedia.com/definition/3641/microcontroller
[356] Definition retrieved from: http://www.utas.edu.au/courses/cse/units/kit605-embedded-systems-for-ict-education
[357] Freeman, A., Adams Becker, S., Cummins, M., Davis, A., & Hall Giesinger, C. (2017)
[358] Definition of microcontroller was retrieved from: https://www.techopedia.com/definition/3641/microcontroller
[359] CEIP Ponte dos Brozos school (Spain) (2013)
[360] Wallonie-Bruxelles Fédération (2011)
[361] With Scratch, student can program their own interactive stories, games, and animations. Scratch helps young people learn to think creatively, reason systematically, and work collaboratively. More information on Scratch available at: https://scratch.mit.edu/about
[362] The Raspberry Pi is a series of small single-board computers developed in the United Kingdom by the Raspberry Pi Foundation to promote the teaching of basic computer science in schools. More information on Raspberry Pi available at: https://en.wikipedia.org/wiki/Raspberry_Pi
[363] More information on Makey Makey app available at: https://en.wikipedia.org/wiki/Raspberry_Pi
[364] Definition retrieved from: https://www.understood.org/en/school-learning/assistive-technology/assistive-technologies-basics/assistive-technology-for-reading
[365] American Foundation for the Blind (AFB)
[366] Idem

Platform as a Service (PaaS) - a cloud-based computing environment designed to support the rapid development, running and management of applications. It is integrated and abstracted from the lower-level infrastructure components[367]. In the field of education, both the Horizon Project Europe and the global Horizon Project K-12 groups highlighted that cloud computing is already in the agenda of schools and will be more so over the next year. The many concrete project examples of schools using cloud-based services such as Google Apps for Education, Skype, Dropbox, and others show a movement toward leveraging this technology to bolster collaboration, digital competence, and productivity[368]. A series of cloud computing projects were implemented in Europe over the last few years, including the projects 'Schools in the Cloud' in Spain369, Killingworth 'School in the Cloud' in the UK370 and 'the Ballerup municipality cloud project' in Denmark[371]. In Spain, the Galicia's Supercomputing Centre, which is supported by the Galician Ministry of Culture and Education and the Agency for Technological Modernisation, headed a two-year research project of 300,000 EUR to research open source-cloud use in schools. 75% of 'Escolas na Nube' (Schools in the Cloud) – this is the name of the project - is funded by the European Commission's Education, Audio-visual & Culture Executive Agency. The project tested if using cloud solutions can improve education and also to see if this enables teachers to work together.

Presentation software (e.g. PowerPoint) - is a category of application software that is specifically designed to allow users to create a presentation of ideas by stringing together text, images and audio/video. The presentation tells a story or supports speech or the presentation of information[372].

Software as a Service (SaaS) - a software that is owned, delivered and managed remotely by one or more providers. The provider delivers software based on one set of common code and data definitions that is consumed in a one-to-many model by all contracted customers at any time on a pay-for-use basis or as a subscription based on use metrics[373].

Smartphones – mobile phones that perform many of the functions of a computer, typically having a touchscreen interface, Internet access, and an operating system capable of running downloaded apps[374].

Speech-to-text tools - are Assistive Technologies solutions that have proved effective and beneficial for some learners who have a physical disability or difficulty in writing using a keyboard.

Spell-checks and grammar checks - assistive technologies to support people that have special writing disabilities. In order to support the student in producing legible and high quality written text, a writing assistive technology must also address grammar mistakes. The grammar checker must be integrated together with the spell checker, enabling a maximum secure writing experience[375].

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367 Definition retrieved from: https://www.ibm.com/blogs/cloud-computing/2014/02/what-is-platform-as-a-service-paas/
368 European Commission (2014)
369 Supercomputing Centre (2013)
370 George Stephenson High School (2013)
371 Municipality of Ballerup (Denmark) (2013)
372 Definition retrieved from: https://www.techopedia.com/definition/16572/presentation-software
373 Definition retrieved from: https://www.gartner.com/it-glossary/software-as-a-service-saas/
374 Definition retrieved from: https://en.oxforddictionaries.com/definition/smartphone
375 Definition retrieved from: https://www.ghotit.com/2010/06/dyslexia-grammar-checker

Spreadsheet software (e.g. Excel, Numbers) - is a software application capable of organizing, storing and analyzing data in tabular form. The application can provide digital simulation of paper accounting worksheets[376].

Text-to-speech tools - an assistive technology that reads digital text aloud. With a click of a button or the touch of a finger, Text-to-speech tools can take words on a computer or other digital device and convert them into audio[377].

VLE (Virtual Learning Environment) platform - an e-learning education system that is web-based, but modelled on conventional face-to-face education. It provides access to courses, course content, assessments, homework, links to external resources, etc. Examples of VLE platforms are Moodle or Blackboard[378].

Voice Assistants (e.g. Alexa, Siri, etc.) - is a conversational, computer-generated character that simulates a conversation to deliver voice- or text-based information to a user via a Web, kiosk or mobile interface. A voice assistant (VA) incorporates natural-language processing, dialogue control, domain knowledge and a visual appearance (such as photos or animation) that changes according to the content and context of the dialogue[379]. As VAs are becoming a more common gadget used at homes, also some teachers have begun to adopt VAs in the classrooms thanks to the natural interactions that this technology enables and thanks to its increasing library of skills. For instance, Amazon's Alexa provides capabilities, or skills, that enable customers to create a more personalized experience. In particular, the Alexa Skills Kit (ASK)[380] is a collection of self-service application programming interfaces, tools, documentation and code samples that makes it fast and easy for teachers to add skills to the kit. ASK enables teachers to build engaging skills which might be used in classroom. For instance, teachers can use ASK for activities such as[381]:

- Engaging students into learning through games: using skills like the National Geographic Geo Quiz[382], and other quizzes and voice-powered trivia, some teachers have started to organize games where kids compete with themselves and with one another answering random questions about different topics;
- A source for answers: some teachers are also experimenting ASK by allowing students to turn to the technology to get answers to some simple questions, thus teaching children how to research topics on their own, and to rely less on their guidance; and
- A source for inspiration: some teachers are using Fact-of-the-day skills[383] as a way to bring in new topics to the classroom in an engaging manner which can be used either as the starting point to approach some specific point in the curriculum, or to get students to conduct a research project.

Virtual Reality (VR) headsets - a heads-up display that allows users to interact with simulated environments and experience a first-person view. VR headsets replace the user's natural environment with virtual reality content, such as a movie, a game or a pre-recorded 360-degree VR environment that allows the user to turn and look around, just as in the physical world. Virtual reality, like Oculus Rift, allows students to experience learning

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376 Definition retrieved from: https://www.techopedia.com/definition/9510/spreadsheet-software
377 Definition retrieved from: https://www.understood.org/en/school-learning/assistive-technology/assistive-technologies-basics/text-to-speech-technology-what-it-is-and-how-it-works
378 Definition retrieved from: Cambridge International Examinations (2015)
379 Definition retrieved from: https://www.gartner.com/it-glossary/virtual-assistant-va/
380 More information on the Alexa Skills Kit available at: https://developer.amazon.com/alexa-skills-kit
381 The pedagogical activities supported by Alexa described here below are retrieved from: Edu4Me. (2017). Voice Assistants Can Become Powerful Allies in the Classroom. Retrieved from http://edu4.me/voice-assistants-can-become-powerful-allies-in-the-classroom/
382 More information on National Geographic Geo Quiz available at: https://www.amazon.com/National-Geographic-Society-Geo-Quiz/dp/B071S2LLQN
383 An example of one of Alexa's fact-of-the-day skills is 'One fact a day' which gives the students a random fact every time is asked. Available at: https://www.amazon.com/Emelie-One-Fact-a-Day/dp/B01NCJOVRA

differently. Students can have a 'live' lesson rather than just reading about it[384]. Several articles and reports attest to the great success of VR technology within classrooms in educationally progressive schools and learning labs in the U.S. and Europe[385]. VR technology is indeed impacting learning by transporting students to any imaginable location across the universe, by transforming the delivery of knowledge and by empowering students to engage in deep learning[386]. There are two ways of using virtual reality in the classroom. The first set-up involves a traditional desktop set-up in which the student explores a virtual environment using a computer, keyboard and mouse, or uses some other input device such as a controller. The second is fully immersive and requires the student to wear a head mounted display (HMD) and data glove to interact within a virtual environment. This environment may take the form of a series of large screens or a complete CAVE virtual reality system[387].

Windows tablets - tablet computers that run the Windows operating system[388].

Wearable wristbands - a wearable technology that can measure heart rate, hydration levels, how many steps students have taken, and even breathing rate. A teacher can monitor all this data from a tablet and ensure students get the physical activity they need while remaining safe[389].

Word processing software - is used to manipulate text and apply a basic design to pages[390].

Dimension 2 (Network requirements)

Broadband - fibre Internet access that is always on and faster than traditional dial-up access. Broadband provides higher-speed data transmission, as it allows more content to be carried through the 'pipe.' Although there is not a particular speed that defines them, broadband connections in schools enable students to engage in rich digital learning experiences such as streaming videos, gaming, and interactive services[391].

The study distinguishes three types of broadband[392]:

- Basic broadband (< 30 Mbps)
- Fast broadband (30 Mbps - 100 Mbps)
- Ultra-fast broadband (> 100 Mbps)

Fibre Internet - consists of a thin cylinder of glass encased in a protective cover. It uses light rather than electrical pulses to transmit data. Each strand of the cable can pass a signal in only one direction, so fibre optic cable must have at least two strands: one for sending and one for receiving data. Unlike Data over Cable Service, fibre-optic cables are not subject to interference, which greatly increases the transmission distance. Fibre speeds are currently limited by the abilities of the equipment on either end of the connection. Some fibre connections allow for speeds up to 100 Gbps[393].

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[384] Definition retrieved from: http://whatis.techtarget.com/definition/VR-headset-virtual-reality-headset
[385] Johnson, L., Adams Becker, S., Cummins, M., Estrada, V., Freeman, A., Hall, C. (2016)
[386] Idem
[387] Virtual Reality Society (2017)
[388] https://www.pcmag.com/encyclopedia/term/64645/windows-8-tablet
[389] Definition retrieved from: Sandall, Brian K. (2016)
[390] Definition retrieved from: https://study.com/academy/lesson/what-is-word-processing-software-definition-types-examples.html
[391] Definition retrieved from: U.S. Department of Education, Office of Educational Technology (2014)
[392] Definition retrieved from: European Commission (2017), European Commission (2016)
[393] Idem

Data over cable service interface specification (DOCSIS) - is an internationally recognized standard allowing high speed data transfer on existing cable TV systems (CATVSs) used by many cable operators to provide Internet access to their customers through a cable modem. In 2016, DOCSIS 3.1 was released, bringing a massive leap in both up and downstream speeds. DOCSIS 3.1 allows to reach 10 Gbps for download speed and 1 Gbps for upload speed[394].

Fibre to the Premises (FTTP) - is a pure fibre-optic cable connection running from an Internet Service Provider (ISP) directly to the school's address[395]. The Cabinet/Curb (FTTC) represents the target broadband solution for each EU school. FTTP technology can indeed allow schools to reach the target broadband speed proposed by the Commission of 1 Gigabit of data per second in 2025[396]. Fibre to the Cabinet/Curb (FTTC) is instead much more common and cheaper than FTTP and combines traditional copper wire cable and fibre optic cable. The expensive to install fibre optic cable runs to a street metal cabinet which contain telecommunications equipment and then more economical copper wire is used to connect schools (and homes and businesses) to the cabinet[397]. In FTTC infrastructure usually the existing copper wire is used with communications protocols such as broadband cable access (typically DOCSIS) or crosstalk-cancellation technologies such as vectoring.

Fixed wireless - can currently provide speeds up to 1 Gbps, is suitable for portable mobile broadband connectivity and cellular backbone as an alternative to cable, and can deliver data, Voice over Internet Protocol (VoIP), and Internet Protocol Television (IPTV). WiMAX comes in two forms: mobile and fixed. Mobile connects buildings to user devices, and fixed connects buildings together. When considering WiMAX, look for industry certification regarding WiMAX standards to ensure interoperability with other certified products[398].

Gbps – is short for gigabits per second. A gigabit is a data transfer rate of 1,000,000,000 bits per second[399].

Infrastructure installation – refers to the set-up of the school IT network.

Kbps - is short for kilobits per second. A kilobit is a data transfer rate of 1,000 bits per second[400].

High-speed local-area network – a local area network (LAN) is a group of computers and associated devices e.g. printers that share common, traditionally wired, communications links to a server, or servers, and a broadband service. LANs operate in a limited area, typically a building or group of buildings e.g. a school (see school network example diagram) and can be linked to other LANs to form a Wide Area Network (WAN)[401].

Mbps - is short for megabits per second. A megabit is a data transfer rate of 1,000,000 bits per second[402].

Mobile internet - is wireless Internet access from cell towers via a mobile phone, tablet, or portable modem. Mobile broadband (also called 4G or LTE) generally provide high-speed connection of 50 Mbps (but can go up to 1 Gbps) for downloading and uploading over the

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[394] Definition retrieved from: https://www.techopedia.com/definition/3575/data-over-cable-service-interface-specification-docsis https://highspeedexperts.com/home-networking/what-is-docsis-and-why-does-it-matter/
[395] European Schoolnet (2017a)
[396] European Commission (2016e)
[397] Idem
[398] Idem
[399] Idem
[400] Definition retrieved from: U.S. Department of Education, Office of Educational Technology (2014)
[401] European Schoolnet (2017a)
[402] Idem

same network infrastructure wireless carriers, which fits in the 'ultra-fast broadband' type of broadband as identified for the study [403].

Satellite Internet - can provide fixed, portable, and mobile Internet access with data rates of up to 1 Gbps downloading and up to 10 Mbps uploading. Satellite broadband is among the most expensive forms of wireless Internet access, but it can provide connectivity in the most remote areas where no other connectivity options exist. Best performance requires a clear line of sight between the satellite and the antenna at the connecting building[404].

Service, maintenance and network monitoring - Network maintenance tasks are those tasks which network administrators perform on a day-to-day basis, allowing for the upkeep of the network[405]. Network monitoring is a computer network's systematic effort to detect slow or failing network components, such as overloaded or crashed/frozen servers, failing routers, failed switches or other problematic devices[406].

Physical aspects of the network: electricity, cabling, access points, number of devices to connect - cabling is used to refer to electrical or electronic cables, or to the process of putting them in a place[407]. An access point is a device, such as a wireless router, that allows wireless devices to connect to a network[408].

Upgrade of broadband infrastructure – refers to the improvement and upgrade of the entire or partial school network infrastructure which is the hardware and software resources that enable connectivity, communication, operations and management of the school network[409].

User help desk / technical support: help desk is a resource intended to provide the customer or end user with information and support related to a company's or institution's products and services. The purpose of a help desk is usually to troubleshoot problems or provide guidance about products such as computers, electronic equipment, food, apparel, or software[410].

Vectoring - is an active technology that reduces crosstalk between signals travelling down nearby copper pairs. By reducing the noise, the performance of the copper is optimized towards the Shannon Limit to provide up to 100Mbps over 500 meters[411].

Virtual private network (VPN) - encryption software enables computers to connect with each other across a public network as if they were connected to a private, secure network[412]. Organisations, including schools, often use VPN to communicate confidentially over a public network, typically the Internet. A VPN provides a secure, encrypted 'tunnel' for information transmitted between the two locations. Individuals may also use VPN services if they wish to protect their online activity and identity. One reason to consider VPN is because free WiFi access is used in a public place and there are concerns that this may not be very secure[413]. Individuals also often use VPNs to circumvent security

403 Idem
404 Idem
405 Definition retrieved from: https://www.howtonetwork.org/tshoot/module-1/network-maintenance-tasks/
406 Definition retrieved from: *https://www.techopedia.com/definition/24149/network-monitoring*
407 Definition retrieved from: https://www.collinsdictionary.com/dictionary/english/cabling
408 Definition retrieved from: https://techterms.com/definition/accesspoint
409 Definition retrieved from: https://www.techopedia.com/definition/16955/network-infrastructure

410 Definition retrieved from: https://en.wikipedia.org/wiki/Help_desk
411 Fibre to the Home, Council of Europe (2013)
412 Idem
413 European Schoolnet (2017a)

arrangements that prevent them from accessing services they have not paid for or are not authorised to access.

Wide Area Network (WAN) - provides the connection between the district office and all the schools and sites within a district. A WAN may also connect to other educational institutions (such as universities and libraries) if your district is part of a regional education network[414].

Wireless local-area network (WLAN) – a wireless local area network (WLAN) is a computer network that may be standalone or part of a LAN and links devices using a wireless method within a limited area such as a school, home or office building. This gives users the ability to move around within a local coverage area and yet still be connected to the network which usually includes a connection to the Internet[415].

Dimension 3 (Professional development of teachers)

Active, hands on workshops (i.e. a show-case of practices, methods or digital technology uses) – are workshops that are characterized by active personal participation in the activity[416].

Face-to-face instruction – refer to course activities that occur in the traditional classroom without the use of online learning and instruction[417].

Full-immersion courses – are courses in which the student learns by using nothing else but the skill that they are learning[418].

In-class coaching - refers to the type of training in which teachers teach and support other colleagues during classroom activities, providing professional development integrated in a meaningful, concrete way that addresses specific issues teachers have in their own classroom[419].

Leadership training – the training related to digital technologies for educational purposes addressed to school leaders (principals and directors) or to those who have specific responsibilities (e.g. head of a specific subject, head of laboratory). Leadership training can encourage the other teachers, who do not hold leadership positions within the school, to follow the examples of school leaders in the development of ICT skills.

Local hub meetings for groups of teachers - are local, face-to-face meetings of Primary and/or Secondary school teachers, to discuss teaching issues related to digital technologies and to share ideas, projects developments and pedagogical resources[420].

Massive Online Open Course (MOOC) - a free Web-based distance-learning program that is designed for the participation of large numbers of geographically dispersed students[421].

Mentored action research - training activity in which teachers are presented with theoretical base (research ideas) and then invited/supported by researchers and experts to explore how these ideas might be translated into their classroom practice. It enables teachers to talk about practice, observe others' practice and work together to plan, design

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[414] Idem
[415] Idem
[416] Definition retrieved from: https://www.dictionary.com/browse/hands-on
[417] Definition retrieved from: https://www.igi-global.com/dictionary/face-to-face-learning-and-instruction/10803
[418] Definition retrieved from: https://dictionary.cambridge.org/dictionary/english/immersion-course
[419] Definition retrieved from: Stephanie Lorenz (1998)
[420] Definition retrieved from: CAS community
[421] Definition retrieved from: http://whatis.techtarget.com/definition/massively-open-online-course-MOOC

and evaluate curriculum incorporating practical help, such as immediate feedback, modelling good teaching and classroom management as well as advising and helping about time management[422].

Online communities of practice – are groups of people who share a concern or a passion for something they do, and learn to do it better as they interact regularly through the Internet[423].

Online learning – refers the acquisition of knowledge through digital means, and includes learning with the assistance of the Internet and a personal computer. The term e-learning, or electronic learning, often is used interchangeably with online learning[424].

Open Courseware - a free and open digital publication of high quality college and university-level educational materials. These materials are organized as courses, and often include course planning materials and evaluation tools as well as thematic content. Open Courseware are free and openly licensed, accessible to anyone, anytime via the Internet[425].

Peer-group mentoring (PGM) – A new model for supporting the professional development of teachers (introduced in Finland). PGM is implemented in groups, based upon the idea that knowledge is constructed according to the model of integrative pedagogy. Knowledge is transferred among peers, independent of hierarchy. In addition, dialogue and and knowledge sharing are key components, in contrast to a hierarchical, one-way relationship[426].

Resources and self-learning materials – are learning sources that can be used by a learner without the physical presence of a teacher[427].

Teachers' competence self-assessment tools - refers to self-assessment tools designed to help educators reflect upon their current teaching practices, as well as their own competencies to implement those teaching practices[428].

Twilight training sessions (i.e. interactive sessions combining lecture and highly practical activities) - interactive training sessions delivered through a mix of lectures, practical activities and discussion over a limited period of time. Each theory session focuses on a different topic part each week; theory session stands alone and therefore it is possible for teachers to miss some weeks and still gain benefit from attending further sessions. Practical sessions are delivered through a mix of demonstration and paired working. Both theory and practical activities are backed by websites, which contain the material taught during the sessions and supplementary material including video tutorials[429].

Webinars - educational, informative or instructional presentations that are made available online, usually as either videos or audio with slides[430].

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[422] Definition retrieved from: https://www.researchgate.net/publication/256546932_Collaborative_Action_Research_Projects_the_role_of_Communities_of_Practice_and_Mentoring_in_enhancing_teachers%27_Continuing_Professional_Development
[423] Definition retrieved from: http://wenger-trayner.com/resources/what-is-a-community-of-practice/
[424] Definition retrieved from: https://www.frostburg.edu/nursing/distance-learning/what-is-online-learning/
[425] Definition retrieved from: http://www.oeconsortium.org/faq/what-is-open-courseware/
[426] Geeraerts,K, Tynjala, P , Heikkinen, H, Markkanen, I, Pennanen,M, Gijbels, D (2015)
[427] Definition retrieved from: Self-learning materials and continuing education (1984), Medical Teacher
[428] Definition retrieved from: https://ec.europa.eu/jrc/en/digcompedu
[429] Definition retrieved from: https://www.academia.edu/2456347/Grand_challenges_for_the_UK_Upskilling_teachers_to_teach_Computer_Science_within_the_Secondary_curriculum
[430] Definition retrieved from: http://whatis.techtarget.com/definition/webinar

Web-based networks - are online communities that allow users to publish resources and to establish relationships, for purposes that may concern business, entertainment, religion, dating, and so forth[431].

Dimension 4 (Access to content)

Digital curriculum- is a comprehensive, customizable collection of resources that are aligned to learning goals and expectations. Digital contents include a variety of formats (videos, texts, images, audios, and interactive media) and are used by teachers to individualise and personalize students' learning processes. These digital contents, also developed by teachers, are available to students also outside the classroom and school day[432].

Digital texbooks – are digital books or e-books intended to serve as the text for a class, and are a major component of technology-based education reform[433].

E-books- is referred to the result of integrating classical book structure, or rather the familiar concept of a book, with features that can be provided within an electronic environment, which is intended as an interactive document that can be composed and read on a computer[434].

Educational software - are educational resources designed to operate on fixed and mobile devices such as desktop computers, laptopos, smartphones and tablet computers[435].

Educational apps - are educational resources designed to operate on mobile devices such as smartphones and tablet computers[436].

Free content – in addition to Open Education Resources, a great variety of free of charge content that is used in education is available online (i.e. free content distributed by textbook providers, TV programmes, public broadcasting companies, etc.). This content differs from OER for the fact that it was not created and published solely for educational purposes (as is the case of OER).

Gaming - games are based on computer models and allow students interactions, but each has unique features. Games are often played in informal contexts for fun, incorporate explicit goals and rules, and provide feedback on the player's progress. In a game, the player's actions affect the state of play[437].

Maker kits - contain tools and materials needed to experiment and create in many different subject areas. Maker kits offer opportunities for hands-on creativity and experimentation for teens, tweens, children and adults[438].

Open Educational Resources (OERs) - refers to any type of educational materials that are in the public domain or introduced with an open license. The nature of these open materials means that anyone can legally and freely copy, use, adapt and re-share them.

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[431] Definition retrieved from: Jennfier Golbeck (2005)
[432] Definition retrieved from: http://www.centerdigitaled.com/paper/Guide-to-Choosing-Digital-Content-and-Curriculum-41458.html and https://www.k12blueprint.com/toolkits/oer-digital-curriculum
[433] Definition retrieved from: https://en.wikipedia.org/wiki/Digital_textbook
[434] Definition retrieved from: Vassiliou, M. & Rowley, J. (2008)
[435] Idem
[436] Idem
[437]Definition retrieved from: https://www.nap.edu/login.php?record_id=13078&page=https%3A%2F%2Fwww.nap.edu%2Fdownload%2F13078
[438] Definition retrieved from: E.g. Cambridge International Examinations (2015)

OERs range from textbooks to curricula, syllabi, lecture notes, assignments, tests, projects, audio, video and animation[439].

School kits - resource guides that support school leaders, teachers and the whole school community to implementing innovative practices. These resources provide a model to experiment and change pedagogies, translating from theory to classroom e.g. how to conduct cooperative learning activity, how to design and run a creative atelier, how to create a digital content repository, etc.)[440].

Science kits - contain a class-set of components for hands-on experiments. Using these, the students can conduct experiments in small groups and explore educational science principles[441].

Single lesson plans/units – are a teacher's detailed description of the course of instruction or 'learning trajectory' for a lesson[442].

Simulations - simulations are computational models of real or hypothesized situations or natural phenomena that allow users to explore the implications of manipulating or modifying parameters within them. Simulations allow users to observe and interact with representations of processes that would otherwise be invisible. These features make simulations valuable for understanding and predicting the behaviour of a variety of phenomena. Simulations are based on computer models and allow user interactions, but each has unique features. Simulations are dynamic computer models that allow users to explore the implications of manipulating or modifying parameters within them[443].

Software subscriptions – are periodic fees payed by the user to have access to a software[444].

Subscription-based materials – are resources that can be retrieved from a source (software, website, etc.) based on the payment of a periodic fee.

Teacher guides - refers to a guide for teachers that explains how to design and run projects for students of different age groups, for different lengths of time and in different subjects. Teacher guides provide teachers with step-by-step indications through a project process, with detailed advices and tips from getting an idea, designing and tuning the project, carrying it out and exhibiting the results. Teacher guides also recommend further reading, advices on connecting with like-minded teachers around the world, examples of project documents, and protocols for critique[445].

Virtual online laboratories - are a low-cost alternative solution of real labs. 3D virtual environments provide an immersion into the learning contents, and interactions within the virtual world of the game, which are governed by established scientific principles[446].

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[439] Definition retrieved from: http://www.unesco.org/new/en/communication-and-information/access-to-knowledge/open-educational-resources/what-are-open-educational-resources-oers/
[440] Definition retrieved from: http://resources.schoolkit.co.nz/article/575-our-pedagogical-model; http://schoolkit.istruzione.it/schoolkit/
[441] Definition retrieved from: National Research Council (2011)
[442] Definition retrieved from: O'Bannon, B. (2008)
[443]Definition retrieved from: https://www.nap.edu/login.php?record_id=13078&page=https%3A%2F%2Fwww.nap.edu%2Fdownload%2F13078
[444] Definition retrieved from: https://www.investopedia.com/ask/answers/042715/how-do-subscription-business-models-work.asp
[445] Definition retrived from: http://keyconet.eun.org/c/document_library/get_file?uuid=d2e33016-9c19-4901-aa00-5d25c5d734f2&groupId=11028
[446] Definition retrieved from: Dongfeng, L. & others (2015)

Annex 2 Tables

Table A.1: Description of the Future Classroom Lab (FCL) six learning zones[447]					
1) Interact	**2) Exchange**	**3) Investigate**	**4) Create**	**5) Present**	**6) Develop**
▪ Using technology to enhance interactivity and student participation ▪ Interactive whiteboards together with media rich content and learner response devices ▪ 1:1 computing for more personalized learning ▪ From 'supervision' to 'communication' with the help of technology (e.g. classroom mgmt. solutions)	▪ Peer-to-peer collaboration skills ▪ Integrating teamwork into different activities ▪ Face-to-face and synchronous/online and asynchronous ▪ Learning by playing: digital games and simulations for more engaging learning	▪ Learning by exploring: students can construct models, test ideas ▪ Promoting students' problem-solving and critical thinking skills through inquiry-and project-based learning ▪ Added value through technology: rich, versatile and real-life data, and tools to examine and to analyse ▪ Encouraging cross-curricular projects	▪ Learning by creating: active involvement in producing and creating their own content ▪ Interpretation, analysis, teamwork, and evaluation part of creative process ▪ Developing learners' soft skills including presentation, planning and teamwork ▪ Showcasing student work (e.g. learning portfolios) helping to link between different disciplines	▪ Tools and skills to present, deliver, and obtain feedback on their work ▪ A dedicated area for interactive presentations that, through its design and layout, encourages interaction and feedback ▪ Online publication and sharing encouraged, (familiarizing with the principles of eSafety) ▪ Communicative dimension in students' work	▪ Zone for informal learning and self-reflection. A more relaxed and less monitored space ▪ Use of personal learning devices ▪ Supporting motivation and self-expression through opportunities for personalized learning, for example, with tailored learning activities ▪ Flipped classroom

[447] European Schoolnet (2017b)

Table A.2: Mapping between HECC scenarios and FCL learning zones

HECC		FLC learning zones[448]					
Scenario	Dimension	INTERACT	EXCHANGE	INVESTIGATE	CREATE	PRESENT	DEVELOP
ENTRY LEVEL	**Dimension 1** (Digital technology equipment)	• Convertible laptops • Interactive Whiteboards (IWB) • VLE Platform	• VLE Platform	• Microcontrollers for coding • Spreadsheet software	• Presentation software	• Word processing software • Software as a Service (SaaS) • Presentation software	• Optical Character recognition
	Dimension 4 (Access to content)			• Digital Games • Simulations • Virtual Online Laboratories	• Educational Apps • Maker kits • School kits		• Educational software • Digital Textbooks
ADVANCED LEVEL	**Dimension 1** (Digital technology equipment)	• Convertible laptops • VLE Platform	• Interactive tables with projectors • VLE Platform • Data Storage	• Microcontrollers for coding • Spreadsheet software	• Presentation software • 3D printer • 3D modelling software	• Word processing software • Software as a Service (SaaS) • Presentation software	• Optical Character recognition
	Dimension 4 (Access to content)			• Digital Games • Simulations • Virtual Online Laboratories	• Educational Apps • Maker kits • School kits		• Educational software • Digital Textbooks • E-books
CUTTING-EDGE LEVEL	**Dimension 1** (Digital technology equipment)	• Convertible laptops • VLE Platform • Voice Assistant	• Interactive tables with projectors • VLE Platform • Data Storage • Database management system	• Microcontrollers for coding • Spreadsheet software • VR headset	• Presentation software • 3D printer • 3D modelling software • Audio and video editing software	• Word processing software • Platform as a Service (SaaS) • Presentation software	• Optical Character recognition • eBook reader • Wearable wristbands

[448] European Schoolnet (2017b)

Table A.2: Mapping between HECC scenarios and FCL learning zones							
HECC		**FLC learning zones**[448]					
Scenario	Dimension	INTERACT	EXCHANGE	INVESTIGATE	CREATE	PRESENT	DEVELOP
	Dimension 4 (Access to content)			• Digital Games • Simulations • Virtual Online Laboratories	• Educational Apps • Maker kits • School kits		• Educational software • eBooks

Annex 3 Bring Your Own Device (BYOD)

Box 1: Highlights BYOD

- **BYOD** is a school policy that allows students and teachers to bring personally owned mobile devices (such as laptops, Convertible laptops, tablets, smartphones, etc.) into educational institutions and to use those devices for educational purposes.
- Research provides diverging views on **BYOD policies.** Potential benefits may include (i) an improvement in the quality and effectiveness of teaching and learning; (ii) an improvement in the efficiency and sustainability of technology enhanced learning and cost-effectiveness; and (iii) organisational benefits.
- However, **concerns with regard to the BYOD model** related to the need of increasing network capacity and traffic in addition to the challenges of having diverse device types and models and to pedagogical and security risks can be raised.
- Although BYOD is important from a policy perspective, it is **excluded from the scope of the cost estimation of the HECC** for various reasons. The desk research and interactions with experts generally demonstrated the complexity of estimating the costs of BYOD, due to the fact that the items relevant for BYOD largely differ in nature and scope from the items part of the HECC model. The HECC model is generally not adapted to the technical and pedagogical requirements needed when setting up a BYOD policy in a classroom. Thus, in case of setting up a BYOD strategy, additional items would need to be considered and added to the HECC model. In addition, the literature mainly describes BYOD in a qualitative manner; there is very limited cost-related data available regarding the set-up of BYOD in the academic literature. This overall renders a reliable and solid cost estimation of BYOD implementation in the classroom not feasible in the framework of this study.

The presence of mobile devices in formal education systems is growing. Two models for mobile learning (i.e. the use of electronic devices such as smartphones, laptop computers, and tablets as teaching devices) in schools are the one-to-one computing (1:1 computing) and the Bring Your Own Device (BYOD) initiative, which are driving transformational change in pedagogical education circles as learning moves from being teacher to student led. Moreover, closer collaboration is fostered between students, parents, and teachers.

The cost estimation has been performed by taking the assumption that students were supplied with devices by their schools, usually at not cost to the learners or their families. Such use of one portable ICT device per learner is rapidly becoming the norm in many education and training contexts around the world. Schools are increasingly deploying laptops, netbooks, tablet computers or smartphones to support teaching and learning both inside and outside classrooms. However, the implementation of 1:1 model, by providing a dedicated (usually mobile) device for each student involves substantial capital investment by schools, or by the funding entities. In addition, the speed at which some of these technologies are superseded by new models and new types of devices, as well as the cost of providing support and maintenance, raises concerns about long-term sustainability, especially in state funded schools[449]. However, in some countries (such as Luxembourg, for instance) a funding model has been put in place where students share the cost of the mobile devices with the objective of reducing costs and, at the same time, to increase responsible behaviours towards the devices. These contributions for educational devices are smaller for underprivileged students.

One alternative model which is growing interest in, and debated around, is **the BYOD policy / strategy** which relies on the prevalence of learner-owned devices and where students use the mobile devices they already own[450]. Under the BYOD policy, the cost of providing a device for personal educational use is transferred to families or students. These may bring a device they already own to their school, or select and purchase a new device,

[449] EUN (2015)
[450] UNESCO (2013)

or pay for a device chosen by the school or local authority. The decision to introduce BYOD to schools in Europe is overall mainly driven by a combination of social, economic, educational and technological factors. The relative importance of these factors varies from country to country and according to the particular contexts in which individual schools operate[451].

BYOD at the EU and national level

At **EU level**, the ET2020 Working Group on Digital Skills and Competences[452] produced key messages on BYOD following the first Peer Learning Activity (PLA) that took place on 6-8 July 2016 in Hamburg. The PLA focused on BYOD policies[453] in secondary schools; taking an in-depth look at Hamburg's pilot project 'Start in die nächste Generation' (Start into the next generation) which was run in six schools over the years 2015 -2016. In summary, the PLA noted that BYOD offers some benefits for schools as it can be seen as a more 'user friendly' approach to technology integration as teachers and (especially) learners are familiar with the device; it would also allow learners to solve problems more independently and devices are less likely to be damaged or be lost. Through BYOD, teachers could also choose the most suitable pedagogy and tools for their intended learning goals. Nevertheless, it also pointed out that, for a more rigorous approach to BYOD, technical, legal, organisational, pedagogical, teacher and student skills, and ethical and equity issues need to be considered. BYOD should further not be seen in isolation but as one part of a wider digital ecosystem and pedagogical practices.

Also at the **national level**, only a limited number of countries have deployed BYOD pilots or implementation initiatives. For example, UNESCO reported that successful BYOD initiatives are limited particularly in primary and secondary institutions[454]. BYOD is nevertheless found to become more widespread and policies are developed by schools allowing students and teachers to connect and use their own portable equipment in school.[455] In the 1st Survey of Schools, over all ISCED levels, between 11% and 16% of students seemed to use an own laptop for learning purposes, at least once a week. Between 28% and 46% of students indicated to use an own mobile phone for learning purposes at least once a week during lessons. In the 2nd Survey of Schools, between 30% and 53% of students indicate an own smartphone for learning purposes during lessons at least once a week. The percentage of students using an own laptop and an own tablet for learning purposes in lessons at least once a week are 12% and 8% in ISCED 2 and 15% and 8% in ISCED 2 respectively. The numbers over the different surveys are in line and the 2nd Survey of Schools cannot present any evidence of a higher implementation of BYOD compared to the 1st Survey of Schools.

Examples of countries that implemented 1:1 computing and/or BYOD are amongst others France, Belgium and Denmark. In France, in September 2012, the British School of Paris (BSP) became the first school in France to equip every student with a tablet. In January 2013, the Flemish Government in Belgium launched a BYOD in 30 schools selected to be test beds for new pedagogical practices such as gaming, tablet computing and the use of mobile phones for educational purposes. In Denmark, the government encouragement to focus on BYOD has resulted in over two-thirds of schools adopting BYOD. To keep Denmark on the cutting edge of education, the Denmark School District entered this year in the 3rd year of the BYOD program for all 6th-12th grade students in which parents can either provide a device for students or pay a 100 USD fee per year for a district-supplied device[456]. In other EU countries government policies require, or are having the effect of encouraging the use of computers in schools. These policies have led to the consideration of BYOD as a

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451 EUN (2015)
452 European Commission (2016a)
453 European Commission (2016b)
454 UNESCO (2013)
455 EUN (2015)
456 Denmark School District (2018)

potentially more sustainable funding model than national, regional or school level procurement and replacement of computers[457].

Although national Ministries of Education might have launched initiatives to enhance the implementation of BYOD across their network of schools, the decision of adopting a BYOD strategy is usually taken at the school level. As a consequence, there are multiple examples of possible BYOD scenarios to be adopted by schools[458]. In some schools, BYOD may begin in an informal, ad-hoc way as a few teachers begin to recognise that students' own devices could be useful in the classroom. This could lead to specific good practices which can be used in other classrooms. Alternatively, the BYOD introduction may be carefully planned, strictly controlled and monitored through a school-wide strategy with a clear vision and objectives[459].

Perceived benefits and challenges of BYOD

The main perceived benefit of BYOD usage refers to **the improvement of the efficiency and sustainability of technology enhanced learning and the cost-effectiveness.** BYOD can indeed improve the cost-effectiveness of technology enhanced learning and enable the introduction of 1:1 computing without increasing school spending on devices. Also, the introduction of BYOD often results in reduced school spending on desktop computers and may allow some computer classrooms to be re-designated as general-purpose classrooms, which allows more efficient use of school accommodation.

Although BYOD receives a lot of attention by European educators and policy makers, setting up a BYOD strategy in practice is also associated with **a range of challenges and risks**. A study of European Schoolnet showed that most practioners in the field emphasise the challenges and risks more than the actual or potential benefits of BYOD[460]. The major concerns raised are[461]:

- **Financial burden on parents** - a major concern of BYOD relates to the shift of the responsibility and cost of purchasing mobile devices from national Ministries and/or responsible institutions towards the parents. Parents could raise concerns on the cost of providing mobile devices for their children. This concern is strongest in countries where the concept of providing free education is a key element of education policy[462];
- **Network capacity and traffic and related additional costs** – shifting the cost of purchasing devices to the parents allows schools to make savings when students and parents pay for mobile devices under BYOD policies. Nevertheless, implementing BYOD in education moves the hardware costs from the school to the learner. In turn, it places additional pressure on the bandwidth infrastructure; it may require at least the same investment in upgrading and maintaining infrastructure (including ensuring: an adequate bandwidth, robust WiFi for large numbers of concurrent users, network security and appropriate mobile device management systems) as those schools which implement a 1:1 model;

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[457] Ambient Insight Regional Report (2013)
[458] European Schoolnet published in 2015 a 'Technical advice for school leaders and IT administrators' which amongst others details different possible BYOD scenarios. These can include: (1) an informal single teacher innovation: (2) a voluntary BYOD for older students; and (3) a planned and controlled whole school approach. See: EUN (2015)
[459] UNESCO (2013), EUN (2015)
[460] Idem
[461] EUN (2015), K-12 Blueprint (2014)
[462] EUN (2015)

- **Challenges of having diverse device types and models** – concerns are expressed by educators relating to BYOD models in which there is not a standard specification for the mobile devices brought into school. This may, on the one hand, lead to a digital divide between students with cutting edge devices and those with less powerful devices or even none at all. On the other hand, in case of having a variety of device types and models in the classroom, courses generated by teachers may need to be designed and adapted for the device with less functionalities compared to the more sophisticated devices. Schools implementing BYOD programmes must also consider to have a policy in place to provide devices to students who cannot afford them, either by buying the devices for the students or by subsidising their purchase;

- **Pedagogical risks** – a BYOD policy requires a significant amount of curriculum analysis and redesign in order to take full advantage of the features of mobile devices. Teachers may say they are on board for BYOD, but they also need to be aware of the impact it has on their teaching approach. Teachers may need more training, support and preparation time to prepare courses and to deal with their students using many different devices. Moreover, many educators believe that using any mobile device in classrooms could distract students from their normal learning activities. BYOD increases these concerns as students using their own mobile devices might access their own non-educational apps and games or use messaging services in class;

- **IT support challenges** – the cultural change of BYOD can be very difficult for in-house technical support staff (in case the IT department is not outsourced) and they may be reluctant to co-operate with the BYOD plans. As is the case for teachers, they may also need additional training to deal with the infrastructure changes;

- **Teachers' concerns about BYOD** – engaging teachers and developing a whole school approach to BYOD need careful planning. Major issues may arise with the adequate professional development for teachers. Furthermore, it might be difficult to persuade the teachers who are not confident with ICT, and/or who had negative experiences when trying to use new technologies with their students, to engage with BYOD; and

- **Security, privacy risks** – further issues include general security and privacy. Implementing any technology related policy involves careful consideration on risks, which mainly covers: (i) damage, loss or theft of student devices; (ii) data protection and system security; (iii) safeguarding of children and staff; and (iv) health risks. The Commission raised these security concerns related to the use of BYOD programmes in companies. These concern might be as well referred to schools when BYOD policies are implemented in the educational context. In particular, the Digital Transformation Monitor of the European Commission published the 2017 'Bring your own device: a major security concern' report. The report shows the increased adoption of BYOD programmes in the business world by highlighting the expected advantages and benefits associated with the BYOD concept in terms of potential increased productivity, increased employee satisfaction and saving of equipment costs. Next to that, the report stresses that strong security concerns should be taken into account despite the BYOD benefits. In particular, as the concept of BYOD involves the mix of personal and company data on the same device, an attack on an employee's mobile phone can compromise the company's entire security system. The study reveals indeed that mobile malware is one of the ten most common attack types making the corporate network vulnerable, and therefore requiring a stronger IT security system.

For these reasons, examples of successful BYOD initiatives, particularly in primary and secondary institutions, are limited[463].

Implementing BYOD in the HECC

Although BYOD is considered very relevant from a policy perspective, it is not considered in the scope of the HECC model. Consequently, the costs to set up BYOD in the HECC model are excluded from the scope of this study. In particular for the following considerations:The desk research and interactions with experts[464] showed that the costs of implementing a BYOD strategy are not yet clearly exploited or defined in the academic literature; hardly any specific case studies regarding the set-up of BYOD and its costs were found.

In addition, the HECC model is not fully adapted to the technical and pedagogical requirements needed for implementing a BYOD policy in a classroom. Hence, in case of implementing a BYOD policy in a classroom, **additional items to the HECC model** would need to be defined and integrated across the four dimensions of the HECC model. An overview of the main additional items is detailed below (non-exhausted list).

Table B.1: Additional items BYOD

Dimension	Item

Dimension 1 (Digital Technology Equipment)	• Additional equipment to recharge the devices:
	  ○ Docking stations;
	  ○ BYOD charging and storage stations, etc.

Dimension 2 (Network requirements)	• Broadband and network: expand existing IT infrastructure, increase the WiFi coverage and capacity • Additional access points • Additional cabling • Restructure segmentation of the IT network • Specific support and training of IT staff • Policy and security: including policy management and mobile device management • Specific software and tool licences • Internet filtering firewalls, etc.
Dimension 3 (Professional development of teachers)	• Technological and pedagogical support • Training of teachers: training courses and workshops
Dimension 4 (Access to content)	• Digital curriculum and lessons • E-books • Mobile apps

Dimension 1 (Digital technology equipment)

With BYOD, there are no direct hardware and maintenance costs for schools and students can work with the tools they need and prefer. However, as noted above, not all students may be able to afford to purchase their own device. Alternatively, schools can choose to supply each student with a standard issue only device (SIOD). Although there are capital and operating expenses associated with an SIOD-based program, it ensures that all

[463] This is also confirmed by e.g. UNESCO (2013)
[464] E.g. the stakeholder consultation with national Ministries, exchanges with European Schoolnet

students have equitable access to mobile devices, streamlines faculty/staff training, and also simplifies the IT support and maintenance.

However, **additional equipment for recharging the devices** brought by the student, such as universal docking stations, BYOD charging and storage stations[465] should be provided by the school in each classroom. Storage stations could, for example, cover different individually lockable compartments, USB ports and power outlets allowing students to charge and secure almost any mobile devices (in case of several device types).

School leaders also would need to decide on the level of responsibility that the school has on the students' devices. Decisions need to be made regarding who is responsible for device **insurance**, device **tracking**, **locking** - and perhaps remote wiping - of lost or stolen devices, **replacement** of lost, stolen or damaged devices and making available temporary loan devices[466]. Each of these items imply varying levels of costs.

Dimension 2 (Network requirements)

One of the most common technical challenge for schools implementing BYOD refers to **connectivity** and obtaining the **necessary broadband speed**. The introduction of BYOD, even when this is on a voluntary basis and/or involves only a few classes, increases the number of users sharing internet bandwidth, as well as of concurrent users accessing the WiFi network and items stored in and retrieved from cloud storage. The 2015 publication from European Schoolnet 'BYOD, a guide for school leaders[467]' recommends that for a large school, or a group of schools, operating BYOD 1 Mbps per connected device (e.g. 1000 devices = 1Gbps) is needed.

In addition to fast bandwidth per device, it is vital to carry out an **upgrade in terms of WiFi network coverage and capacity** across the school. The WiFi service should meet the needs of many users (including students, teachers, administrators and visitors) using diverse devices in a variety of physical locations within and around the school. To upgrade the WiFi network, the total number and the coverage of **access points** have to be increased in order to provide a density of one access point per classroom[468]. With the increase of access points, **additional cabling** in the buildings also needs to be run in order to provide connectivity[469].

Outside of the hardware updates, the school implementing BYOD also needs to restructure the **segmentation of its network**. Before the implementation of BYOD, the network is generally divided into two segments, public and staff, with the staff network allowing access to network resources and requiring authentication through active directory. On the other side, the public network could be accessed by anyone, and is largely unregulated aside from basic Internet filtering and a firewall. In order to accommodate students bringing devices from home an additional network segment outside of the public and staff networks has to be created in order to allow students access to dedicated network resources.

Implementing BYOD can be very difficult for the **technical support staff** (in schools that employ IT support staff rather than outsourcing this service). Consequently, arrangements for IT support are reviewed and enhanced as required. This may include **recruiting additional staff**, providing extra staff training and/or outsourcing some support services.

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[465] Examples of commercial products available on the market as 'BYOD charging and storage stations' can be consulted at the following link: https://www.lockncharge.com/eu/category/byod/
[466] EUN (2015)
[467] Idem
[468] Hackler, R.J. (2015)
[469] Idem

Based on real cases studies[470], schools which have successfully introduced BYOD or other mobile learning initiatives recommend involving IT support staff (or external providers of IT support) early in the planning stages, asking for their advice, providing them with devices to research potential issues and solutions and encouraging them to communicate with and learn from other schools' experiences. If a school's BYOD strategy includes responsibility for supporting the students' devices, the number and knowledge of IT staff currently employed may be insufficient, necessitating additional investment in staff and staff training or outsourcing of IT support to a company or organisation that provides a 'managed service'.

In addition to the adjustments to the wireless infrastructure, significant **security concerns**[471] will need to be taken into account. Security risks are referred to malicious actions undertaken by people from within or outside the organisation aimed to damage the network infrastructure. This risk increases with the increased use of the WiFi network, such as in the case of BYOD strategy. Consequently, several actions need to be considered when implementing BYOD in order to prevent the risk associated to the network security. In particular, a robust and protected network should ensure that only properly authenticated users and devices can access the network. In addition to network security, schools putting in place BYOD strategy also need to protect and safeguard children from inappropriate content access via their devices. From a technical point of view, there are a variety of tools which IT administrators or their service providers can employ to help protect students from illegal, distasteful and age inappropriate content such as, for instance, **firewalls, proxy servers and content filtering.** For example, using popular social networking sites such as Facebook, schools may impose age restrictions for access or grant user access to all students, but restrict access to online gaming applications inside Facebook that draw on vital bandwidth across the network[472].

Dimension 3 (Professional development of teachers)

Teacher's continuing professional development (CPD), pedagogical as well as technical support for teachers are essential in order to successfully implement a BYOD strategy in schools. When a school opts to implement a BYOD strategy, a project team, that coordinates the BYOD-related actions, should be established in order to plan and oversee the implementation of the school-wide BYOD strategy.

Teachers' training courses, workshops and technological and pedagogical support will need to be arranged by the BYOD project team. These might take different forms such as face-to-face training, online training, hybrid training, etc. aiming to foster the integration of BYOD in classrooms.

However, it should be additionally considered that drafting the BYOD policy and related procedures requires time due to the fact that specific topics (i.e. data protection, privacy, children's safeguard, etc.) need to be carefully assessed and explained in **the BYOD school's policy**. Therefore, the time spent by teachers and school's leaders in drafting BYOD policy and procedures has to be carefully evaluated before the launch of the BYOD implementation.

Dimension 4 (Access to content)

When the BYOD strategy is in place, students can get access to a wide range of pedagogical content and resources from their personally owned devices. Teachers and school leaders will need to embed the use of mobile devices into curriculum design and lesson planning. Textbooks can be gradually replaced with eBooks and multimedia resources developed by

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470 EUN (2015)
471 European Commission (2017a)
472 Netgear (2013)

teachers and students have to be continually updated. Mobile apps can be created or purchased to support learning activities.

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