ESA LearnEO!

A Roadmap for Earth Observation Education in Europe

DRAFT v3

ESA AO/1-7008/11/I-BG Earthnet - ESA Learn Earth Observation Project LearnEO!

Deliverable D-170, December 2015

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Revision History

Issue	Date	Change records	Author(s)
v1.0	2015-02-14	Draft roadmap based on presentations, discussion and summaries at the ESA LearnEO Education Workshop, Frascati 5-7 Nov 2014, with post workshop input from participants.	V. Byfield, F.Del Frate, M.Higgins, R.Kapur, with LearnEO Education Workshop participants
v1.1	2015-05-05	Revised Roadmap based on workshop discussions, post workshop feedback from participants on priorities for future EO education activities.	V. Byfield, F.Del Frate, M.Higgins, R.Kapur, with LearnEO Education Workshop participants
v1.2	2015-05-31	Minor revisions to text.	V. Byfield, F.Del Frate, R.Kapur, M.Higgins, with LearnEO Education Workshop participants
v2.0	2015-12-15	Version 2 of the Roadmap, extensively revised to include information and priorities from EO Open Science 2.0.	V. Byfield, F.Del Frate, R.Kapur, P.-P. Mathieu M.Higgins
V3.0	2015-12-31	Version 3 of the draft Roadmap with minor changes to finalize layout and text	V. Byfield, F.Del Frate, R.Kapur, P.-P. Mathieu, M.Higgins

Content

Executive Summary

For society to benefit fully from its investment in Earth Observation the data must be accessible and familiar to a global community of users who have the skills, knowledge and understanding to use the observations appropriately in their work. Future Environmental Data Scientists will need to draw on multiple data and information sources, using data analysis, statistics and models to create knowledge that is communicated effectively to decision-makers in government, industry, and civil society. Networks, cloud computing and visualization will become increasingly important as citizen scientists, data journalists and politicians increasingly use Earth observation products to give their arguments and decisions scientific credibility.

The overarching aim of Earth observation education must therefore support life-long learning, allowing users at all levels to remain up-to-date with EO technologies and communication mechanisms that are relevant to their individual needs. Emerging interactive education methodologies (such as 'MOOCs' and mobile learning), and hands-on engagement with real data (such as through citizen science projects) will become increasingly central to outreach, training and formal education. To achieve this, it is necessary to engage a community of experts from a range of disciplines, in order to establish a comprehensive network of educators, technical experts, and content producers. It will also be important to encourage 'crowd-sourcing' of new contributions, to help maintain scientific and educational quality. This is a formidable task, beyond the resources of any individual organisation.

This Roadmap for future EO education is the result of two workshops held at ESA-ESRIN, the ESA LearnEO! Education Workshop 5-7 November 2014, and EO Open Science 2.0, 12-14 October 2016. Based on material presented at these workshops this roadmap includes:

- a brief review of existing resources and initiatives to deliver EO education in Europe,
- a preliminary identification of current gaps,
- an assessment of the potential for modern information and communication technologies to help deliver EO education and training, and
- a set of justified recommendations for future activities to ensure delivery of the education and training needed to take full advantage of EO data to provide information for environmental monitoring and decision support.

Both workshops revealed blurring of boundaries between EO data science and EO education. For example, tools presented at EO Open Science 2.0 come with supporting tutorials and use-cases, and these have a role to play in formal and informal education. Case studies from scientific research often use image data that can inspire and inform audiences from outside the scientific community. Research initiatives that contain 'citizen science' elements need to inspire and educate volunteers in order to be effective. To harness the education potential of such activities requires an inclusive approach, open to anyone interested in contributing to the on-going development of EO education – regardless of their background.

Fragmentation of effort and the long-term sustainability of tools, outreach initiatives and education projects are on-going concerns. The difficulty in maintaining user support when a project ends cropped up in many contexts at both workshops. Open data, open source, open science and open education can mitigate some of the problems that may occur when successful initiatives become static as funding stops. However, to meet user needs for ease of access to available resources and technical support there will always be a need for a stable 'core' effort that can maintain a basic level of activity and use this to leverage contributions from the wider community.

Two considerations are central to the recommendations from the workshops:

1. Future education initiatives should build on and include quality education material and established training networks from a wide variety of past and current projects.
2. New users should have easy and time-efficient access to available suitable education resources, which can inspire interest and meet individual needs.

To reconcile these two conflicting requirements will require effective use of modern technologies for providing access to online resources and present available choices in ways that meet a users preferences and individual learning needs. The recommendations below have been divided into short-term (1-3 years), medium term (3-5 years) and long term (6-10 years).

Short term (ST) measures seek to establish a network of interested experts, review existing resources, identify gaps, set priorities for future work, develop outline specifications for a 'gateway' tool to provide one-stop targeted user access to distributed resources, and investigating potential mechanisms for providing user feedback and on-line peer support.

In the medium term (MT) plans for a 'gateway tool' will be developed in detail and implemented as a prototype. This should provide user access to widely distributed resources, facilitate user feedback, peer review and user support.

In the longer term (LT) user access to the gateway will be further improved to support 'crowd-sourcing' to fill gaps in and keep abreast of new developments, and to facilitate peer review in order to maintain technical, scientific and educational quality.

Summary of the main recommendations

- Recruit and support a network of experts to facilitate interaction between scientific, technical, education and communication experts to plan and deliver a more integrated approach to EO education. (ST)
- Review existing education resources, including those that are not part of formal education initiatives, mapping these to broad user groups and application areas, in order to identify gaps, and set priorities for future development. (ST)
- Encourage the development of new 'hands-on' tutorials and other activities associated with EO-related apps and toolboxes, to show how these may be used in education contexts. (ST)
- Develop additional on-line courses (e.g. MOOCs), which show how EO data can provide information for scientific research and decision support in a variety of contexts (ST-MT).
- Detailed planning and implement an adaptive EO education 'gateway tool' to facilitate user access to distributed resources, tailored to individual interests and education needs. (MT)
- Develop a 'recommendation engine' associated with the 'gateway tool' to facilitate user feedback, user recommendations and on-line support. (MT)
- Set up a forum for providing local and on-line peer support, linked to the gateway tool and recommendation engine.
- Encourage the inclusion of 'citizen education' in citizen science, using the gateway tool and recommendation engine to facilitate links between citizen science projects and suitable external education initiatives. (LT)
- Develop mechanisms to encourage, support and facilitate crowd-sourcing of new education contributions from the wider EO data science community, reviewing these and making them available through the EO education gateway (LT).
- Maintain and extend the gateway tool, recommendation engine and associated fora, to include support for 'specialist' EO education networks where users and resource providers can collaborate to develop, test, review and translate material. (LT)

1 Introduction

For society to benefit fully from its investment in Earth Observation (EO) the data must be accessible and familiar to a global community of users who have the skills, knowledge and understanding to use the observations appropriately in their work. To achieve this, EO education must support life-long learning, allowing users to remain up-to-date with new data sources, processing techniques and communication mechanisms that are relevant to their individual needs.

Providing education resources for life-long learning by users at all levels across the full range of EO applications is a formidable task, beyond the resources of an individual organisation. Recognising this, the European Space Agency (ESA) has taken the initiative to develop a Roadmap for Earth Observation Education.

This Roadmap starts with a vision of the future (Section 2), followed by an overview of key education needs of different audiences (Section 3), a brief review of existing EO education and training initiatives (Section 4), and an analysis of barriers to effective EO education for all (Section 5). The Roadmap itself, in the form of justified recommendations for future education activities is presented in Section 6.

The review and recommendations are based on talks and discussions that took place during a 3-day Earth observation education workshop, organised as part of the ESA LearnEO! Project[1] at ESA-ESRIN in Frascati, Italy, 5-7 November 2014. Additional suggestions ideas were provided by workshop participants over the following weeks. Details of workshop objectives, programme and participants may be found in Annex 1. The analysis and recommendations resulting from the LearnEO! Education Workshop have been updated and revised in the light of discussions that took place during Earth Observation Open Science 2.0 in Frascati, 12-14 October 2015.

This document is not a comprehensive review of all existing resources for EO education. Nor is it a detailed specification for a future European EO education system. Instead it sets out a vision of how EO data could contribute to European society in the future and gives some ideas for how to make the vision come true. We hope that our recommendations will help European institutions engaged in EO education and training to deliver educational tools and training activities that remain relevant an and up-to-date.

The ideal system is one where users at all levels have easy access to data, information and training resources delivered in a way that suits their individual needs. It is not a system that sees educators and students as distinct and separate groups, but one where all who wish to learn or contribute to the education of others will have the opportunity to do so. This will a richer learning environment for everyone, and will ultimately help to make Earth observation a familiar and natural component of environmental science, policy-development, resource management and daily life - an enjoyable and useful source of information for Europe's citizens.

2 A vision for the future: where do we want to be in 2030?

2.1 The vision: Earth observation in Environmental Data Science (EDS)

In 2030 Environmental Data Science (EDS) will be a discipline whose practitioners can draw on multiple data sources from a range of scientific disciplines, in order to create environmental knowledge to support their decisions. Data will be bio-geo-chemical, physical and social. The data sets will be large, cover space and time and vary in range and resolution. Knowledge will be created using data analysis, statistics and models. Debates about the role of theory in 'big data' will be on going. The role of cloud computing will be significant. As today, networks and collaboration across different disciplines will be important. Outputs will allow meaning to be easily recognised, so visualisation will be crucial.

[1] http://www.learn-eo.org

There will be more citizen scientists and more data journalists. Environmental data science products will be a natural part of civil society and governmental advocacy. Politicians will use products that are accessible to them in order to give their arguments and decisions scientific credibility. As today, however, no argument will be won solely on the grounds of environmental data science.

Future EDS professionals will have a wide range of skills that allow them to provide decision support for government, industry and civil society in a timely and appropriate manner. They are 'meta-experts' who can identify, access, process and analyse data from multiple sources to retrieve relevant information and know how reliable it is. Good communication skills allow them to interact with different users to establish their information needs and deliver the required information in suitable formats. As 'meta-learners' they keep abreast of new developments in their field of expertise and in computing and communication technologies, making effective use of available training opportunities. From their own experience, they know the value of openly available education resources, and are therefore prepared to share their expertise by developing new case studies and lessons, reviewing resources provided by others, offering feedback to authors and advice to other users.

2.2 User Portraits

2.2.1 A new EDS graduate

Ada just graduated in Environmental Data Science from a Consortium of European Universities. Her honours project looked at changing agricultural patterns in Europe since 2010. She received particularly high marks for the clarity of her presentation of uncertainty. She used economic, social and environmental data from over 30 different sources, and hopes she got all the attributions right (the ones with DOIs will be ok). She only used data that can be presented as text or gridded NetCDF. She used a GIS for the visualisation and the R-Py plug-ins[2] for the data processing. Processing was done using the university consortium cloud server, with access to the data via open-dap and web-map servers. Her studies were really practical. Many of the early classes involved taking an on-line course on EurEONet[3], which would then be discussed in class. The best lessons had great interactions – so you could play with data and really understand its applications. Some of her classes were taught with the open data science stream[4]. Her entire degree was taught online. She is now ready for the first step in her career in industry, civil service or research.

2.2.2 A career changer

Bill is starting a new career in Earth Observation after several years as an oceanographer, where he used EO data to support the development and validation of ocean models. As a data user, he was acting on panels to support the development on new data products, and found himself increasingly interested in the effort to deliver data products of known quality (including uncertainty estimates), traceable to reference standards. He felt he could make a contribution, but switching disciplines would be a big change, not to be taken lightly. Luckily he had the opportunity to use self-paced online modules available via EurEONet to obtain more in-depth information and test the water before deciding finally to make the switch.

2.2.3 A research scientist who needs to work with a new type of data

Claire is an ecologist who wants to include new EO data in her work. Through EurEONet, she had easy access to the product guide, example data, and citations for research that included the use of this data type. She found that the product guide was clearly laid out and easy to navigate, to find

[2] R-Py provides a low-level interface to R (an open-source language and environment for statistical computing and graphics) from Python (a widely used general-purpose, high-level, oopen-source programming language). R-Py plug-ins includes wrappers to graphical libraries, as well as R-like structures and functions.

[3] Our proposed on-line 'market place' for European EO education resources (see Section 6.X).

[4] Data stream processing allow environmental data scientists to access streams of real-time data and carry out their own processing and analysis, storing the results in the cloud and sharing information and data online.

the information she needed with minimal effort. The data were easy to access and manipulate, and it was clear where to begin. Some of the review papers that analyse the application of several datasets to specific problems were really useful, and allowed her to adapt available analysis methods to her own work. The DOI made the data easy to reference in papers, and the data providers track who is publishing based on their data – information that is of value both to users and data providers, who can tell their funders just how much value is being generated for Europe by having accessible data.

2.2.4 An environmental consultant

Dan is a consultant wanting to develop his professional skills to include the analysis of EO data for environmental monitoring and resource management. A busy professional, he needs to do this whenever time allows, through self-paced modules that assist his learning and makes it more effective. These modules cover the data, visualisation, statistics, and communication. He also appreciates the opportunity afforded by EurEONet to contribute case studies based on his own experience and link these into existing training modules. A great way to learn is to teach, and the increased exposure he gets by contributing training materials also brings him new clients and collaborators.

2.2.5 A university lecturer

Eva has just started her job as a university lecturer in environmental science. One of her tasks is to help develop a new remote sensing module, and she is desperately looking for material she can use to make her lectures informative, scientifically valid, visually appealing, and relevant to the subject area. Through EurEONet she has easy access to diagrams, figures, images and photos provided by EO professionals and data users from around the world, and made available on-line through a Creative Commons licence. Access to suitable data sets and analysis tools supported by easy-to-use, peer-reviewed instructions, allows her to build a tailored series of hands-on practical exercises for her students. Her students can also use the on-line resources for individual and group projects. In return they contribute by testing new material, providing feedback to authors and data providers, and reviews that make it easier for other users to evaluate and select material for their particular use in the future.

2.2.6 A school teacher

Finn is a schoolteacher looking for education material he can include to make his teaching more relevant and exciting. Through 'EurEONet' he has access to interesting case studies which are supported by education resources for the subjects he teaches. The materials are easy to link to national curriculum objectives, with activities that are easy to implement in the classroom, and really engaging and suitable for students at different levels, so he can make his teaching suit the differing needs of his students. As a result all his students have at least one experience of using EO data to solve a simple, interesting problem by the time they leave school. Knowing the importance of good feedback, Finn provides information on how the material is used by his students and offers suggestions for improvements. He also makes recommendations to other users and shares his experiences with colleagues through the on-line teacher forum.

2.3 Easy access to EO education for all

The portraits above are examples of how different types of EO data users might take advantage of openly available education resources, and also contribute to making these resources comprehensive, relevant, user-friendly and up-to-date. The 'EurEONet' of our vision brings together existing European resources and initiatives and adds value to these by harnessing the expertise of EO data users from many walks of life. An over-arching system makes it easy for different users to identify and access resources that suit their own needs. Those who wish to contribute can easily do so by providing their own material, testing and reviewing material provided by others, or by offering advice to their peers through appropriate on-line fora.

The development of such a system for 'easy access to learning for all' requires us to address several interrelated problems:

- The need to 'demystify' EO and increase 'visibility' of the data and its applications in all senses, (including literally showing people how EO works and what the data looks like).
- Navigation and search issues, (including enabling more direct and intuitive access to relevant data and imagery using common search terms relevant to the target user groups).
- The need for 'standards' in terms of platforms, technologies and common tools used to develop apps and to facilitate access to data for new audiences.
- The role of data visualization, info-graphics, CGI and film production in highlighting, interpreting, and enabling better understanding of the data.
- Ensuring curriculum links for school-based education.
- The need for broad segmenting of 'non-technical' user groups, and tailoring apps and services accordingly.
- The idea of making use of local expertise to support new users (e.g. in university settings).
- Encouraging and facilitating the crowd-sourcing and peer-review of new education resources by making it easy to contribute, and ensuring that contributors are credited and receive feedback on their work.
- The need for good user support without over-burdening resource providers.

3 Meeting the education needs of different audiences

Group discussions at the LearnEO! Workshop dealt with two broad audiences: those in formal education at schools and universities, and those participating in more informal education activities as part of continued professional development. One might equally distinguish audiences based on their level of education, technical expertise, or motivation for wanting to learn more about applications of Earth observation.

To achieve the vision for 2030 where EO data is an integral part of decision support at all levels, EO education must

(i) attract, inspire and inform new audiences, and show them the value of EO data for environmental monitoring and management, and

(ii) provide high-quality, on-going education and training for environmental data science professionals, enabling them to use EO-data appropriately in their work.

3.1 Attracting, inspiring and informing new audiences

Although Earth observation is an inherently powerful and compelling tool once understood, for many potential new audiences the data sets seem inaccessible and too technical to warrant more detailed attention. There are perceived barriers to entry, which stem from the technical 'jargon' of the sector, the bewildering diversity of data types, and a lack of coherent routes to accessing the data. Some user groups will need to be equipped with an understanding of fundamental concepts and underlying technical principles, but at the outset the main aim must be to grab the attention of potential users and show in clear unequivocal terms what EO can do for them.

This means trying to 'personalise' the concepts of EO and to make the content feel less 'remote'. Efforts should be made to make EO feel less remote by demonstrating that the underlying principles are actually quite straightforward. It is crucially important to not make wrong assumptions about what these new audiences already know, including in terms of the basic physics, but rather to demonstrate, as simply as possible, how the technology works, and how it can play a key role by informing the decision-making process in a wide variety of contexts.

3.1.1 EO education in schools

3.1.1.1 Inspiring students, building engagement and developing innovation and skills

Earth observation is not a curriculum subject, but it has the potential for bringing other subjects to life and to make them feel more personally relevant and emotionally engaging. We want the next generation of decision-makers and policy developers to have grown up with a routine, embedded, and day-to-day exposure to Earth observation data products, so that they grow into adults with a deep-seated understanding of the majesty, vulnerability and fragility of our environment. Emotional engagement can be derived from clear communication about the context of the data, but also through high production values in terms of the quality of apps, the way in which stories are told through animation and video, and the way in which imagery and other data is interpreted through high-quality info-graphics and data visualisation.

In many ways, EO education at school level and for younger people can be seen as a form of 'capacity building' two generations hence. It can combine skills development with the growth of an inherent, intuitive understanding of the power and role of Earth observation and the perspective it provides for policy development, forward planning, and good decision-making.

To achieve our vision of the future, we need to cater for a new generation of multi-skilled workers, and EO education should bear this in mind by providing pathways to understanding how to use specific data for specific purposes, whilst also encouraging the next generation to be innovative and resourceful in extending and expanding upon existing resources and software tools.

3.1.1.2 Ensuring curriculum links for schools and meeting teacher needs

To give students the opportunity to develop an intuitive understanding of EO it is essential to give students and teachers easy access to relevant EO data, instantly and on their own terms, both in school-based education and informal learning through, for example, science centres.

Teachers are more easily engaged if EO education resources include in-depth curriculum links, and the ability to search for data using curriculum terms. Making this possible in multiple international curricula is not a trivial task, and requires collaboration between EO scientists and educators at national and international level.

3.1.1.3 Computer-assisted learning

Modern technologies such as apps and social media provide considerable scope for developing EO education resources that can engage students while relieving the burden on over-worked teachers. This potential is already recognised in some of the more recent education resources developed, for example by ESA (Section 4).

There are three important considerations in developing an EO app for formal or semi-formal education use, where the principal users will be teachers and to some extent students:

1. Extreme 'time poverty'. An app for teachers has to meet the very highest standards of intuitiveness, ease of use, and ease of navigation. Teachers work under high levels of time pressure for lesson preparation and delivery. For an app to have a chance of being used, in-depth and regularly, it must be seen as more than just an occasional gimmick. It must stand up to the very low tolerances of the target audience, in terms of patience and expectations for ease of use.

2. Delivery of the curriculum. Teachers in general will only be able to make substantive and regular use of software tools and visual resources if they help to deliver the curriculum. The curriculum is the focal point of all teaching and learning, and no matter how innovative the teacher, they will generally avoid tools that do not meet this need. Therefore, curriculum linked terminology in the interface of any app or other education resource is key.

3. Self directed learning. To enable teachers to allow their students to use an app as part of their own guided or self-directed learning, the core and any associated apps, tools and or multimedia resources must have features that allow students to 'solve challenges' or 'investigate' the data. It has to do more than just provide information. There must also be a 'narrative' dimension that provides context for the data.

3.1.1.4 Combining education and 'citizen science'

Provided these considerations are addressed, teachers and students generally relish the opportunity to engage directly with real-world data. This creates depths of learning and insights that are hard to develop in other ways and allows students to feel they can make a contribution to science.

If an app has the additional aim of being useful to scientific audiences and to assist with matters such as data validation, it may offer considerable opportunities for added value to both the education and scientific communities. When students feel they are taking part in real scientific investigation their motivation is likely to increase, with positive effects on both learning and personal engagement. Simultaneously, the scientific community may benefit from a large and willing cohort of 'citizen scientists'.

3.1.2 Non-technical users in the wider community

Many of the issues that apply to teachers and students also apply to other 'non-technical' user groups, such as NGOs, local authorities, policymakers, science communicators, and small and medium size enterprises. 'Time poverty' is a fact of life for almost everyone, with corresponding need for easy access to material that is relevant to an individual or organisation's remit and responsibilities. Unless EO data sets, case studies and technical information are easy to access and demonstrably relevant, decision-makers are unlikely to invest much effort in acquiring the knowledge and skill they need in order to use EO data appropriately in their work.

Given the myriad of EO data products and application areas developed over the last decades, and the fact that much more will be available in the future, the task of developing suitable education resources and training opportunities is formidable. It is therefore important to identify the main audiences, and segment them according to information needs – at least along broad lines. To segment them at too granular a level would, however, over-complicate the process of tailoring apps and other tools, cause further fragmentation of available data sources, tools and other training resources, and ultimately make it more difficult for an individual or organisation to identify and access what they need.

The best way to ensure that user requirements are met is likely to be through partnerships between EO scientists, data-providers, and professional educators on the one hands, and representatives of key user groups such as NGO's on the other. This could help to amplify the 'real world' educational and citizen science contexts with which educators can engage new users and potential students (including those in formal education). It will also help in identifying and addressing major challenges associated with developing and maintaining the skills need to use EO data appropriately as one of several decision-making tools.

3.2 Professional education for environmental data scientists

When planning the education of Environmental Data Scientists it is important to consider the different categories that are included in this 'umbrella' term. The workshop discussion made a distinction between formal, university-level education and more informal professional development through short courses and self-study – a division we also follow here.

However, there is also a need to look at the role and functions of different groups who are involved in either formal or informal education - students, lecturers, scientific researchers, technicians, senior engineers, consultants, policy makers etc. Other divisions are created by the many environmental science disciplines (e.g. meteorology, oceanography, geology, biology, agriculture), each with separate requirements in terms of background information, data access, and (to a lesser extent) data processing and analysis methodologies.

Courses that bridge the gap between social and environmental sciences also blur the boundaries between education designed to deliver a high level of technical expertise and education for a more general audience who will take on the role of bridging the gap between EO-based data science and policy- and decision-makers in the wider society.

Some general considerations apply to most of these groups, including, for example:

- the need for learners to acquire technical, computing and communication skills at a level that enable them to perform well in their chosen profession,
- the need to understand the strengths and limitation of Earth observation and other data types in different contexts, and
- the need to address geo-ethics issues that may arise from the use of EO data for different purposes.

Education resources and training courses should aim to provide students with examples and activities that will facilitate the development of technical skills and understanding of the data, as well as a sense of wider responsibility for how the data may be used.

3.2.1 University-level education of environmental scientists

Formal education in universities or equivalent technical training is the main route to educating new environmental data scientists, and to equip them with the skills they will need to perform effectively in their future professions. Whilst the skill set required by different scientific disciplines, technicians, engineers, EO-experts and students or researchers in different science disciplines may vary slightly, good computing skills are needed for all these groups.

Students on environmental science courses are not necessarily interested in how to use EO data. However, given the increasing importance of EO for environmental monitoring, it is important to demonstrate, at least on an introductory level, how EO can contribute. This will require good, relevant examples relevant to the different disciplines.

For those who decide that EO data is of interest, the ability to access, read, manipulate, analyse and display data using commonly available tools is essential. This can, however, be difficult to master for many students as it commonly includes software development environments such as Mat Lab and IDL, and now increasingly open source tools such as Python and R, or toolboxes such as those provided by ESA for use with Envisat and Sentinel data. Being able to take advantage of new, cloud-based data initiatives to bring together different data sources is also becoming increasingly important.

Interacting with non-expert users of information derived from EO-data and other sources is now almost a pre-requisite for science professionals. Training in how to do this effectively is important, not only for individual scientists, but also for the on-going effort to make EO more accessible to users in the wider community, and students learning 'science communication' can make a valuable contribution.

Being able to demonstrate the societal benefits of EO (and environmental science generally) is important for data providers, organisations funding scientific research, and many other organisations active in this field. Hence training that enables students to combine socio-economic and environmental information, for example through the use of GIS, will be important for many.

Closely allied to societal benefits of EO is the concept of Geo-ethics. Earth observation is a tool, and like all tools, it has the potential for being used to the detriment of the 'greater good'. Education of environmental data scientists is not complete without at lest some consideration of the different ways in which EO can contribute to sustainable environmental management or to the depletion of resources, depending on how it is used.

Lecturers and other trainers in universities and equivalent organisations require access to high-quality information, case studies and hands-on training material. Whilst internal quality control may go some way to ensuring that trainers have the necessary competencies to equip students with the necessary knowledge and skills, this task can be made easier through access to peer reviewed quality-controlled education resources. Such material may be used, not just in formal education, but also in continued professional development.

3.2.2 Continued professional development

Workshop discussions identified three broad groups that require on-going professional development training:

- Professionals with a teaching role need training courses or self-study training materials that will allow them to incorporate EO into their existing role.
- Researchers in a decision support role for risk management; upstream they interact with scientists and data providers; downstream they support risk management of some sort, for example through insurance, contingency planning, emergency response, etc.
- Professionals providing decision support for longer term planning and management in order to advise policy-makers in government, civil society and industry, or offer guidance to non-EO science that benefits from EO as one of many observational tools.

An effective EO education program needs to look at the needs of these users and decide how best to make necessary resources easily available. This means working backwards from the decision makers in different application areas. What are their needs? What information do they require, in what format? How do they use this information?

From such an analysis it becomes possible to determine what training is necessary to equip decision support scientists with the knowledge and skills they need in order to provide timely and reliable information to end users. For example, what level of understanding of different data products, sensors, processing systems, algorithms and analysis methods will data scientists need in order to have confidence in the information they provide? Knowing the strength and limitations of different sensors and data products under different conditions or in different geographical regions can be important here. There may be a need to consider the role of supporting data, for example from *in situ* monitoring systems or numerical modelling. Training may also be needed in how to deliver environmental information to different target audience in ways that are understandable, inspire confidence and include appropriate estimates of uncertainty.

In the met community the US based COMET programme provides effective professional training, and has been around for a long time, so that it is trusted. Something similar is needed for long-term professional training in other areas of environmental science.

4 Existing EO education resources and initiatives

The wide variety of Earth observation satellites, data sets and application areas is reflected in the diversity of existing EO education resources and training initiatives. We have organised these into four different categories: web-resources and e-learning, capacity building, software and tools, and EO outreach. The review integrates material presented at the Frascati EO Education Workshop with other information from ESA LearnEO! and from some of the presentations given at EO Open Science 2.0. It should not be seen as a comprehensive review of available resources.

4.1 Web-Resources and E-Learning

4.1.1 ESA

A dedicated website for **EO Education and Training activities** is published on ESA's EO portal.[5] This provides a comprehensive overview and easy access to all ESA programmes in EO education, training and capacity building. A section on primary and secondary level EO education includes descriptions and links to online tools, teacher training courses and material that can be ordered from the ESA education office. Another section includes summaries of EO training courses at university level with links to their respective webpages with access to presentations and ESA / Third Party Mission (TPM) data used for exercises. Similar material is available for advanced training at post-graduate level.

The **ESA Eduspace multi-lingual website**[6] is dedicated to secondary education. The aim of

[5] https://earth.esa.int/web/guest/eo-education-and-training

[6] http://www.esa.int/SPECIALS/Eduspace_EN

Eduspace is to provide attractive image data, information and tools suitable for teaching and learning a variety of topics in Geography, Physics, Environmental Science and related subjects, according to the curriculum of each country. The main value of Eduspace lies in the practical nature of its e-learning content. The website not only explains the theory and applications of EO in terms suitable for a secondary school audience, but also provides case studies that give practical examples of how EO data is used. Each case study presents student with a real world problem, which they need to address through hands-on processing of EO data using software designed for use in schools.

The **Eduspace Image Catalogue**[7] provides Eduspace users with a multi-mission catalogue of EO data over Europe. This provides teachers and students with carefully selected example data for use in Eduspace case studies and allows them to adapt (personalise) the case studies with EO data from their specific region of interest. The **Interactive Meteosat on-line application** - a new online tool that shows satellite data combined with student measurements - has been developed as an Eduspace module along with a case study on the interpretation of Meteosat images.

In the field of e-learning ESA has also developed "Earth from Space: The living beauty"[8] - the first **electronic book** showcasing EO applications, developed for Apple's iPad and available through iTunes. The 105 page book takes the reader on a scientific voyage that shows how some of the latest technology has changed the way we view the Earth. There are five chapters: Solid Earth, Oceans, Cryosphere, Atmosphere and Land, showing the latest and most impressive results of ESA's EO missions. Electronic books on individual missions are also being developed.

ESA LearnEO[9] provides hands-on lessons on different EO application areas, using data from ESA satellites. The lessons are designed for the Bilko software, and come complete with background information, step-by-step instructions, example data and model answers to questions posed in the lessons in order to stimulate student learning. Material from the lessons are available under a Creative Commons licence to anyone who wishes to build on LearnEO resources to create their training materials.

An **ESA MOOC**, **Monitoring Climate Change from Space**[10] provides basic information about the use EO data to monitor and study climate variability and change. The MOOC has been specifically designed to overcome perceived 'barriers' to the use of EO by non-technical users. It encourages wider use of EO data by providing practical, real-world examples of how of EO data are used to monitor and adapt to climate change, increase resilience to climate-related hazards, and provide decision support for sustainable development and resource management planning. The course explores and addresses some of the problems related to the take-up and usage of EO data, and demonstrates the benefits of using EO data in scenario planning.

4.1.2 NASA

The goal of the NASA Applied Remote SEnsing Training (**ARSET**)[11] is to increase the utility of NASA earth science and model data for policy makers, regulatory agencies, and other applied science professionals in the areas of Health and Air Quality, Water Resources, Eco Forecasting, and Disaster Management. The primary activities of this project are webinars and in-person courses.

NASA WorldWind[12], opens up possibilities for virtual globe applications. The use-cases include social media type activity as well as more sophisticated urban infrastructure management, climate research, disaster response and all types of navigation, from personal directions to industrial supply chain, to aeronautics and satellite tracking.

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[7] http://maps.eo.esa.int/Eduspace/index.jsp?nocombo=true

[8] www.esa.int/Highlights/ESA_s_first_iBook,

[9] www.learn-eo.org

[10] https://www.futurelearn.com/courses/climate-from-space

[11] http://arset.gsfc.nasa.gov/

[12] http://webworldwind.org and http://worldwind.arc.nasa.gov/java/

4.1.3 NOAA

NOAA's National Weather Service (NWS) and other organizations are sponsoring **MetEd**[13] **-** a free collection of learning resources for the geoscience community. The training consists of lessons and courses. A lesson is targeted toward one focused subject, whereas a course is a collection of lessons that pertain to a broader subject area. It is possible to receive certificates of completion for both lessons and courses. Courses are entirely self-paced and available for open enrolment. Links are also provided to selected resources not hosted on MetEd.

4.1.4 European Spatial Data Research (EuroSDR)

European Spatial Data Research (EuroSDR) holds distance e-learning courses on EO and geo-information topics. [14] These courses can be followed over the Internet from any location, allowing participants to update their knowledge with minimum disruption. Each courses requires about thirty hours of online study and is completed in two weeks.

4.1.5 Other resources

SAR-Edu[15] is an online learning portal that gives access to lessons, tutorials and talks; together these provide in-depth information about SAR data, processing, and data analysis for a range of applications. The material is at an advanced level, aimed at scientists and future EO professionals.

4.2 Capacity building initiatives

Developing human capacity to access, process and analyse EO data requires training at many different levels. Here we review some of the initiatives supported by international organizations, EU funded projects and other international collaborations.

4.2.1 On-going international programmes (in alphabetical order)

The **COMET**[16] Program was established in 1989 by UCAR and NOAA's NWS to promote a better understanding of mesoscale meteorology among weather forecasters and to maximize the benefits of new weather technologies. The COMET mission has expanded, and today COMET uses innovative methods to disseminate and enhance scientific knowledge in the environmental sciences, particularly meteorology, but also areas such as oceanography, hydrology, space weather and emergency management. COMET's innovative educational solutions include cutting-edge distance learning materials, on-site and virtual training events, and support for the effort of individuals to advance their skills and scientific knowledge. A free collection of learning resources for the geoscience community has been created within **MetEd**.[11]

The **European Association of Remote Sensing Laboratories (EARSEL**) organises workshops for secondary school teachers.[17] These typically last 1-2 days, often associated with conferences or exhibitions of interest, and are supported by ESA.

The **European Geosciences Union (EGU) Committee on Education** has organised **Geosciences Information for Teachers (GIFT) Workshops** since 2003. These 2.5-day teacher-training workshops are held in conjunction with EGU's annual General Assembly, and typically host about 80 teachers. Their main objective is to spread first-hand scientific information to science teachers in primary and secondary schools, thereby shortening the time between discovery and text-book significantly. Teachers are provided with material that can be used directly in the classroom, and lectures from the GIFT workshops are freely available as videos on YouTube™ or

[13] https://www.meted.ucar.edu/index.php

[14] http://www.eurosdr.net/education/current

[15] https://saredu.dlr.de

[16] http://www.comet.ucar.edu/

[17] http://www.earsel.org/?target=educ

EGU TV[18]

ESA: Every summer ESA's Education Office welcomes around 40 secondary school teachers from across Europe to ESA's European Space Research and Technology Centre (ESTEC) in the Netherlands for the **ESA Summer Workshop for teachers[19]**. Over four days teachers participate in a variety of activities that show how space can be used as a context for teaching different school subjects. Entitled **Watching over the Earth**, the ESA Teacher's Pack includes a selection of Remote Sensing/EO topics and is targeted to lower secondary level students (age 11-14). The pack is available in several languages (English, French, German, Spanish, Italian and Dutch) in hard copy, and may also be downloaded from a dedicated ESA website.[20]

ESA summer schools on Monitoring and Modelling of the Earth System[21] promotes the exploitation of EO data across disciplines, with a specific focus on EO data assimilation into Earth System models. The summer schools take place every other year at ESA/ESRIN in Italy, and are attended by an average of about 65 PhD students and early-career researchers.

ESA's advanced thematic training courses in land, ocean and atmospheric remote sensing for the next generation of Principal Investigators (PIs)[22] are typically attended by PhD students and early post-doctoral scientists, who work on the scientific exploitation of ESA and Third Party Mission EO data. These courses are held annually and are hosted in European Universities and Research institutions, with the host country rotating among the ESA Member States.

The **ESA TIGER** initiative[23] was launched in 2002 to promote the use of EO data for improved Integrated **Water Resources Management** (IWRM) in **Africa**. Besides facilitating EO data access and supporting crosscutting activities of coordination and outreach, TIGER also focuses on training and capacity building courses (3-5 days events), designed to support the efforts of its African partners (water authorities, technical centres, universities) to develop independent capacity to exploit EO technology in the management of water resources and adaptation to climate change.

The **EUMETCAL**[24] programme started in 2001 and will develop European training cooperation in the field of meteorology until 2017. Today it is the European Virtual Organisation for Meteorological Training. Its objectives are to: (i) serve as the European virtual training organisation, providing a forum for creation and exchange of training resources in meteorology and related topics; (ii) provide a mechanism whereby European National Meteorological Services can collaborate to enhance their training capabilities on a long-term basis; and (iii) meet the training requirements of European NMSs in the long term. Key achievements are its extensive virtual training library, its training workshops, interactive learning modules and coordination of blended and on-line courses in meteorology. EUMETCAL activities link trainers and professionals from participating and partner countries, promote the exchange of best practice, and encourage sharing of training material.

GEO for All[25] aims to make geospatial education and opportunities accessible to all. By combining the potential of free and open GI software, open data, open standards, open access to research publications, open education resources in Geospatial education and research will enable creation of sustainable innovation ecosystem to advance the discipline. Over 100 labs around the world are part of the initiative.

The **Global Earth Observation System of Systems (GEOSS)** [26] provides decision-support tools to a wide variety of users. This 'system of systems' will proactively link together existing and planned observing systems around the world and support the development of new systems where

[18] www.egu.eu/outreach/egu-tv

[19] www.esa.int/Education/Teachers_Corner/Annual_ESA_Summer_Teacher_Workshop

[20] www.esa.int/Education/Teacher_s_pack

[21] https://earth.esa.int/web/eo-summer-school/home

[22] https://earth.esa.int/web/guest/eo-education-and-trainingweb/eoedu/pis-advanced-training

[23] www.tiger.esa.int

[24] http://www.eumetcal.org/

[25] http://www.geoforall.org

[26] http://www.earthobservations.org/geoss.php

gaps currently exist. It promotes common technical standards so that data from the myriad different instruments can be combined into coherent data products. The **GEOSS Portal**[27] offers a single access point for users seeking data, imagery and analytical software packages relevant to all areas of the globe. The portal connects users to existing databases and data portals and provides reliable, up-to-date and user-friendly information – vital for the work of decision makers, planners and emergency managers. For users with limited access to the Internet, data sets are made available via **GEONETCast**[28] using the network of telecommunication satellites.

The oceanographic component of GEOSS is the **Global Ocean Observing System GOOS**[29] - organised as a system of regional alliances, each of which is working towards establishing an operational ocean observation capability that covers all oceans and marginal seas. Capacity development, including training in coastal and marine applications of EO data is an important aim for developing nation coastal states, and is a key aim of **GOOS-Africa**[30] - the regional alliance for African coastal states.

Monitoring for Environment and Security in Africa (MESA) has an extensive training programme to build regional capacity to take advantage of EO data to monitor the environment and provide effective support for decision makers tasked with managing natural resources, deliver sustainable development goals, increase resilience to climate change and extreme events, and respond to natural hazards. The programme runs a series of regional training courses, and works closely with African Centres of Excellence and universities, who obtain EO data in real-time via GEONetCast.

SERVIR[31] Regional Visualization and Monitoring System is a collaboration between NASA and USAID, dedicated to helping government officials, managers, scientists, researchers, students, and the general public in developing countries to make informed decisions by providing Earth observations and predictive models based on data from orbiting satellites. The goal of SERVIR is to build geospatial capability in Mesoamerica, Africa, and the Himalayan region. Data and applications are organized along the eight societal benefit areas identified by the Group on Earth Observations (GEO): disasters, ecosystems, biodiversity, weather, water, climate, health, and agriculture. Decision-makers use SERVIR to monitor air quality, extreme weather, biodiversity, and changes in land cover. The system has been used over 35 times to respond to threats such as wildfires, floods, landslides, and harmful algal blooms. In addition, SERVIR analyzes, provides information about climate change and offers adaptation strategies for affected nations.

UNESCO and its network of **Space for Heritage**[32] partners use results of various space projects to develop educational packages and to organize exhibitions for the general public. These bring space science and technology closer to society.

The **UNESCO Bilko** project[33] provides software, example data and tutorials for teaching marine and coastal applications of remote sensing to users in over 170 countries around the world. Most are in university education, with a growing number in environmental monitoring and research.

The **UN-Spider Knowledge Portal**[34] hosted by the UN Office for Outer Space Affairs (UNOOSA) provides information about the use of space technology in disaster and risk management, how to access relevant satellite data and products, how the data may be used, and who are the main users. UN-Spider Regional Support offices provides emergency support to member states. The website provides information about symposia, workshops and training events[35] relevant to preventing, mitigating and reacting effectively to natural hazards and humanitarian crises.

[27] http://www.geoportal.org/web/guest/geo_home_stp

[28] http://www.eumetsat.int/website/home/Data/DataDelivery/EUMETCast/GEONETCast/index.html?lang=EN

[29] http://www.ioc.goos.org

[30] http://www.ioc-unesco.org/index.php?option=com_content&view=article&id=205:goos-africa&catid=14&Itemid=100063

[31] http://www.nasa.gov/mission_pages/servir/#.VN3BAPmG-CM

[32] www.unesco.org/new/en/natural-sciences/science-technology/space-activities/space-for-heritage/education-and-outreach

[33] http://www.bilko.org

[34] http://www.un-spider.org

[35] http://www.un-spider.org/news-and-events/events/past-events?lf=1090&lng=en

The Virtual Laboratory for Training and Education in Satellite Meteorology (VLab)[36] was established by the World Meteorological Organization (WMO) and the Coordination Group for Meteorological Satellites (CGMS). VLab is a global network of specialized training centres and meteorological satellite operators working together to improve the utilisation of data and products from meteorological and environmental satellites. Its 13 Centres of Excellence (CoE) around the world work closely with satellite operators and often co-located with WMO Regional Training Centres. The CoEs are set up to meet user needs for increased skills and knowledge in using satellite data within their region.

Working Group on CAPacity building and data Democracy (WGCapD) [37] has been set up to unify efforts by the Committee on Earth Observation Satellites (CEOS) to develop the capacity of individuals and institutions to use EO data. It is based on the four pillars of the Data Democracy Mission (data access, data dissemination, sharing of software tools, training & education). WGCapD aims to (i) provide wider and easier access to Earth Observation data, (ii) increasing the sharing of software tools through the use of open source software and open systems interface, (iii) increase data dissemination capabilities, transferring relevant technologies to end users, and (iv) providing intensive capacity building, education, and training (including awareness and outreach) in order to enable end users to gather the information they need and communicate EO-based information effectively. WGCapD works closely with the CEOS and GEO communities and leaders. Current WGCapD projects include: an e-learning introductory course on remote sensing technology for educators from Africa (English speaking countries); an inventory of EO capacity-building efforts; the Digital Elevation Model (DEM) project, which makes high resolution DEM data available to developing countries; practical EO education for students and teachers and the CEOS Disaster Risk Management (DRM) Activity - Floods area Pilot project.

4.2.2 EU funded projects (in alphabetical order)

The **BALKANGEONET**[38] project aims to identify the existing EO-data providers and users in the wider Balkan region, to determine their status, potentials and needs, and to coordinate the EO players by establishing a proper interface and networking between them. Main outcomes of the BalkanGEONet project will be the creation of the permanent web-based networking facility (PNF), and the design of the roadmaps and recommendations for an active, coordinated and sustained participation of all Balkan countries in global EO initiatives. **OBSERVE**[39], another EU-projects focussing on the Balkan countries have similar aims.

The **DevCoCast** project broadcast environmental data from data providers in Europe, Africa and Latin America via GEONetCast to users in Africa, Latin America and Asia. The project provided GEONetCast receiving stations and training in data acquisition, management and analysis through training courses aimed at environmental scientists in Latin America and Africa, and developed the GEONetCast Toolbox[40] for the ILWIS open source GIS software to facilitate training and data use. As part of a final training course, DevCoCast partners and data users developed an application manual containing 17 case studies with detailed descriptions of how to use the broadcast EO data products in different contexts. [41]

EAMNet[42] (Europe-Africa Marine Earth Observation Network) built on the marine component of DevCoCast to build a network of European and African EO experts and data users who share training resources, and collaborate on scientific research using EO data. The project distributed ocean colour and sea surface temperature data at 1km resolution from providers in the UK and South Africa via GEONetCast for African waters to users in different African countries. Training activities included short courses, the development of an MSc module in ocean remote sensing for

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36 http://www.wmo-sat.info/vlab/

37 http://ceos.org/ourwork/workinggroups/wgcapd/

38 http://www.balkangeo.net/

39 http://www.observe-fp7.eu/

40 http://www.itc.nl/Pub/WRS/WRS-GEONETCast/GEONETCast-toolbox.html

41 ftp://ftp.itc.nl/pub/52n/gnc_devcocast_applications/description/devcocast_application_manual.pdf

42 https://www.eamnet.eu/cms/

use in African universities and fellowships to support staff and students from African institutions to spend time in European and African centres of excellence in marine EO. The partners continue to interact, and lectures and computer exercises from EAMNet are available on-line[43].

The **EnviroGRIDS**[44] project has contributed to the Global Earth Observation System of Systems (GEOSS) by promoting the use of web-based services to share and process large amounts of key environmental information in the Black Sea catchment (24 countries, 160 million inhabitants). The main aim of the project was to assess water resource in the past, present and future, according to different development scenarios. Developed datasets t are compatible with the European INSPIRE Directive on spatial data sharing across Europe. The data and metadata gathered and produced on the Black Sea catchment are distributed through the enviroGRIDS portal.

The purpose **EOPOWER**[45] is to create conditions for sustainable economic development through the increased use of EO products and services for environmental applications. This serves the higher goal of effective use of Earth observation for decision-making and management of economic and sustainable development processes. The EOPOWER project builds on the results of the GEONetCab (Section 4.2.2.5 below), BalkanGEONet, OBSERVE, enviroGRIDS, SEOCA[46] and EGIDA[47] projects. Global and regional marketing studies, success stories, marketing tool-kits and feedback from promotion activities and quick-win projects produced in GEONetCab (below) allows EOPOWER and its partners to benefit fully from the other projects.

The **GEO Network for Capacity Building (GEONetCab)**[48] project was designed to support GEO capacity building activities, especially its framework for climate monitoring - with special emphasis on developing countries, new EU member states (and EU neighbouring states). The GEONETCAB data catalogue[49] allow users to search for resources, including case studies demonstrating the application of EO to the eight GEO societal benefit areas. The portal delivers information about useful products as well as links to resources that allow users to exploit the different products.

The **IASON**[50] project aims to establish a permanent and sustainable network of scientific and non-scientific institutions, stakeholders and private sector enterprises from EU and third countries in the Mediterranean and the Black Sea regions. The main focal points are the application of EO data to monitoring climate change, deliver resource efficiency, and support raw materials management. A web-based platform provides information about clustering projects that demonstrate synergy potential and networking tools to enhance communication between members of the network.

MYGEOSS[51] is a project by the European Commission to develop GEOSS-based (Global Earth Observation System of Systems) smart Internet applications informing citizens about changes to their local environment. Some applications are developed in-house by the Joint Research Centre (JRC) of the European Commission, others through open calls for innovative ideas.

The Science Education through Earth Observation for High Schools (SEOS) web site[52] provides teaching modules that use remote sensing to teach the science education curricula in high schools throughout Europe and the Middle East. Its 15 internet-based eLearning tutorials were developed on selected topics and tested in co-operation with European partner schools. These are available from the project web site in different languages.

[43] https://www.eamnet.eu/cms/?q=node/113
[44] http://www.envirogrids.net/
[45] http://www.eopower.eu
[46] http://www.geo-seoca.net/
[47] http://www.egida-project.eu/
[48] http://www.geonetcab.eu/
[49] http://geonetcab.mdweb-project.org/search/main.jsf
[50] http://www.iason-fp7.eu/index.php/en/
[51] http://digitalearthlab.jrc.ec.europa.eu/mygeoss/
[52] http://www.seos-project.eu/home.html

4.2.3 Other international cooperation

Post-graduate training is a key component of the **ESA-MOST Dragon Cooperation Programme**[53] Training seminars and advanced courses are organised routinely for Ph.D. students, post-doctoral and research scientists from China and other Asian countries. Courses provide training in processing, algorithm and product development from EO data.

To support the countries of Eastern Europe and the Baltic to build EO capacity ESA and NASA have agreed to co-sponsor the realization of a series of **TAT (Trans-Atlantic Training)** events from 2012 onwards. These events include annual 7-8 day workshops and training courses for post-graduate university students and professionals that use of geo-information in their work.

EO education and capacity building has been active in South America for many years thanks to collaboration between **ESA** and the **UN,** the French Space Agency, **CNES,** and South American organisations, such as the Society of Latin American Specialists in Remote Sensing (**SELPER**), the Argentinian Space Agency (**CONAE**), the Brazilian National Institute for Space Research (**INPE**) and the Peruvian Space Agency (**CONIDA**).

The TOPEX/Poseidon educational website[54] provides education resources for schools related to applications of radar altimetry. It is a joint venture between the NASA Jet Propulsion Laboratory (JPL) and CNES. For Data, articles, news and tools to discover or improve skills in the altimetry domain through four key themes: ocean, coast, hydrology and ice can be also found in the **AVISO** website.[55] A radar altimetry tutorial[56] developed in collaboration with ESA provides information and short tutorials in the use of altimetry data for university students and environmental scientists.

The **Earth Observation Capacity Building Portal, GEOCAB**[57] is a joint GEO - CEOS - EU initiative that provides a searchable inventory of programs, services, training materials, best practices and links to stakeholders. It is designed to facilitate cooperation and coordination among existing capacity building resources and facilities, and allows register users to upload metadata on a wide variety of capacity development resources, including case studies (quick-win projects and success stories), tutorials, user guidelines, scientific publications, data catalogues, data products software tools, marketing tool-kits, workshops, training courses and organizations offering EO products and services. A search allows users to find resources related to a particular topic (keyword search) and limit this to a geographical region if desired. During the workshop GEOCAB was suggested as potential example of how a future 'gateway tool' for EO education (Section 6.2) might be organized.

4.3 Software and tools for data analysis

Two software packages are indicated by ESA for general education purposes: LEOWorks and Bilko. **LEOWorks**[58] is a didactical tool with extensive help pages and an all-inclusive tutorial, allowing secondary school students to process satellite imagery and combine them with other geospatial information. The new version is developed in Java, is platform independent (Windows, MacOS, Linux) and will be released under a General Public License (GPL). It will include advanced GIS functionality and optical and SAR image processing in a user-friendly environment.

The **Bilko** software[59] was first developed for UNESCO in 1987 to provide free image processing capability for education and capacity building in developing countries. The software was soon adopted by universities around the world for hands-on training, and in recent years the software has increasingly been used for research and monitoring, particularly scientists in developing countries who need to use EO data occasionally, but are not themselves EO specialists. Since its

[53] https://dragon3.esa.int/web/dragon-3/home
[54] http://www.tsgc.utexas.edu/topex/
[55] http://www.aviso.altimetry.fr
[56] http://www.altimetry.info
[57] http://www.geocab.org/
[58] http://leoworks.asrc.ro
[59] http://bilko.org/software.php

start in 1987, Bilkohas since been updated regularly, to keep pace with developments in remote sensing technology. LearnEO! has extended Bilko's capabilities to include support for data from ESA satellites such as ERS, SMOS and CryoSat, as well as along-track altimeter data from Envisat and Jason-2.

ESA toolboxes[60] are designed for professional users of EO data, but are also extensively used in the training of more advanced students, for example through computer exercises for university courses as well as shorter summer schools and professional development courses. The ESA toolboxes (mostly open source) are freely available from the web and include the Basic ERS & Envisat (A)ATSR and MERIS Toolbox (**BEAM**), the Next ESA SAR Toolbox (**NEST**), a toolbox for the scientific exploitation of polarimetric SAR data (**POLSARPRO)**, the Basic Radar Altimetry Toolbox (**BRAT**), the GOCE User Toolbox (**GUT**) and many more.

SNAP[61] (ESA SeNtinel Application Platform) build on these earlier tool boxes, using a common architecture to facilitate analysis of data from different sensor types without the need for the user to learn how to use yet another software package. SNAP is fully open source, GPL-3 licensed. ESA's **STEP**[62] initiative is designed to make it easier for users to find appropriate toolboxes, and to identify tutorials, documentation and other resources that explains how to use the tools in data analysis.

CIS[63] (Community Intercomparison Suite**)** is an open source command-line tool for easy collocation, visualization, analysis, and comparison of diverse gridded and ungridded datasets used in the atmospheric sciences.CIS is intended to facilitate a number of oft repeated operations on scientific data, such as subsetting and aggregating datasets or collocating with other data, helping users to provide replicable, repeatable analysis which scientists and policy-makers can understand and trust.

4.4 Outreach activities

4.4.1 DLR

The DLR_School_Lab Oberpfaffenhofen[64] is an extracurricular science lab, designed to attract secondary school students to Mathematics, Informatics, Natural Sciences, and Technology (MINT). It has been developed and operated since 2003 and offers thirteen hands-on experiments for secondary school classes, as well as advanced teacher trainings in physics and geography.

4.4.2 ESA

School Labs: A collaboration between ESA and the German Aerospace Centre, DLR (Deutsches Zentrum für Luft- und Raumfahrt) was set up in 2012 to produce 3D videos that will be used in the virtual theatre facilities at ESA.

Building on this and the DLR School Lab for schools a School Lab was organised at part of IEEE International Geoscience and Remote Sensing Symposium 2012 in Munich. A similar school School Lab took place at the ESA Living Planet Symposium in 2013, in collaboration between ESA, DLR, the UK Space Agency (UKSA), the National Centre for Earth Observation (NCEO) and the National Space Centre in Leicester, UK.These events allowed secondary school students and their teachers to learn about the science and technology behind EO and gain hands-on experience with remote sensing, using spectrometers and thermal cameras, observing radar experiments, following practical exercises to manipulate and analyse EO data, and watch impressive 3D visualizations. Similar resources and activities for similar outreach events may be included in future EO symposia and conferences.

[60] https://earth.esa.int/web/guest/pi-community/toolboxes

[61] http://step.esa.int/main/toolboxes/snap/

[62] http://step.esa.int/main/

[63] http://www.cistools.net

[64] http://www.dlr.de/schoollab/en/desktopdefault.aspx/tabid-1708/

New **videos for schools and the general public** have been created in ESA/ESRIN. This includes an educational video on EO and Volcanoes for schools, produced jointly with the Italian National Institute of Geophysics and Volcanology, INGV (Istituto Nazionale di Geofisica e Vulcanologia).

4.4.3 University of Heidelberg

The University of Heidelberg has developed a web-based learning environment for high schools[65] called Satellite Image Learning Center (SILC). Ten game-based learning modules allow students to test their existing knowledge of satellite images and pick up new information. The games are organised into easy and difficult.

4.5 Apps and interactive books

The increasing sophistication of tablets and mobile phones is creating new opportunities for developing resources that can bring EO data and information to a wider audience.

A number of **ESA apps** for iphones and iPads are available on iTunes, under education. This includes apps to track satellite orbits, learn more about specific satellite mission, and two **EO handbooks** on the use of EO data in disaster monitoring and to meet climate information challenge (the latter produced for COP21).

ESA has also published three **interactive books** for iPads. **Earth from Space: the Living beauty** shows how EO data is used to learn about the solid Earth (volcanoes, earthquakes, plate tectonics), the oceans (waves, currents, marine life), the atmosphere (weather, aerosols, ozone), the cryosphere (ice sheets, sea ice, glaciers) and land (vegetation, urban development, water resources). **Earth's gravity from space**[66] tells the story of the GOCE mission and the scientific discoveries it supported in the fields of geodesy, oceanography, geology and geophysics. A third book deals with the **CryoSat mission**[66] and its role in climate science.

4.6 Citizen Science

Cities at Night[67] aims to create a map of the world using night photographs taken by astronauts on the ISS. Citizens help classify and georeference the photographs, which have true colour and higher resolution than satellite-based nighttime light products. Applications range from helping municipalities to save energy, research on breast cancer, reducing air pollution, mitigating light pollution and increasing road safety.

Crowd4Sat[68] are a consortium of European research institutes and companies currently funded by ESA to explore new ways of using citizen science in space data validation and space data exploitation as well as demonstrating the value of citizen science to scientific research and its capacity to enhance education. Four use cases have been chosen: (i) snow coverage monitoring in the Spanish Pyrenees; (ii) traffic and pollution mapping and management; (iii) flood emergency mapping; and (iv) land use mapping for validation of CORINE land cover[69].

Educ-EO[70] is an ESA programme currently funding four citizen science projects to test and explore the potential and limits of CS in EO These pilots look at agriculture support, forest monitoring, land-use classification and air quality. The overall aim is to foster the use of new and emerging information and communication technologies (ICT) such as location-enabled mobile devices, Web 2.0 and the 'Internet of Things', in combination with CS. The hope is that this will enhance the scientific exploitation of EO data while simultaneously supporting education and raising public awareness of the benefits of EO.

[65] http://www01.ph-heidelberg.de/wp/kollar/

[66] Also available in PDF format from LearnEO! http://www.learn-eo.org/books/

[67] http://www.citiesatnight.org

[68] http://www.crowd4sat.eu

[69] http://land.copernicus.eu/pan-european/corine-land-cover

[70] http://educeo.net/

The **Geo-wiki Project**[71] is a global network of volunteers who wish to help improve the quality of global land cover maps by adding information on species distribution, habitat, ecosystems and other scientific land use information. Volunteers are asked to review land-cover maps of areas where the classification is unclear or poorly verified, and use their own observation and local knowledge determine whether the classification based on satellite data is correct. Their input will be used in a new and improved global land cover map in the future.

Humanitarian OpenStreetMap[72] [HOT] applies the principles of open source and open data sharing for humanitarian response and economic development. Pre-disaster satellite and aerial imagery helps volunteers trace homes, buildings and the road network into OpenStreetMap. During an emergency this enables first responders to carry out search, rescue, and relief activities. Post-disaster imagery facilitates identification of damage to roads and buildings and can serve as a first step in identifying camps and temporary shelters for internally-displaced persons. An example of how citizens working remotely were trained by local staff to provide maps after the Nepal earthquake showed the effectiveness of citizen involvement.

iSPEX[73] involves citizens in the monitoring of aerosol by measuring optical thickness (AOT) using a low cost add-on to an iPhone. Successful campaigns have involved thousands of people in taking measurements across the Netherlands, producing high resolution maps which compare well with AOT from MODIS, but provide more detail. The project informs citizens about optical measurements of air pollution, its negative effect on human health, Topics include the effect of volcanic ash on jet engines and the effect of aerosols on climate change.

The **WeSenseIt**[74] citizens observatory is concerned with better management of water resources, and with building resilience to droughts and floods. The participatory sensing involves submitting flood reports and photographs and interacting with local authorities via a mobile app. The photographs are used to calculate river levels and flows using computer vision.

Zooniverse[75] provides opportunities for people around the world to contribute to real discoveries in fields ranging from astronomy to zoology. It is the largest online platform for collaborative volunteer research. In collaboration with Humanitarian OpenStreetMap, Zooniverse volunteers have helped to create maps of population density, which showed areas of potential vulnerability that had not yet been mapped by HOT in detail. This information provided responders with locations of where water supplies should be sent.

5 Overcoming existing barriers to effective EO education

Discussions at the Frascati workshop identified a number of barriers to effective EO education at different levels. Chief among these were

(i) the difficulties in identifying and accessing data suitable for education at different levels,

(ii) the relative lack of clear and intuitive example data and case studies, suitable for learning about different applications or relevant to specific geographical regions, and

(iii) the fragmentation of European education resources, which leaves newcomers to the arena of EO education overwhelmed by the task of finding resources that suit their own needs.

5.1 Lack of access to data and information suitable for non-experts

Although a number of outreach projects have been working to offer engaging and interesting examples from different EO application areas, these may often be hard to find for anyone who was not included in the target audience for the original initiatives. New users find it difficult to assess if

[71] http://www.geo-wiki.org/

[72] https://hotosm.org

[73] http://ispex.nl/en/ and http://ispex-eu.org/nl/

[74] http://wesenseit.eu

[75] https://www.zooniverse.org

a resource is useful for them, sometimes because limited information is available before encountering barriers to access such as a requirement to register, or the need to download and use specific tools. In some cases this can cause users to give up the search before they find what they need – even when a suitable resource is freely available on line.

5.1.1 Scientific users with limited EO expertise

The GEOSS, EC and ESA policies on access to data for research and education makes it possible for environmental scientists to access archive data of their choice at little or no cost. New on-line tools are now making it easier to identify and obtain the data sets they require. A growing number of free toolboxes and handbooks are available to help users to analyse and understand the data. Despite this, the effort involved in finding and accessing the different data products is still a barrier to their use by the wider scientific community.

Different data products have different access mechanisms, available on a wide array of portals that require users to register and remember different passwords. Although data are increasingly delivered in standard formats, this is not always the case.

Considerable effort has been spent on creating free or open-source toolboxes and other software for accessing and analysing data from different sensors (or suites of sensors), but mastering these is another daunting task. Many toolboxes are limited to the data sets they support, and each data type often comes with its own specific suite of tools, its own internal data formats, and limited import/export facilities. As a result an occasional user that requires access to data from multiple sources may either have to learn several toolboxes, or face the cost of investing in commercial software. Moreover, there is often a shortage of training resources that demonstrate how to use of specific data and tools in different contexts.

Efforts are being made to address these issues, by combining existing tools under a common graphical user interface, and by encouraging common data formats, which will make it easier to provide tools that can access products from a wider range of data providers. However, we still have some way to go.

5.1.2 Schools and non-technical users in the wider community

The problem is even more pronounced for non-scientific audiences with an interest in EO education, who do not usually have access to archives designed for professional audiences, and even if they did, would lack the necessary technical skills and the motivation to invest a large amount of effort to identify and select relevant examples.

ESA and others have a number of initiatives to remedy this, with libraries that provide inspiring and often spectacular examples of EO images. However, newcomers to the field are not necessarily aware of these opportunities and miss out as a result.

5.2 Lack of relevant examples and case studies

For policy and other decision-makers case studies that demonstrate in clear, unequivocal terms how Earth observation can contribute information in different contexts are likely to more important than access to libraries of spectacular imagery. A number of initiatives have been set up to provide such studies, and many offer interesting examples. However, there are still a number of application areas that are not well covered. Even where good case studies exist, they may not be easy to find for users who are not already involved. This problem leads on to a major issue, which was raised several times in different contexts during the education workshop – the fragmentation of European EO education resources and initiatives.

5.3 Fragmentation of European EO education resources and initiatives

People coming to the EO field for the first time face an impressive and wide array of information, websites and education related tools. ESA alone has multiple websites, and there are several websites or portals developed with EC or national funding. This diversity makes it possible to cater for a wide variety of audiences, but from a different perspective it may be seen as a barrier to effective education and training. The mass of supportive offerings can hit newcomers as a 'tsunami' of information, creating further disorientation and resistance to entering into this arena; particularly for users whose time is limited and precious. The basic question for many is not so much "what is available to suit me?" but rather "where do I even start?"

More sustained efforts are provided, for example by the ESA portal for education and training,[76] which provides access to resources for schools in EduSpace as well as information about training resources provided for professional users. As noted in Section 4, there are also a number of overarching portals supported by other organisations, which offer access to smaller EO education initiatives – but many of the resources they list may be short-lived, out of date or 'frozen in time'.

5.3.1 Causes of the fragmentation

The fragmentation of EO education resources is almost inevitable. It springs partly from the wide range of application areas and user needs, and partly from the diversity of funding sources for EO capacity development and education. Many initiatives were set up as pilot studies, with no clear idea of how the resources that were being developed would be supported once the initial funding were no longer available. Sometimes such initiatives 'limp on' for several years, supported by the goodwill of the individuals and organisations that originally created them, but with limited capacity for user support and updates without sustained funding to support continued work.

Funders, data-providers and educators are aware of the problem, and some have tried to address it by setting up on-line portals to provide overviews of on-line resources such as data sets, case studies, analysis tools, on-line tutorials, apps, and and other education resources. Such portals are often developed with a particular user community in mind and address specific user needs, but when seen from the perspective of a newcomer they may actually increase the feeling of being overwhelmed.

The challenges of providing access to EO data for so many different audiences often means that when a narrow problem is fixed, the solution adds to the bigger problem of too much choice, too many apps, too many websites.

5.3.2 Overcoming the fragmentation to provide easy access

Finding a good way to overcome the fragmentation without the loss of many high-quality resources developed over the last decade is a considerable challenge.

An important consideration here is to ensure that any solution is long-term and sustained. Educators, particularly school teachers, will want to know that once they have found a good resource and learnt how to use it, it will remain available and up-to-date for years. This means long-term funding support, at a level sufficient to offer at least a minimum of user support, and sufficiently sustained to adapt and develop as new data products emerge and new user needs arise.

Knowledge of good, online resources often spreads gradually through the education community through personal recommendation, as well as through more targeted marketing. If support is too short-term a new resource will barely have time to be recognised before it is no longer in a position to continue to serve its user community.

The workshop discussed how one could implement a user-friendly solution to the fragmentation problem, and some suggestions are put forward briefly in Section 6. However, as always with a problem as complex as this the "devil" will be in the detailed implementation of the suggested solution. Care must be taken not to sacrifice the need for in-depth and specialist information in order to meet demands for easy access. The need for on-going training of professional users must be balanced against the desire to attract new users reluctant to waste time on resources that turn out to be unsuitable for them.

[76] https://earth.esa.int/web/guest/eo-education-and-training

5.4 Poor Internet connectivity

Lack of bandwidth to access online resources is a serious barrier to EO education at all levels. As data sets increase in size, and more and more web sites are designed for broadband connections, the digital divide between many developing countries and the rest of the world is widening. Often a combination of low bandwidth and the pressure of many users means that it is only realistic to access on-line data portals between midnight and the early hours of the morning in order to find and download data, or post data processing requests.

Initiatives such as GEONetCast[77] address this through the use of Digital Video Broadcast (DVB) technology. Regional Centres of Excellence take on the responsibilities for establishing a satellite-based regional dissemination system and provide complementary services to a common user community. Users in universities, research institutes and operational agencies can select and order data, which is broadcast via satellite and downloaded using commercial TV satellite dishes connected to a local computer. Services include training in the use of EO data, through regional training courses and via an on-line training channel.

Although efforts are on-going to improve the connectivity of developing countries, it is important to maintain EO education initiatives that also suit those who do not have reliable access to online resources. For example, Humanitarian OpenStreetMap (HOT) depends on effective involvement of citizens around the world in the analysis of satellite imagery. In remote areas this training cannot easily be give on line, so the project also runs satellite image camps where people are trained to work with EO data.

To meet the demands of EO-based information for all, the EO community needs to respond with processing tools and training materials that are suitable also in regions where Internet access is limited. This requires stronger collaboration between volunteers, humanitarian initiatives such as HOT and the research community.

6 Recommendations

Recommendations from the two Frascati workshops address four areas where action is needed in order to deliver more effective training for providers and users EO-based data and services:

(i) the need to harness a wide range of technical, scientific, environmental, educational and communications expertise in order to develop resources that inspire, inform and facilitate the development of key skills;

(ii) the need to make it easier for users at all levels to identify and access resources tailored to their interests and level of expertise;

(iii) the need to inspire new users and future environmental data scientists by employing existing and new approaches to computing and communication; and

(iv) the need for education resources and training initiatives to keep up with new application areas, EO and computing technologies, using examples that are relevant to people from a wide range of backgrounds and geographical areas.

6.1 Maintaining and extending the core EO education community

Participants in the original ESA LearnEO! Workshop on Earth Observation Education were mostly environmental scientists involved in formal education and professional capacity development. Participant agreed on the importance of keeping this community together, and expanding it to build an EO education network that also includes participants from initiatives not represented at the workshop.

It was seen as particularly important to include professional educators, environmental scientists

[77] http://www.eumetsat.int/website/home/Data/DataDelivery/EUMETCast/GEONETCast/index.html

from a broader range of application areas, technical experts, providers of data and processing tools, and communications professionals.

Maintaining and expanding this EO education community would ideally involve a list of actions:

- Setting up a forum on a social networking site allowing community members to discuss priorities and more detailed actions needed to implement the roadmap.
- Engaging others who were not present at the original workshop and inviting them to join the community, paying particular attention to engaging professional educators to ensure that training builds on the latest research into education and learning.
- Setting up a COST action[78] for EO education, to secure funding for community members to continue meeting to explore collaborations and develop this roadmap in more detail.

6.2 Working towards a one-stop 'market place' for European EO education

The COMET approach to online professional development, which includes apps, animations, lesson plans, software code etc., could provide an example for how to develop EO education in a European context. COMET was established to promote a better understanding of mesoscale meteorology among weather forecasters, but has since expanded to disseminate scientific knowledge in other environmental sciences, such as oceanography, hydrology, space weather and emergency management. Currently the program offers training not only to the US, but also to Europe and meteorological agencies around the world.

In order to design and implement a similar system, it will be important to understand the full range of available online professional development and knowledge brokering tools and to gather expert input on how best to use these. An important consideration here is to what extent a one-stop source of European EO education materials should be similar to COMET, with a central organisation having control of course designs and selection of material, or whether a more distribute approach might be more appropriate and feasible given the current diversity of European initiatives.

European initiatives already target different user communities. Many have user networks that are well established and supply these with technical information, example data, case studies, software tools and tutorials that have been developed with a particular audience in mind. Discarding these resources in favour of a single, large initiative simply in order to facilitate easy access is not an option. Even if it were possible, there would be considerable duplication of existing efforts, and a single initiative would be unlikely to deliver the breadth of material that currently exists.

A more appropriate solution would be to

(i) develop inventory of what is already available, matching available resources to broad user groups based on level of expertise and user information needs,

(ii) design and develop a 'gateway tool' capable of bringing existing EO education resources together and allowing users to select these based on individual needs,

(iii) provide local and on-line peer support, and

(iv) engage the wider EO education community to help set priorities for future development and contribute to meeting these through collaborative effort.

6.2.1 Review of existing resources and their relevance to broad user groups

Building on existing EO education initiatives will require a more extensive review of European education resources and training initiatives than has been possible in Section 4 of this document. The review should provide more detailed descriptions of each initiative and an inventory of the resources they currently provide, with emphasis on matching these to the education and information needs of broad user groups. Such matching could be based on application area, specific information needs, levels of technical expertise, and existing capacity of different user

[78] COST (http://www.cost.eu) is a funding mechanism for establishing and supporting networks of European researchers, engineers and scholars to jointly develop their own ideas and new initiatives across all fields of science and technology.

groups to access on-line portals to select and download EO data and on-line resources.[79] It could also include an assessment of how best to make example data, software tools and supporting information available so that users can use cloud computing and to carry out exercises that access large data sets, without the need for downloading and storing these locally.

Given the considerable overlap between education, citizen science, and toolbox development evident, for example, at EO Open Science 2.0, the review should be based on a broad definition of what constitutes education and training. Ideally it should cover not only existing education projects and programmes, but also training elements associated with the provision of software tools for data analysis, the education aspects of citizen science initiatives, and case studies and use cases designed to demonstrate the utility of different data products in different contexts. The review should consider the widest possible range of mechanisms for delivering information and imparting new skills – ranging from new developments such as apps, video tutorials and on-line courses to more conventional methodologies used in formal education.

To make sure the review is as comprehensive as possible, it will be important to engage the wider EO community, including existing users of the resources under review. This could include a mechanism for allowing educators, technical experts and existing users to contribute suggestions for resources and initiatives to be included in the review, and – if possible – to provide an assessment based on relevance to the target audience, scientific correctness, educational efficacy, ease of use, etc. The use of on-line surveys and social media such as discussion groups could facilitate this. Allowing sufficient time for wider community participation will be important here; if the time-scale is too tight, the review may miss valuable resources and user input simply because important groups were not aware of its existence.

In addition to a more detailed description and 'audience matching', the review could also include an outline recommendation for how best to include the individual resources in an overarching EO education network to facilitate user access. This would pay particular attention to issues such as search, navigation and other mechanisms employed by existing initiatives, in order to match services to users.

6.2.2 Development of a 'gateway tool' for easy user access to relevant resources

The development of one-stop user interface providing easy access to distributed resources will be central to attracting and inspiring new users of EO data. This will not be achieved by simply adding yet another conventional web site that provides links to existing projects. Instead some form of consolidation, or overarching mechanism might be developed in order to link a network of initiatives and provide them with a common 'face' to the world. This user interface would be more like a 'gateway tool' than a conventional list of links.

The gateway should build on the best among the new technologies that have emerged in recent years to give users personalized, on-line access to data, tools and information. The challenge will be to allow this, while still allowing existing users of a valued resource to continue to access and use it the way they are used to. Given limited resources and the wealth of existing and future initiatives, it is likely that the 'market place' to which the 'gateway tool' provides access continues to remain distributed across many hosting organisations and web sites.

The gateway could be based on a metadata system, which allows users to easily find what they need, based on information they provide about their own needs - whether they are individuals looking to learn new skills or educators looking for material to help them improve learning experience for their students. The detailed implementation of the system is important, and will require state-of-the-art classification systems and search tools, as well as an ability to track user needs, allow user review and deliver feedback to providers of the original material.

The gateway must also be flexible and adaptable, allowing new resources to emerge while gradually giving less prominence to resources that have become out-dated or are falling into disuse.

[79] Issues such as bandwidth and data storage/management capacity are particularly important for developing country users and education initiatives that target users in these countries.

6.2.3 Supplementing the gateway with a 'recommendation engine'

While initial classifications could be based on the matching of existing resources to user groups. In the longer term this would be supplemented with a 'recommendation engine' not just for data, tools, case studies and training courses, but also for apps and websites. Such a 'recommendation engine' could pay particular attention to how different users interact with search tools and the GUI, in order to overcome actual and perceived barrier to user access of data and other resources. It could also build on user reviews of existing resources, allowing users to assess not only a particular resource, but also whether or not review by other users were helpful.

The 'recommendation engine' would incorporate new, intuitive search tools, using AI/semantic web technology. A beautiful and user-friendly interface design will be important, and will inspire newcomers to become engaged with the data and other resources.

One possibility might be to make the gateway an app in its own right, pushing suggested content to different user types depending on identified needs. The gateway app could, for example, also act as the route to more specific apps that serve narrower user communities. In a sense the recommendation engine is another way of manifesting the notion of the gateway as a 'broker', i.e. in a role that 'enables' rather than duplicates existing technologies and applications.

Before going down this route it would be worth exploring the boundaries between such a recommendation engine based on an 'app store' / marketplace approach, and a more traditional web 'portal' augmented with mechanisms for tailoring what it presents to what it 'knows' of a user's needs. Some users, who are already familiar with the Internet, may feel that they can ill afford the time to acquire and learn yet another app. The two may not be mutually exclusive, however. It is possible, for example, to have an app that is a cut-down version of a fuller on-line EO education 'market'. Finding the best approach to such a gateway will require a more detailed needs analysis than is possible here; this should include a description of the difference between the 'app store' and 'web portal' approaches, and some suggestion for established metadata systems and search technologies that may be investigated.

Successful implementation of a 'gateway tool' depends critically on a comprehensive analysis of everything that is already happening in European EO education (see Section 6.2.1). It may well be that the foundations for a solution already exists, and this possibility should be thoroughly investigated before further investment is allocated to the development of a specific gateway tool.

A gateway tool with a 'recommendation engine' is likely to be of particular value if it is linked to more extensive social media, including the opportunity to recommend resources to peers, surveys for providing feedback to resource providers, discussion groups, and on-line user forums. This will provide users with an opportunity to ask questions and receive answers from others with more experience, offer support to others, share their own experiences, and provide feedback on data sources, tools, apps, training courses and other resources in the 'EO education market'. If collected in a systematic way, such user input can help to refine future versions of existing resources, develop new ideas support collaborative efforts to implement theses, and improve the effectiveness of the gateway tool itself.

In addition to acting as a gateway to a distributed resource network, the gateway could also contain a 'toolkit' of the most popular resources, information packs, downloadable tools and so on held on the central website, and supported, for example, by ESA. Several such packs might be envisaged, designed for specific user groups. A challenge here would be to make sure that software and other resources were kept up-to-date, for example through an automated up-date-service provided in collaboration with developers of the original resource.

6.2.4 Providing local and on-line peer support

On-line fora that allow users to seek the advice of their peers are now common in many areas, such as, for example computer programming and web development. The most successful are often moderated by a core group of experts, and may be combined with a wiki where technical and other information is provided in a more systematic manner. A forum for tips and advice on using and learning about EO data would be a valuable addition to the EO education 'market place'. It could also reduce the burden of user support borne by providers of software tools, data products, and teaching materials. The forum could be targeted at teachers, students, researchers, and policymakers, linking users with similar interests, and be available through the gateway tool to provide users with easy access to areas of the forum most suited to their needs.

Such a forum would benefit from using existing social networking tools and approaches, but can also have areas with a more professional and portfolio-based approach that could eventually support some form of professional development accreditation within the EO arena. There are examples of how this works in other sectors, and these should be examined in more detail before deciding on the way forward.

Guidance about data products, including associated uncertainties could also be part of an online forum/wiki system. This could be linked to lesson plans, lecture videos and other resources, allowing users to recommend material and share resources they have developed in their own work.

A simple mechanism to enable people to easily find local EO expertise in their university or institutional setting could also be provided via the 'gateway tool'. For example, most universities will have within them a range of experts in various aspects of EO, and several international organisations already keep searchable expert databases. An online database of experts who have volunteered to offer support and advice related to the use and development of the EO education 'market place' could benefit both providers and receivers of the expert advice. Users needing advice would use it to identify resource persons for their courses, collaborators for the development of new training resources, reviewers, translators, or simply people prepared to offer advice on particular aspects of EO education, locally or online. Volunteering experts would benefit from wider exposure and access to potential opportunities for future work as employees, consultants or participants in new, collaborative projects.

6.2.5 Identifying gaps and setting priorities for future development

The review and matching of existing resources to user needs will almost certainly reveal gaps in terms of application area, geographical coverage, or the specific training needs of identified user groups. Environmental scientists in different fields will for example need to learn how to manipulate EO and other environmental data using available tools (e.g. Python, R, ESA toolboxes), and libraries of available programming routines, supported by e.g. alumni networks, would benefit such users. Where existing online support exists (e.g. for Python and R) a resource library could link to these, and a forum might provide opportunities for more tailored discussions and advice related to the use of these tools to examine EO data in different contexts. This type of resource library could bring together relevant resources from existing EO education initiatives, data libraries and websites already offering toolbox support. This would make it easier not only to identify existing resources, but also to establish where there are gaps and help set priorities for development of new material.

One gap identified at the LearnEO! workshop is a lack of hands-on courses which give up-to-date technical information about satellite sensors, receiving stations, data types and data archives. Such courses would be valuable for developing countries, and are also of interest more widely provided they are kept up-to-date with the latest information about new sensors, systems and data products. This information is already available online, but collating it is an on-going and time-consuming task, and sharing the result more widely will save overall community effort.

Citizen science is coming of age, with an increasing number of pilot studies and larger projects. Participating in such projects is a valuable experience for students in formal education, from school to university level. Facilitating participation in existing projects, or enabling the setting up of new ones through support data collection and advice on quality control could be a way to inspire wider use of and support for Earth observation.

A comprehensive analysis of current gaps in EO education might benefit from an analysis of competencies required by industry or government and civil society organisations that use EO data.

Geo-ethics issues are not always adequately addressed in the education of environmental data scientists. This can be a difficult topic to teach well, but also one that would benefit from a good selection of carefully documented case studies.

Implementation of a gateway tool that includes opportunities for user feedback and questions may further reveal areas that require attention in order to satisfy the needs of particular user groups. User feedback through the 'recommendation engine' and potential user forum or discussion groups may further help to identify gaps. This will help funders and resource providers to set priorities for future development of EO education resources, and also to identify new contributors with relevant expertise, as well as the time and enthusiasm needed to develop relevant and inspiring new material.

6.3 Harnessing new computing and communications technologies

Modern computing and communications technologies offer a wide range of opportunities for EO education to reach new audiences and meet the needs of existing users more effectively. Interactive apps, citizen science, discussion fora, wikis, open on-line courses, creative commons licencing, and new developments in data management, processing, analysis and on-line access, creates new opportunities to provide more targeted and effective EO education.

Any developments to harness new technologies for EO education should look carefully at other projects that address similar issues, such as ESA's 'rapid prototyping' mobile apps project and other initiatives looking at crowdsourcing and related emerging technologies.

6.3.1 App development

Apps are increasingly employed in an education context. This includes new apps designed specifically for use in schools, but also a wide range of other apps that can be used, for example, to provide specific information or support citizen science. ESA and other providers of EO data are already funding initiatives to employ apps for different purposes.

To develop apps efficiently and ensure appropriate standards and commonalities between new apps for multiple purposes, a toolkit could be developed. This might be hosted, for example by ESA, in effect supplying developers with a 'kit of parts' that they can work with to develop new EO apps. This might include hybrid and proxy tools for multi-platform development, hosting and server space, building blocks such as social tools, data recommendation engine, and other elements.

The arrival of nimble, savvy, Silicon Valley-based ventures such as PlanetLabs[80], Urthecast[81], Skybox imaging[82] and so on, along with a variety of new citizen science projects, will themselves be likely to drive innovation, new web standards, and a more accessible and intuitive approach to providing data. It is important that public institutions and the custodians of public data keep up with this approach and align themselves with these emerging standards.

A developer's toolkit hosted centrally and updated to comply with emerging standards will make this task easier. When developing such a resource issues such as licencing and IPR have to be carefully considered, and ideally standardised so that developers can feel confident both about using existing components, and offering their own to the common resource if they wish

6.3.2 Citizen science and direct engagement with real data

As the citizen science session at EO Open Science 2.0 shows, the involvement of citizens in providing data for research is a powerful tool, from support for validation or EO data products and image classification to support for emergency response and humanitarian aid. Citizen science is prevalent in the fields of nature conservation, ecology and biodiversity where it can help to map habitats and species distrbutions in support scientific research. An important aspect here is the need to understand uncertainty in citizen science data. Both researchers and citizen scientists would benefit from better tools to communicate the uncertainty the uncertainty in data collected by citizens.

Citizen science offers substantial and wide ranging opportunities for focused educational use of

[80] https://www.planet.com/

[81] https://www.urthecast.com/

[82] http://www.skyboximaging.com

EO data. It may also allow students in formal or informal education to make a direct contribution to science, thus creating a sense of 'ownership' and participation. Citizen science that targets schools and youth organisations is a good way to make an emerging generation of decision-makers and future leaders familiar with applications of Earth observation. When used in schools, it creates an ideal 'excuse' for teachers to be 'forced' to look at EO data, research it in a structured manner, and support their students to do the same. However, as all education initiatives for schools, it must be clearly in line with the curriculum to be sustainable and popular.

Educational citizen science and crowdsourcing methodologies have been tried and tested over considerable time in other scientific arenas, especially in astronomy. For example the Faulkes Telescope project[83], the National Schools Observatory project in the UK[84] and many others have enabled students to directly operate major telescope facilities for astronomical observations. A similar approach may be possible for Earth observation, using existing EO platforms, ISS mounted cameras, perhaps in partnerships with emerging satellite platforms, nano-sat providers, and amateur satellite groups such as AmSat[85] and SEDS.[86] The approach could include enabling university access to satellite ground segments – an idea discussed at the workshop and worth exploring further.

There is also a potential role for incorporating haptic and gesture control technologies in EO education or public engagement with EO data - for example at conferences and science centres. Haptic technologies already available include the Leap Motion[87] range of technologies and Microsoft Kinnect[88]. When combined with the emerging virtual reality, augmented reality, and immersive technologies (including Oculus Rift[89], Google Glass[90], and full-dome interactive cinema using spherical projection technology), it becomes possible to give a new generation exciting, first-hand experience of engaging with the data. These new technologies may eventually allow decision makers, policy developers, and the general public to reach a deeper understanding of how Earth observation may help meet different challenges related to sustainable development, environmental hazards and risk management, adaptation to climate change etc. Supporting specific development projects for EO education that take advantage of new visualisation and gaming technologies areas will be particularly valuable for bringing Earth observation to new audiences.

An integrated approach means encouraging the inclusion of 'citizen education' in citizen science projects, Citizen science can be a powerful way to engage citizens and motivate them to learn more about the science they are supporting. Where the science also draws on EO data from satellites, this engagement could be harnessed by including an EO education element in the project itself, or by linking with an appropriate external education initiative. A closer link between citizen science projects and appropriate education initiatives can make it easier for citizen science projects to 'educate' their volunteers, and may also help providers of education resource to include case studies from citizen science project, to demonstrate the power of combing this approach with more conventional uses of EO data.

6.3.3 Including other technologies

In addition to citizen science and a crowd-sourced approach to operating EO platforms for education, other technologies may offer an even more direct way of getting to grips with the principles of Earth Observation, data processing, and analysis. Low-cost drones and UAVs is one such area where research is already advanced. A number of established projects use fixed wing remote control aircraft to enable non-technical and educational users to obtain aerial imagery at extremely low cost. The explosion of interest in rotor-blade drones of all shapes and sizes, ranging

[83] http://www.faulkes-telescope.com

[84] http://www.schoolsobservatory.org.uk

[85] http://www.amsat.org

[86] Students for the Exploration and Development of Space - http://seds.org

[87] Motion controller for computer games - https://www.leapmotion.com/

[88] Motion sensing input devices developed by Microsoft for Xbox video games

[89] Virtual reality headset for 3D video games.

[90] A type of wearable technology with an optical head-mounted display (OHMD).

from small toys with cameras to highly expensive professional film equipment for television and movie production, contains opportunities for new education activities. Cubesats and radical ultra-low-cost satellite platforms emerging in Europe, the US and India, potentially also offer opportunities for 'end-to- end' educational experiences at both school and university level, incorporating engineering, design, missioning planning, software development, data acquisition, data analysis, and so on. ESA's role here could be to support R&D and provide guidance and educational resources relating to these emerging opportunities.

Specific effort could also be made to explore technologies from the gaming industry, including gaming engines such as Unity, which enable rapid development of immersive applications, using interfaces and tools familiar to many users.

6.3.4 The role of MOOCs

Massive Online Open Courses (MOOCs), and possibly even 'SPOCs' (small private online courses) are likely to play an increasing role in education, including for Earth observation. MOOCs are intended to cater to a wide range of abilities and background knowledge, so a single course cannot be comprehensive and highly detailed in every aspect of the subject, whereas SPOCs can be highly tailored and targeted to smaller, more homogenous audiences, and deployed for more professional training purposes. ESA's MOOC on ' Monitoring Climate from Space', currently under development, is not intended to be either a comprehensive EO course nor a comprehensive climate change course, but a bit of both, so there is scope for further MOOCs that look at EO applications in other contexts, as well as for MOOCs that deal with more specialised topics such as the use of EO to support resource management, water management, biodiversity, agriculture, etc.

Pulling a MOOC together is a considerable task, which could be made easier through a modular approach that takes advantage on existing material relevant to the MOOC topics. Such an approach may also represent an additional gateway to more specialised material available in the 'EO education market place'.

6.4 Keeping EO education relevant and up-to-date

Keeping education resources and training courses relevant and up-to-date is a formidable challenge in a world where new sensing technologies, data products and applications are emerging at an increasing rate, and where software tools, algorithms and analysis methods continually evolve. A further challenge stems from the rapid development of computing and communication technologies. To keep abreast of all these changes means on-going development of new training material and regular revision and adaptation of existing tools and information sources. This is particularly important for resources used in the formal education of new environmental data scientists or for on-going professional development.

At the same time, the rapid evolution of EO, computing and communication technologies also offer an opportunity for creating new and inspiring education resources. If harnessed in appropriate ways these technologies will allow the 'market place' place for EO education to provide for an increasing diversity of users. Moreover, emerging developments in computing and communication will offer opportunities for refining the 'gateway tool' to make it increasingly effective in matching selections of resources to individual user requirements.

To harness new development effectively requires expertise from many different fields within Earth observation, environmental science, computing, communication and education. It will require both interdisciplinary collaboration and considerable investment in terms of effort and resources. Given this, the most effective approach will most likely be one that combines conventional funding of EO education initiatives with 'crowd-sourcing' of material from 'volunteer experts'. This will help to keep available resources up-to-date, identify gaps and fill these by creating new material. Both professional EO education providers and expert volunteers will benefit from access to clear guidelines for the development and quality control of learning resources, whether modern apps, or more traditional handbooks, lessons and lectures. Of equal importance is an effective system for peer review, testing and user feedback.

6.4.1 Crowd-sourcing of new education resources

Conventional thinking divides the education community in to teachers and students, trainers and trainees. In reality the distinction is much less clear-cut than it first appears. To create an effective learning environment for their students, teachers often need to acquire new skills and assimilate new knowledge. Similarly students learn best through active involvement, including opportunities to contribute by helping their peers. As their skills and knowledge grow, they are increasingly able to share their specific expertise with others who have less experience. Students are experts at what increases their own motivation, and often also of what approaches will be most appealing to their peers.

Given this blurring of the divisions between teachers and students, experts and non-experts, it may be more helpful to think in terms of an EO education community whose members are both users and producers of education resources. In such a model individuals may act as trainers or trainees according to their circumstances at a particular point in time. An EO education system capable of capturing the contributions of these user/producers will have a better opportunity to remain up-to-date and relevant, than one that draws purely on the efforts of a small group of professional experts whose job is consists mainly of developing education materials and deliver training courses.

Considerable effort will be needed to set up and maintain an on-line system capable of 'crowd-sourcing' new education resources. Capturing the input of a multitude of user-producers while maintaining easy access to relevant, high-quality services will require a dedicated core of professionals with the scientific, technical and educational expertise to:

- coordinate community efforts,
- provide encouragement, advice and support to new contributors,
- maintain the quality of education resources through peer review and user feedback,
- ensure that producers if existing and new resources receive appropriate credit,
- respond to user queries that or not adequately addressed by other users of on-line fora,
- collect good advice and suggestions for best practice into wikis and handbooks,
- ensure that search and navigation tools are effective in matching existing data sets and information resources to the needs of new resources developers in order to reduce the effort involved,
- facilitate peer review of scientific, technical and educational efficacy, and
- bring new developments into the education market, without loosing the ease of access that is so essential for time-constrained professional users.

6.4.2 Setting standards and guidelines

Whether used in a formal, supervised setting, as part of a distance learning course, or in completely informal 'self-education', software tools, conventional lessons and apps will be most effective and avoid frustration if they follow basic educational guidelines that have been developed over decades by experienced educators. For example, a practical lesson designed to teach a specific EO application will be more effective if it:

- provides a brief overview that allows a users to see quickly whether the material is suitable for them,
- sets clear learning objectives,
- presents information in a clear, direct way at a level of complexity and style suitable for the stated target audience,
- combines the presentation of data and information with activities that re-enforce learning,
- gives instructions that are detailed enough to avoid confusion without being too verbose,
- asks questions to make students think about what they are learning, and (for those working without supervision) provides model answers with enough detail to explain the reasoning involved,

- is visually appealing and easy to navigate, with extra information available as required,
- provides all the necessary data, tools, and background information required for students to carry out the activities and meet the stated learning objectives.

Similar consideration will apply to other resources, such as apps. Even where the main objective is not to teach specific skills and knowledge, but merely to inspire newcomers and demonstrate the potential of Earth observation to make a difference, simple activities help to maintain interest.

The task of developing a new lecture, lesson, case study or app can seem daunting, even for experienced educators. For EO experts with limited education experience, access to guidelines with suitable examples will be particularly useful.

The need for standards and guidelines in app development has already been discussed briefly in Section 6.3.1. Guidelines and standards for development of case studies, selection and presentation of example data, development of hands-on exercises and lessons, and suggestions for how to pull material together into longer courses are also needed. Such guidelines should build on best practice from both the EO and wider education community, and must consider the different needs of different target audiences. It will be helpful to supplement the guidelines with examples of best practice.

6.4.3 Building on existing material to reduce effort

Access to a searchable resource library of existing material that is available for re-use will greatly reduce the effort required in the development of new tutorials or training courses. As with apps, it is important that such material can be easily identified and accessed, and that licencing and IPR are handled in a clear and understandable manner.

Universities and other organisations involved in EO education in some way are a potential source of training materials. Lecturers and course organisers often use resources from existing education initiatives funded by ESA, the EC, EUMETSAT, as well as other international and national providers of EO data, tools and information; thus reducing the effort involved in keeping their teaching relevant, active and up-to-date. Many have adapted more general resources for use with different application areas or new geographical regions, and often have good examples available from the research and teaching activities they and their colleagues participate in. Over the years they may have collect a wide variety of teaching materials, which have been tested and refined through use with cohorts of students. Such material represents a valuable resource, which could be shared more widely if a suitable forum and resource library are made available.

Post-graduate students and recent postdocs are another potential source of new material such as quality case studies, example data and computing routines for data processing and analysis. Finding a way of soliciting contributions from these groups and linking these to a system that offers peer review, author credits and citation tracking, will make the sharing of treasured resource more attractive to potential contributors. If designed for ease of use and with respect for the rights of original authors, such a system can benefit the career prospects and reputation of both individual contributors and the organisations to which they belong.

6.4.4 Review, testing and quality control

Peer review, both educational and scientific, is critical for the development of new training resources. Equally important is initial student testing and feedback, followed by revisions if necessary. This should take place before a new resource is widely released. An expert database and on-line discussion forum can help by holding information about the interests and expertise of individuals who have volunteered to help with review and testing. If necessary, the core group of experts responsible for looking after a particular crowd-sourcing initiative, can offer help and advice to new authors, and facilitate the review process by linking developers and reviewers.

Many resources will also benefit from on-going user feedback and review taking place through a 'recommendation engine' that allows users to rate and review resources they have used, and recommend these to their peers. When appearing in user searches, resources could be presented with a brief description along more formal guidelines, followed by short reviews and an audience rating, in a similar way to that done on Amazon or the Apple App Store for books, apps and software.

Adding a min-forum that allows users to ask questions and receive answers from other users and/or the resource developer will provided added value. Care must be taken when soliciting and moderating such open feedback and reviews, in order to avoid being inundated with malicious, nonsensical or irrelevant comments from non-users. Some sort of registration and screening of users before accepting their feedback is recommended.

6.4.5 Crediting contributors and providing feed-back

When making existing and new resources available through a common gateway, it will be necessary to set up a system for crediting the various contributors and providing them with information about the number and types of users accessing their material.

The 'gateway tool' should contain a mechanism for keeping this type of information, and making it available to contributors. It will also be necessary to maintain some sort of traceable citation system to credit developers who also make their material available for others to use. Mechanisms for this are already well established in existing online initiatives.

6.4.6 Mechanisms for engaging potential contributors

Experience from LearnEO! shows that it is not always straightforward to attract new contributors. A major barrier is the amount of effort involved, and although many volunteers offer to contribute, only a fraction of these actually follow up by providing their own material.

Competitions are one way to encourage potential contributors to share their expertise. The publicity and rewards associated with a competition is particularly attractive to those at the start of their career. When organising, for example, a lesson-writing competition, it is important to consider the effort involved. A competition that requires less effort is likely to have a larger number of entries. If the effort required is too great, some authors will inevitably drop out because of other priorities and more pressing commitments.

Competitions that encourage short case studies or mini-lessons are likely to attract larger numbers. However, it is also possible to reduce the effort involved in participating, for example, by

- encouraging teams that include a combination of EO experts, environmental scientists, computing experts and educationalists, and providing a team 'match-up' service similar to that provided for the EC's Framework and Horizon-2020 proposal service;
- emphasising the advantages of adapting existing work such as scientific research or environmental reports, which will already have identified data, analysis methods and background information needed for interpretation, and could be adapted for education purposes,
- offering access to figures, diagrams, and background information on sensors, platforms, data products, processing algorithms, analysis methods, etc., which may be re-used or easily adapted to a new context;
- providing a service for matching potential authors with users prepared to offer review and initial testing of a resource prior to submission

Similar considerations would apply, not just to more conventional lessons and activities, but also to competitions for the development of apps.

6.5 Showing consideration for users with poor Internet connectivity

Given the exciting development in Earth observation technologies, computing, open data, open source tools, communication mechanisms and social media it can be easy to forget scientists and decision makers in developing countries, whose main source of environmental data comes from freely available Earth observation data. The digital divide between many developing countries and the rest of the world make EO education a particular challenge for schools, universities, environmental scientists and decision makers in countries where broadband is unavailable much of the time. Many may not have Internet access, or only slow and unreliable connections that are overloaded during normal working hours.

When developing new education resources to deliver training and education at all levels, it is important to also keep these users in mind. Delivering training in person, providing data and other resources on DVD, or through broadcasting technologies as in GEONetCast may be the only realistic option for training future EO data scientists in countries with poor access to the Internet.

To avoid widening the digital divide, it is important not to dismiss more conventional technology and education methods as 'old hat'. Harnessing new technologies is important in order to inspire and inform new and existing users of EO data products. However, much of the information made available this way, could also be made available in slightly different formats by more conventional means – often with relatively little extra effort.

6.6 Summary of Recommendations

Developing a 'market place' of up-to-date and relevant education resources that harness a wide range of available technologies to inspire, engage, educate and support existing and future users of EO data will take time and effort. Providing suitable material for users with a widely differing needs while maintaining ease of access will require both a detailed assessment of what is available, mapped to user needs, careful planning to ensure that existing gaps are met by future initiatives. Future EO education needs to build on best practice and successful approaches from existing work in Europe and elsewhere, while learning from approaches that have been developed in the wider environmental science, education, computing and communication communities.

In the summary below our recommendations are organised into actions that should be taken in the short, medium and longer term, to ensure that European EO education will allow our vision of Environmental Data Science in 2030 to become a reality.

When implementing the recommendations below it is important at all stages to bear in mind how to involve EO data users and educationalists with poor Internet connectivity, in order to ensure that new developments also meets their requirements and information needs.

6.6.1 Short term recommendations (1-3 years)

1. Set up and maintain an **on-line forum** for EO education, inviting participants at the Frascati workshop to join, and asking them to help extend the network by help engage colleagues involved in EO education, including technical experts and education professional with an interest in EO education and human capacity development (Section 6.1).
2. Develop a proposal for a COST action on Earth observation education for submission to the COST open call[91] (Section 6.1).
3. Carry out an In-depth review of existing training resources and initiatives, their relevance to the training needs of broad user groups and application areas, and suggestions for how to these available through a future EO education gateway tool (Section 6.2.1).
4. Carry out a consultation of the EO education community and EO service providers to identify gaps and set priorities for future development of EO education (Section 6.2.4).
5. Investigate options and develop specifications for a 'gateway tool' to give users easy access to training materials and courses relevant to their individual needs (Section 6.2.2).
6. Investigate options and develop specifications for a 'recommendation engine' associated with the gateway tool, which will allow users to evaluate existing resources, provide feedback to authors and course providers, and recommend new material for inclusion in the 'EO education market' (Section 6.2.2).
7. Investigate mechanisms for providing local and on-line peer support via the gateway tool and recommendation engine (Section 6.2.3).
8. Encourage and support the development of 'hands-on' activities associated with EO-related

[91] http://www.cost.eu/participate/open_call

apps and toolboxes, demonstrating their use in different education contexts. (6.3.1)

9. Facilitate the creation of links between citizen science and EO education initiatives with a view to develop more interactive tools and training materials aimed at citizens and the next generation of EO data users. (Section 6.3.2).
10. Develop tools to understand and communicate uncertainty in data sets collected by citizen scientists or derived form analysis of EO data. (Section 6.3.2)
11. Support development of additional on-line courses to show how EO data are used to provide information for research and decision support in sustainable development, dealing with environmental hazards (e.g. building resilience, emergency response), or deliver science-based management of natural resources. (Section 6.3.4)

6.6.2 Medium term recommendations (3-5 years)

12. Plan and implement a European ‘gateway tool’ to give easy user access to training materials courses and other resources relevant to their individual needs (Section 6.2.2).
13. Develop a ‘recommendation engine’ associated with the gateway tool, which will allow users to evaluate existing resources, provide feedback to authors and course providers, and recommend new material for inclusion in the ‘EO education market’ (Section 6.2.2).
14. Set up a forum for providing local and on-line peer support linked to the gateway tool and recommendation engine (Section 6.2.3).
15. Support the development of new resources to fill gaps identified by the EO education review and user consultation (§6 -7 above), using conventional training materials and tools as well as new approaches such as apps, MOOCs, citizen science (Section 6.3).
16. Investigate mechanisms for encourage the wider participation of the EO and education communities in the development and sharing of EO education materials and case studies.

6.6.3 Long term recommendations (6-10 years)

17. Maintain and extend the gateway tool, recommendation engine and associated fora, where necessary modifying these in response to user feedback and the development of new technologies for data access, processing and analysis.
18. Develop and maintain mechanisms for crowd-sourcing new education resources ensuring that scientific and educational standards are maintained through peer review,
19. Make crowd-sourced material accessible through the ‘gateway tool’, and integrating the new resources into systems to provide user feedback and facilitate user support.

References

Brovelli, M.A.: A New Era for Open Science and Earth Observation, Open Science 2.0. White Paper, ESA, 2015.

COMET (2013): The COMET® Program Strategic Plan 2014-2019, http://www.comet.ucar.edu/presentations/COMETStrategicPlan2014-2019.pdf

Craglia, M., K. de Bie, D. Jackson, M. Pesaresi, G. Remetey-Fülöpp, C. Wang, A.Annoni, L. Bian, F. Campbell, M.Ehlers, J. van Genderen, M. Goodchild, H. Guo, A.Lewis, R. Simpson, A.Skidmore & P.Woodgate (2012): Digital Earth 2020: towards the vision for the next decade, International Journal of Digital Earth, 5 (1). DOI: 10.1080/17538947.2011.638500

ESA (2014): ESA Earth Observation Education And Training, Activities & Achievements 2010-2013.

GEO (2006): Capacity Building Strategy, Document 13, GEO-III, https://www.earthobservations.org/documents/geo_iii/13-Capacity_Building_Strategy.pdf

GEO (2007): Mobilizing Resources for Implementing GEOSS - The Seville Roadmap; Document 23, GEO-IV 28-29 November 2007.

https://www.earthobservations.org/documents/geo_iv/23_Mobilizing%20resources%20for%20implementing%20GEOSS_The%20Seville%20Roadmap.pdf

GEONETCAB Capacity Building Strategy http://www.itc.nl/library/papers_2012/general/noort_capacity.pdf

Hausamann, D. (2014): “Practical EO Education for Students and Teachers”, CEOS WG-D, draft strategy for K-12 education.

EO Open Science 2.0. 12-14 October, 2015: Presentations and white papers. http://www.eoscience20.org

Lehmann, A., G. Giuliani, E. Mancosu, K.C. Abbaspour, S. Sözen, D. Gorgan, A. Beel, N. Ray (2015): Filling the gap between Earth observation and policy making in the Black Sea catchment with enviroGRIDS, Environmental Science & Policy, 46, 1–12. DOI: 10.1016/j.envsci.2014.02.005

Mannaerts, C.M., B.P.M. Maathuis, M. Molenaar, R. Lemmens (2009): The ITC GEONETCAST Toolbox: A Geo capacity building component for education and training in Global earth observation & Geo information provision to society. Geoscience and Remote Sensing Symposium,2009 IEEE International,IGARSS 2009.

See, L. S. Fritz, H. Leson, S.Wrigley, B. Simmons, F. Snik, T. Bartoschek, P. Schneider, A. Sánchez de Miguel and E. Bruce (2015): Citizen Science, Open Science 2.0. White Paper, ESA, 2015.

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