# Chapter 1
# Introduction: Participation in Science, Technology, Engineering and Mathematics (STEM) Education: Presenting the Challenge and Introducing Project IRIS

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## Improved Participation in Science, Technology, Engineering and Mathematics (STEM): What Does It Mean, and Why Is It Needed?

### *Science and Technology Shape Our Lives and Provide Career Opportunities*

Science and technology[1] matter. They shape our daily lives, as they have done in the past and will continue to do in the future. They influence the way we work, how we keep healthy, how we spend our time, how we communicate – and how we think. Just as science and technology have contributed to some of the great challenges the world faces today, such as climate change, it is also impossible to meet these challenges without employing science and technology in developing solutions. Scientific and technological advances – from the heliocentric worldview, the theory of evolution and the invention of the steam engine to current computer technology and genetics – have profoundly influenced our views of ourselves and the world we live in.

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[1] In the present book, the terms “science and technology” and “science, technology, engineering and mathematics (STEM)” are used more or less interchangeably. In most cases, when the focus is on young people’s relationship to this broad area of study as opposed to other disciplinary and professional areas like humanities, law, or crafts professions, no strong distinction is made between the different STEM disciplines. In some cases, STEM disciplines like physics, biological sciences or computer science are specified when the difference between STEM disciplines appears relevant or when the results reported concern only a subset of the STEM disciplines.

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Arguably, young people in developed countries today experience greater freedom than ever before in shaping their life in general and their education and career in particular. In a globalised world, they can take all or parts of their higher education abroad and they can choose between a wide range of different studies and disciplines. For modern youth, choosing an education may be seen as part of their identity project: through this potentially important life choice, they seek to express who they are and which values they wish to pursue. How do the science and technology disciplines present themselves in the marketplace where young people evaluate different educational options? Do young people see the potential of STEM to contribute to their personal development through a challenging education and diverse career opportunities? Do they see how science and technology will contribute to changing the world and their personal lives during their lifespan? This book is about understanding how young people make their educational choices and how they evaluate science, technology, engineering and mathematics in this context.

## *Science and Technology Contribute to Solving Global Challenges and Promote Economic Growth and Equitable Societies*

In year 2000, world leaders adopted the United Nations Millennium Declaration, committing their nations to work towards a series of targets – with a deadline of 2015 – that have become known as the Millennium Development Goals (UN 2012). Among these eight goals are: to end poverty and hunger; secure maternal and child health, combat HIV/AIDS, and promote environmental sustainability. In order to reach these goals, science and technology are central in developing and improving renewable energy technology, communication systems, agricultural technology, medical treatments, systems for transporting and storing food and medical supplies, etc. Thus, a competent and responsible workforce within the science and technology disciplines is essential in order to meet some of the greatest challenges the world faces in the first decades of the twenty-first century.

STEM is also identified as an important sector for economic growth and stability in individual countries and regions. In its strategy “EUROPE 2020”, the European Union (EU 2010) put forward three mutually reinforcing priorities:

- Smart growth: developing an economy based on knowledge and innovation.
- Sustainable growth: promoting a more resource efficient, greener and more competitive economy.
- Inclusive growth: fostering a high-employment economy delivering social and territorial cohesion.

The same report identified five measurable targets for 2020: for employment; for research and innovation; for climate change and energy; for education; and for combating poverty. Working towards these targets will involve "investing in research and development as well as innovation, in education and in resource efficient technologies" (EU 2010).

Along similar lines, there are recognised needs for strengthening STEM participation in most European countries (see for instance Norwegian Ministry of Education and Research (2009), Ministry of Higher Education Science and Technology of Republic of Slovenia (2010), Royal Academy of Engineering (2012)).

## *Improved Participation in STEM: Diversity and Equity Issues*

Improved participation in STEM is not only a question of numbers of STEM students and practitioners; it is also a question of diversity. The FP7 Capacities Work Programme for Science in Society (EU 2008) states that "the pursuit of scientific knowledge and its technical application towards society requires the talent, perspectives and insight that an increasing diversity in the research workforce will ensure. Therefore, a balanced representation of women and men at all levels in research projects is encouraged". Similar views are expressed in the report "Land of Plenty: Diversity as America's Competitive Edge in Science, Engineering and Technology" (NSF 2000):

> Our economy will not only be positively affected by bringing more women, underrepresented minorities, and persons with disabilities into the SET workforce, but our high-tech, scientific, and engineering industries will benefit from their diverse viewpoints and approaches, as well as their skills.

UNESCO (2007) stated that "increasing women's involvement, input and access to S&T is essential to reducing poverty, creating job opportunities and increasing agricultural and industrial productivity". Thus, there is a broad recognition of the role of STEM in creating a sustainable and knowledge-based economy in an equitable society.

Increased STEM participation concerns not only the needs of the STEM establishment and society at large; it also concerns the interests of individuals. Bøe et al. (2011), discussing reasons why participation in STEM is an important issue, contended that involvement in STEM gives people literacy, empowerment and economic freedom to shape their world and everyday life and that women and other under-represented groups need to engage in STEM to be empowered to influence their own lives and the development of the world. These groups should be encouraged to participate with their priorities on the arenas where decisions are made regarding research and technology development. A classic example concerns women's health, which has received increasing focus in medical research as a result of women's engagement (NIH 1999). Another aspect of this argument is that the failure of women to pursue STEM careers limits their career opportunities and earning potential.

Furthermore, equitable access to STEM education and career means that everyone should be given the chance to engage in the scientific and technological world, which may enrich their lives and contribute to their individual development, in line with the ideals for a liberal education as described for instance by Carson (2002). Access to STEM is seen as a means of empowering individuals and opening up opportunities for self-development as well as a profession and career.

Finally, in an equitable society, everyone should have a real, not only a formal, free choice of education (Bøe et al. 2011). This requires that youth has access to sufficient and reliable information about the various educational and occupational options available, and that there are no formal or informal obstacles to a free choice. An example of the latter would be norms, stereotypes or expectations which young people are confronted with and which limits their perception of the options available to them and the roles they are expected to take on, as for instance discussed by Mujtaba and Reiss (2013) for the case of physics. Stereotypical views of scientists are still prevalent and fit poorly with the ideals that are held up, particularly for young women, by contemporary culture. Young people will not have a real free choice of education before these cultural barriers are reduced.

In this book, we use the term "improved participation in STEM" to denote a situation where society's needs for scientific and technological expertise are fulfilled and where each individual has a real opportunity to participate in STEM practice and STEM-related decision-making, and to pursue a STEM education and career, regardless of gender, ethnicity, class or other potentially inhibiting factors.

By *improved participation* in *STEM* we mean a situation where:

1. a larger and more diverse group of young people, based on reliable information and realistic impressions of their STEM education and career opportunities, consider STEM a viable possibility when making their educational choice;
2. a larger proportion of students complete a higher education within STEM after having entered.

## Current Situation and Projected Needs for STEM-Educated Persons

### *Young People's Participation in STEM on Various Levels of the Educational System*

In project IRIS (and in this book), the main focus is on educational choice in the transition from upper secondary to higher education. However, STEM participation in higher education can only be understood if school and childhood experiences as well as discipline cultures, possibilities and barriers in higher education STEM departments are taken into account. Thus, students' experiences with STEM in school as well as in higher education up to PhD level are all addressed in this volume. Moreover, as discussed in several of the chapters, educational choice can be seen as an on-going and dynamic process extending in both directions from the educational decision-point of entering higher education. Notably, the choice process continues through the first years of higher education, greatly influencing retention rates of STEM students, as discussed in Part III of this book.

STEM participation challenges vary between countries and disciplines and between levels of the educational system, as discussed by Bøe et al. (2011). We do not provide a detailed discussion of these variations here. However, the following paragraphs provide an overview of some tendencies that are found in several countries and several disciplines. These serve to document that despite variations, the challenges concerning STEM participation warrant continued attention from policymakers as well as the research community.

There is substantial evidence that many young people are disengaging from science from the first possible decision point during secondary education. In the UK, for instance, the proportion of students taking A-level physics and chemistry fell markedly between 1990 and 2008 (Joint Council for Qualifications [JCQ] 2009) but increased slightly again from 2008 to 2010 (JCQ 2010). In Norway, one third of the students choosing Level 1 physics in upper secondary school, choose *not* to continue to Level 2, and girls are overrepresented among the "leavers". In contrast, 97 % of biology Level 1 students continue to biology Level 2 (Norwegian Directorate for Education and Training [NDET] 2009). In Australia, proportionally fewer students have been choosing science at the first decision point. According to Ainley et al. (2008), between 1992 and 2007 the proportions of senior high school students taking physics, chemistry and biology courses declined by 26 %, 22 % and 29 % respectively. More recent figures suggest a stabilisation (Lyons and Quinn 2010). Researchers in New Zealand have also reported early student disengagement from science and mathematics (Hipkins and Bolstad 2005).

In many countries, increased student disengagement from STEM has been most apparent in the secondary to tertiary transition. In France, for example, the percentage of high school graduates enrolling in first year university science courses (excluding health and medicine) almost halved from 8.4 % in 1995 to 4.3 % in 2007 (Arnoux et al. 2009).Over the last decade, universities in Japan have been increasingly concerned about the 'flight from science', since the number of students studying science and engineering at university decreased by 10 % between 1999 and 2007 (Fackler 2008). Since 2000, the proportion of tertiary graduates specialising in science, mathematics and computing in Europe has been reduced from around 12 % to 9 % (Eurydice 2012).

In order to increase the number of STEM graduates, retaining the students who have started on the STEM track is as important as increasing the number of entrants. According to the OECD (2008), science and technology are among the disciplines where non-completion rates are highest. Understanding – and responding to – students' reasons for leaving their chosen STEM study thus becomes an important task. Ulriksen et al. (2010) discussed student drop- out/opt-out from STEM higher education programmes. They suggested that instead of describing drop-out as a problem belonging to the student, retention should be addressed as a relation between the student and the institution. In this context, there is a need to study how teaching approaches and department culture influence student achievements, attitudes, self-image, well-being and – ultimately – completion.

## *Projected Needs for STEM Professionals in the Future Workforce*

The STEM participation challenge arises not only from falling enrolments in some disciplines, as described above, but also from projected needs for *increases* in the STEM workforce in the future. The widely cited report "Europe needs more scientists" (EU 2004) called for a substantial increase in the percentage of science and technology researchers in the total workforce. Projections from a number of countries indicate that the demand for STEM-educated labour will increase during the years to come, and there is widespread concern that the supply of people educated within STEM will be too small to meet future demands (see for instance Bjørnstad et al. (2008), Confederation of Danish Industry (2010), ERT (2009), Confederation of British Industry (2010)).

The STEM participation challenge does not apply equally to all STEM disciplines. University enrolments in life and health sciences are considered sufficient to meet projected demands in most developed countries (Organisation for Economic Co-operation and Development [OECD] 2008), while there are predictions of shortages in most engineering disciplines (United Nations Educational, Scientific, and Cultural Organization [UNESCO] 2010). Engineering graduates are in great demand in Australia, Germany, the US, Canada, Norway, the UK and New Zealand (Kaspura 2010; Manpower 2009), while serious shortages of physics and chemistry teachers have been reported in the UK, Norway, Denmark, the Netherlands (Osborne and Dillon 2008) the US (Hodapp et al. 2009) and Australia (Department of Education, Science and Training [DEST] 2006). For biology teachers, on the other hand, the demand in England has been decreasing in relation to that for physics and chemistry teachers, with the result that the amount of funding available to biology student teachers has been reduced in recent years (Department for Education 2013).

However, there are challenges to the suggestion that we need more students to be following post-compulsory science courses in order to address a shortage of scientists. Smith and Gorard (2011) analysed the educational and career trajectories of those students following post-compulsory science courses in England. They showed that for the majority of science graduates the occupations they enter immediately after study are not directly science-related. One possible interpretation of this is that the demand for scientists is indeed met by the supply of science graduates. However, it is also likely that many science graduates *choose* not to follow science-related careers. These findings call into question the assumption that increasing the numbers of science graduates will necessarily lead to an increase in the number of STEM graduates entering science-related careers.

## *Women's Participation in STEM*

As discussed above, there are good reasons to promote increased participation of under-represented groups in STEM. Such groups may be defined through parameters such as gender, ethnicity, class or socioeconomic status. Although several of these parameters may interact in forming young people's relationship to STEM, as discussed by Archer et al. (2012), the main focus in the present book is the under-representation of females. Women continue to be under-represented in a number of STEM disciplines, notably in physics, mathematics and engineering (NSB 2010; Eurydice 2010). In the report "Europe needs more scientists" (EU 2004), it was remarked that increasing the number of women entering science and engineering careers would go a long way towards filling the demands for an increased R&D workforce in terms of numbers.

The publication "She Figures" (EU 2009) documented the under-representation of women in most STEM disciplines. For instance, in the fields of engineering, manufacturing and construction, women accounted for only a quarter of PhDs earned in 2006 in the EU countries (ibid., p. 51). In the USA, men earned four out of five bachelor's degrees awarded in engineering, computer sciences, and physics in 2007 (NSB 2010). Among fields with notable increases in the proportion of bachelor's degrees awarded to women were earth, atmospheric, and ocean sciences, agricultural sciences and chemistry, whereas women's share of bachelor's degrees in computer sciences, mathematics and engineering declined in recent years (ibid). The 2011 "Education at a glance" report (OECD 2011) shows that in 26 of 33 countries, women represented fewer than 30 % of graduates in the fields of engineering, manufacturing and construction.

In the report "Why so few?", the American Association of University Women states:

> By graduation, men outnumber women in nearly every science and engineering field, and in some, such as physics, engineering, and computer science, the difference is dramatic, with women earning only 20 percent of bachelor's degrees. Women's representation in science and engineering declines further at the graduate level and yet again in the transition to the workplace. (AAUW 2010)

Will more women and other under-represented groups come to the STEM field if given sufficient opportunities and encouragement? In the Scandinavian countries (two of which are represented in IRIS), a situation persists which has been termed "the Scandinavian paradox". These societies are among the world's most gender equitable according to the "Gender Inequality Index" in the UN Human Development Report (UNDP 2011), but educational and occupational patterns in these countries are distinctly "gendered", with men clustering in science and technology and women in teaching and health care; see for instance NMCE (2006) and Holt et al. (2006). Thus, there are indications that improving women's STEM participation is not a simple matter of removing inequitable practices.

The project UPGEM (Understanding Puzzles in the Gendered European Map) looked at the differences (in terms of numbers, experiences and outlook) between female researchers in physics in five European countries and described how the career paths of female physicists are conditioned by cultural patterns both within the discipline and in society at large. For instance, the UPGEM researchers compared women in physics in Italy and Denmark and noted that Italy has a higher proportion of female physicists, and also a higher proportion of women who stay on in research after having children. The reasons they suggested for this difference included different paths from school into higher education; differences between societies in how class interacts with gender; different family patterns, and variations in workplace cultures (Hasse and Trentemøller 2008).

The study "Meta-analysis of gender and science research" collected and analysed research on horizontal and vertical gender segregation in research careers, as well as the underlying causes and effects of these two processes. The project's synthesis report (European Commission 2012) stressed "the reality of horizontal and vertical segregation, the existence of pay gaps, stereotypes, and the biased nature of criteria of excellence" and stated that "the key challenge is not to change women but, on the contrary, to change the culture of science and research".

The issue of females in STEM will be discussed in greater depth in a number of chapters in this volume, notably in Chap. 4 and in Part IV.

## Project IRIS

### *Introducing IRIS*

The Science in Society programme under EU's 7th framework programme states on its web pages[2]:

> Science is part of almost every aspect of our lives. Although we rarely think about it, science makes extraordinary things possible. At the flick of a switch, we have light and electricity. When we are ill, science helps us get better. It tells us about the past, helps us with the present, and creates ways to improve our future.
>
> (. . .)
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> With the pace that the world keeps and the speed with which technology advances, an understanding of science is a crucial part of a rounded education. Moreover, Europe needs more scientists and more people skilled in science and technology in order to compete in the global arena. It is, however, becoming increasingly difficult to attract young people to science careers. There is also a clear gender imbalance in science, engineering and technology: while 59 % of graduates in EU universities are female, only 18 % of professors are women.

In response to this challenge, project IRIS was established in 2009 with support from the European Commission's "Science in Society" programme and with the following overall aim:

> The objective of IRIS is to develop knowledge and recommendations informed by evidence on how the participation of young people, women in particular, in STEM higher education may be improved.

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[2] http://ec.europa.eu/research/science-society/, Accessed May 2013.

To approach this overall aim, we have addressed three broad research questions, each with a view to the role of gender:

1. Which priorities, values and experiences are prominent in young people's educational choice processes?
2. How can education, interventions, information and outreach be designed in order to improve young people's participation in STEM higher education?
3. Which factors are important for retaining students in the STEM higher education they have embarked on?

The IRIS consortium consisted of researchers from six academic institutions in five European countries:

- **Norway (co-ordinator):**
  University of Oslo and Norwegian Centre for Science Education
- **United Kingdom:**
  King's College London
  University of Leeds
- **Denmark:**
  University of Copenhagen
- **Italy:**
  Observa – Science in Society
- **Slovenia:**
  Institute for Innovation and Development, University of Ljubljana

## *IRIS Research Activities*

The IRIS project draws on a range of theoretical frameworks in order to address different aspects of young people's educational choice processes and their relationship to STEM. The most important of these are described in Part I of this book (see below).

Data has been collected and analysed within the IRIS project using a variety of quantitative as well as qualitative approaches. A data collection instrument common to all IRIS partners was the questionnaire IRIS Q, which was completed by almost 7,000 first-year STEM students in the five IRIS consortium countries in 2010–2011. The questionnaire was based on the theoretical perspectives adopted and on previous projects, notably the ROSE study (Schreiner and Sjøberg 2007). The questionnaire comprised a total of 65 items (most of them multiple choice; some open-ended) covering school science experiences, sources of inspiration for choice of education, expectations for future job, first experiences as a STEM student, and attitudes to gender equity in STEM. The target population for IRIS Q was first-year STEM students within eight selected disciplines defined through the International Standard Classification of Education (ISCED). IRIS Q may be found in the Appendix, together with details about questionnaire development, target population, data collection etc. Several chapters in this volume use data from IRIS Q.

In addition to the questionnaire, a range of qualitative and quantitative modules contribute to the overall results of project IRIS. These include for instance a combined questionnaire, focus group and individual interview study of the impact of school science curriculum content on students' subject choices in post-compulsory schooling, an interview study of how first-year students make sense of their experiences (with a view to identifying factors of importance for completion), and a study of first-year female STEM students' written narratives ("life stories") of their relationship to STEM and how they came to choose a STEM education. Analyses of students' choice narratives are prominent in several of the qualitative modules.

It should also be mentioned that an international network of *IRIS associated partners* has been established and that several of these have used the IRIS questionnaire to collect data in their respective countries. At the time of writing, only the Australian associated partner has published results (Lyons et al. 2012). This partner is also represented with a chapter (Chap. 10) in the present volume. The IRIS associated partners may in time provide possibilities for wider international comparisons.

## The Structure of this Book

The book's **Part I** describes the most central theoretical frameworks that have been employed in IRIS. The Eccles et al. expectancy-value model of achievement-related choices (Eccles and Wigfield 2002; Eccles et al. 1983) offers a comprehensive framework for analysing the various factors influencing young people's considerations concerning educational choice. Another theoretical perspective informing the work in IRIS is sociological theories about youth in late modern societies, particularly the focus on education as a component of young people's identity development. Expectancy-value theory and perspectives on late modern youth are described in Chap. 2. Choice of education is a dynamic process (Cleaves 2005) in which young people constantly negotiate their choice in interaction with their surroundings, developing a narrative describing their choice to themselves and to their "significant others". The narrative approach to studying educational choice, which is detailed in Chap. 3, focuses on identity and emphasises choice as a process rather than as a decision taken at one particular point in time. Finally, project IRIS employs feminist perspectives (Haraway 1991; Harding 1986; Schiebinger 1999) on the processes that contribute to women's continued low participation in STEM. Such perspectives are presented in Chap. 4.

In **Part II** of this book, a range of results concerning students' participation in STEM and factors of importance for their educational choice are presented, based on results produced within IRIS as well as in related projects. Chapter 5 sums up previous research related to STEM attitudes, interests and participation.

Chapter 6 is an invited chapter from researchers in the ASPIRES project, which looks at how gender and identity shape young adolescents' science aspirations. In Chap. 7, the role of the school science curriculum in students' educational choice trajectories is addressed, whereas Chap. 8 examines the role of *place* in students' educational decision-making process. Short narratives where first-year university students describe the background for their educational choice are analysed in Chap. 9 with attention to how they describe their development of interest in STEM. Chapter 10 is again an invited chapter from one of the IRIS associated partners and adopts a systemic perspective on educational choices, examining how educational reforms contribute to shaping STEM participation in Australia. Chapter 11, building on questionnaire data from Slovenia, examines factors influencing STEM students' decision to pursue a PhD, whereas Chap. 12 looks at how three different recruitment and outreach efforts in Norway are received by their target groups and, based on these results, discusses success factors for initiatives aimed at improving STEM participation.

The book's **Part III** treats the issue of students' completion, or non-completion, of the STEM higher education they have embarked on. The first chapter in this part, Chap. 13, presents an overview of central research and theoretical approaches to this issue, with focus on Tinto's model and the work of Seymour and Hewitt. Chapter 14 builds on an extensive quantitative data material to track Danish students' movement from upper secondary school into (STEM) higher education, and specifically addresses background factors relating to completion or non-completion. In Chap. 15, focus is on individual students' meeting with STEM higher education and how the teaching environment influences their social and academic integration. Data collected using the IRIS Q questionnaire in Italy forms the basis of Chap. 16, which treats educational choice motivations as well as first-year experiences of STEM students with a view to factors that promote completion.

Although gender and STEM is a theme running through many of the chapters, **Part IV** of this book specifically shows how feminist perspectives may be used to analyse and understand female students' relationship to, and participation in, STEM. Chapter 17 displays nuances and variations in female STEM students' relationship to their chosen education and warns against communicating broad generalisations about STEM participation patterns based on gender/sex. In Chap. 18, Italian STEM students' short narratives about their educational choice are analysed in a similar manner to Chap. 9, but with particular attention to gendered patterns in the responses. Students' negotiation of their identity as minority-gender participants in first-year STEM educational environments is described from a Danish setting in Chap. 19, whereas Chap. 20, again from an Italian setting, employs a feminist interpretative framework to analyse the views that students express about gender and STEM.

The final part of the book, **Part V**, sums up theoretical, empirical and methodological outcomes and experiences of the IRIS project and presents insights that may be of importance for understanding, and improving, STEM participation. In Chap. 21, focus is on what the studies presented in this book have contributed to our understanding of students' educational choices and of how these choices may be approached through research. Chapter 22 presents insights that may be of use to stakeholders aiming to improve STEM participation through the educational system or through information, outreach, campaigns or other measures.

The various approaches described in the chapters of this book have yielded multifaceted results and interpretations concerning STEM participation. The book constitutes the main outcome of the IRIS project. However, IRIS data, perspectives and analyses have been, and will continue to be, used in a number of research articles, conference presentations, policy documents, and other dissemination arenas.

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