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IDENTITIES

Enlightening
Interdisciplinarity
in STEM
for Teaching

Recommendations for policymakers to promote interdisciplinarity and innovate prospective teachers education for STEM challenges

- Intellectual Output O6 -

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Introduction

This report was developed in the context of the ERASMUS+ project IDENTITIES which aimed το build innovative and transferable teaching modules and courses to be used in contexts of pre-service teacher education (e.g. curricula in Physics Education, Mathematics Education or Computer Science Education within Master's degree courses). The central theme of the modules is interdisciplinarity among STEM disciplines, with a focus on the links and interweaving between physics, mathematics and computer science. Specifically, the modules were constructed to provide prospective teachers with professional skills to be used in the design and implementation of teaching activities for upper secondary schools.

These recommendations, as part of the sixth Intellectual Output of the project, constitute the result of a meta-analysis of all the Intellectual Outputs that were produced in IDENTITIES. The formulation of the recommendations was based on an open-ended questionnaire distributed to all partners, in order for them to describe their institutional and/or national contexts of teacher education, professional development and STEM education research, the obstacles faced and possible strategies to address them.

The recommendations are organised into three chapters. The first chapter is addressed to institutional policymakers in charge of organising, offering, and managing programmes of pre-service teacher education at the local and national levels. The second chapter is addressed to institutional policymakers in charge to support the creation of interdisciplinary research groups at the local and national levels. Finally, the third chapter is addressed to research policymakers in charge of supporting STEM professional development programmes.

Each chapter presents (i) the good practices experienced in different institutional and national contexts regarding each case, (ii) the barriers and wider constraints as well as the key strategies to address them, (iii) the contribution of the outcomes of the IDENTITIES project in each case and (iv) the final recommendations.

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Chapter 1: Recommendations for institutional policymakers responsible for pre–service teacher education programmes (local & national levels)

Good practices

The good practices that have been recognised or implemented by the IDENTITIES project partners regarding the creation of interdisciplinary contexts in pre-service teacher education programmes refer to four different levels:

I. Undergraduate courses
II. Master programmes
III. PhD programmes
IV. Summer schools, winter schools and/ or webinars for pre-service teachers in the context of national and European projects

As far as the undergraduate courses are concerned, IDENTITIES project partners highlight the existence of undergraduate courses for STEM education, especially in preschool and primary education departments. These courses are mainly focused on Science, Mathematics and Technology Education and aim at equipping pre-service teachers with the necessary interdisciplinary knowledge and skills for supporting STEM teaching as future teachers. These courses are usually offered and shared by educators from different disciplines (e.g. science, mathematics, science education, mathematics education etc.).
Regarding the Master's programmes, IDENTITIES project partners acknowledge the existence of curriculums for Physics or Mathematics education in the Master's programmes of Physics or Mathematics respectively. These Master's programmes are usually addressed to pre-service teachers of secondary education and include courses both on disciplinary contents (mathematics, physics, chemistry, biology etc.) and on the didactics of each discipline. In addition, they usually include non–mandatory courses on the History of Science, Philosophy of Science, pedagogy, psychology etc. Moreover, the master courses in science communication that are offered in the partners' institutions are also considered to be fruitful contexts for interdisciplinary approaches.
At the PhD programmes level, IDENTITIES project partners highlight the joint programmes in Science, Mathematics and/or Engineering Education which aim at forming researchers with an international level of competency in STEM education.
Finally, the summer schools, winter schools and/or webinars for pre-service teachers that take place in the context of national or European projects support the creation of interdisciplinary groups where university students, PhD students, pre and in–service teachers, educators, science communicators, STEM scientists and researchers collaborate and communicate. These projects usually focus on STEM advanced topics which are intrinsically interdisciplinary and try to define how these frontiers topics can impact STEM teaching.

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Key Strategies & Barriers

In order for the aforementioned good practices for the development of interdisciplinary pre–service teachers' training programmes to be implemented in the countries of partner institutions, specific key strategies are employed. These key strategies refer to four axes:

I. The creation of collaborative settings among experts and peers of different disciplines and backgrounds
II. The connection and collaboration of pre-service teachers with the school contexts
III. The employment of specific teaching practices
IV. The alignment with national and European educational reforms.

In particular, the interaction, communication and collaboration between both instructors and peers with different disciplinary expertise, backgrounds and experiences seem to be of great importance for the development of interdisciplinary contexts in pre-service teacher education programmes. This collaboration is considered to be the first prerequisite for the co-design of evidence-based curriculums and teaching materials as well as for co-teaching processes to be employed.

In line with the key strategy of creating collaborative settings among experts and peers of different disciplinary backgrounds, IDENTITIES project partners find constructive for the development of interdisciplinary contexts in the pre-service teacher training programmes the interaction of pre-service teachers with the real school contexts and in-service teacher professional development programmes. Moreover, it is considered of great importance the connection of pre-service teacher education with researchers in different disciplinary (e.g. physics, chemistry, biology, mathematics etc.) education.

In addition, the IDENTITIES project partners highlight the importance of implementing specific teaching practices and approaches during pre-service teachers' training courses such as a. the inquiry-based learning approach, b. problem-solving in real-world contexts, themes and problems and c. the engagement with STEM advanced topics that are intrinsically interdisciplinary. The aforementioned practices can motivate pre-service teachers and support the development of their 21st – century skills.

Finally, it is considered that the development of national normative acting based on the European educational curricular reforms can provide incentives to both the institutions and teacher educators for creating a new professional profile of STEM teachers.

Despite the aforementioned key strategies that have been used and implemented in the IDENTITIES partners' countries, the partner institutions have also encountered some barriers that limited the implementation of interdisciplinary pre-service teacher training programmes. These barriers mainly revolve around two axes:

I. The disciplinary-based departments, curricula and programmes
II. The lack of recognition of the expertise of researchers in STEM education

Regarding the first barrier of the disciplinary-based departments, curricula and programmes, the IDENTITIES project partners highlight the fact that most of the university programmes are mono–disciplinary or multidisciplinary. Thus, the different disciplines are taught in separate courses, something that consequently leads to the development of mono–disciplinary identities and attitudes. Additionally, in these disciplinary–based departments, usually, courses for STEM education are conceived as "extra–curricula" and

are optional. Moreover, the disciplinary–based departments and their institutional organisation restrict collaborations both among disciplinary scholars and among disciplinary scholars and the educational community.
As far as the second barrier in developing interdisciplinary contexts in pre–service teacher education programmes is concerned, the IDENTITIES project partners emphasise the difficulty in recognizing STEM education researchers' expertise and competencies within the disciplinary–based departments. This lack of recognition usually contributes to university students' demotivation of being involved in STEM education courses and master programmes.
The aforementioned barriers and ideas limit both the understanding of the rationale and the place of interdisciplinary education in disciplinary–based departments while at the same time restricting the collaborations among disciplinary scholars and the educational community to plan courses, master and PhD programmes in STEM education.

The role of the IDENTITIES project

The IDENTITIES project's main goal is to design novel teaching approaches on interdisciplinarity in the context of pre-service teacher education. Hence, the results of the IDENTITIES project give insights into how we can inform pre-service training programmes in order to be more interdisciplinary.
At first, the main output of the IDENTITIES project is eight modules for pre–service teachers (see Intellectual Outputs 2 & 3, https://identitiesproject.eu/modules/, https://identitiesproject.eu/identities-final-intellectual-outputs/) which aim at highlighting the interdisciplinary potential of a given topic as well as at making use of boundary zones for teaching and learning. These modules can be used in the context of pre–service teachers' training courses as they deal with both curricular and STEM advanced topics. In addition, during the IDENTITIES project many learning teaching training activities took place - both in face-to-face and online mode (for more details see Intellectual Output O5 https://identitiesproject.eu/identities-final-intellectual-outputs/) – by engaging pre–service teachers with diverse backgrounds (e.g. physics, mathematics, computer science). In particular, two international summer schools for pre–service teachers, local training courses, workshops etc. were carried out during the IDENTITIES project. These implementations can work as exemplar settings for interdisciplinary teaching and can be followed or further elaborated by other institutions.
Moreover, design principles for developing teaching modules that highlight interdisciplinarity was developed, tested and proposed by the IDENTITIES partnership. Particularly, the project implemented the Study and Research Paths for Teacher Education and adopted it in order to design and develop teaching modules for preservice teacher training. Therefore, the project provides specific methodological guidelines for developing teaching modules that emphasise integrated STEM instruction.
Additionally, the framework that was developed and employed by the IDENTITIES project partners can provide valuable tools for teacher educators to approach interdisciplinarity in their courses (for more details see Intellectual Output 4

https://identitiesproject.eu/identities-final-intellectual-outputs/). In particular, the frameworks of a. interdisciplinary taxonomy, b. boundary zones and objects, c. boundary-crossing mechanisms, d. epistemological and linguistic activators were re-formulated in the context of the IDENTITIES project and can work as powerful tools to guide, orient and support the design and the implementation of interdisciplinary teaching activities. Finally, it is important to emphasise the fact that in the IDENTITIES approach to interdisciplinarity, the role of disciplines and their epistemological identities remain very crucial.

Final conclusions as recommendations

To support the development of interdisciplinary contexts in pre-service teacher training programmes, institutional policymakers should consider:

- The creation of spaces and institutional contexts that do not belong to any disciplinary context. This can give the opportunity of developing new professional profiles and identities that are based on interdisciplinarity.
- The design principles of developing interdisciplinary modules, based on cross-national and cross-departmental design and implementation practices proposed by the project.
- The promotion of a “new way of thinking” regarding STEM education researchers and their position in disciplinary–based departments. This cultural change will support the collaborations among scholars of different expertise and the overcoming of the “binary perspective” of disciplinarity vs interdisciplinarity.

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Chapter 2: Recommendations for Institutional policymakers responsible for the creation of interdisciplinary research groups (local & national levels)

Good practices

The good practices experienced by partners enabling the establishment of interdisciplinary STEM education research groups at local and national levels revolved around three main axes:

I. national research projects,
II. post-graduate / PhD programmes, and
III. cross-departmental collaborations within the institutions.

As regards the national research projects, IDENTITIES project partners highlight the opportunities for creating interdisciplinary STEM education research groups offered by their participation in national research programmes that focus on enhancing the provided education at the school and university levels. These research programmes aimed at the design, implementation and analysis of interdisciplinary study and research paths, involving teams of researchers-teachers from different S-T-E-M specialities.

Partners also acknowledge the interdepartmental post-graduate and/or PhD programmes as valuable for strengthening the connections among STEM education researchers from different specialities. Particularly, post-graduate and/or PhD programmes on (aspects of) STEM education that are provided jointly by S-T-E-M and education departments within the institutions and are addressed to both primary and secondary school prospective teachers constitute a fertile ground for establishing interdisciplinary research groups.

Finally, the recruitment of researchers and teacher educators with special qualifications or the professional development of the current research staff of the institutions with a goal to design and implement new interdisciplinary curricula and develop and sustain interdisciplinary research groups constitutes a more direct way to enhance interdisciplinary collaborations that partner institutions follow.

Key Strategies & Barriers

The strategies followed in order to effectively create and manage interdisciplinary STEM Education research groups are of great importance in this process in order to describe the contexts that allow this kind of collaboration. These key strategies are employed either by individual institutions or more centrally.

At the institutional/local level, the STEM education research groups included researchers with diverse expertise and experience in STEM-related career positions who had incentives

to collaborate (eg. formulation of communities of practice with shared goals). Moreover, in these research groups participated (i) both experienced and novice researchers in order to develop and distribute leadership among the members of the research community and (ii) researchers from underrepresented groups (gender, race, language etc) in order to empower STEM in a more equitable manner.
At the national level, partner institutions had the opportunity to participate in these STEM education research groups within the context of governance's or national research agency's support of groups consisting of researchers from different backgrounds and expertise and surveillance in the recruitment actions of researchers. Additionally, calls for new research projects that favoured this kind of collaboration were announced as well as curricular reforms towards STEM education from the prism of different disciplines.

On the other hand partner institutions also experience barriers in the formulation and functioning of such interdisciplinary STEM education research groups. These difficulties had mostly to do with

I. the little support from Departments and Academic Governance to disciplinary didactics,
II. the shortage of communication channels among different departments,
III. the lack of common culture among different didactical traditions, and
IV. the lack of governmental support.

Particularly, as regards the little support from Departments and Academic Governance to disciplinary didactics, the gradual diminution of courses of disciplinary didactics and their retreat in departments of Education has led to the dissociation of scholarly communities (chemists, mathematicians, physicists etc.) from the training of future teachers.
This marginalisation also has an impact on the communication among the researchers of the different departments. In many contexts, a shortage of communication channels and respective supportive environments is noted that delimits cross-departmental collaborations. This lack of interaction has resulted in more "close" traditions in disciplinary didactics, and in different frameworks and research approaches that render the intersection of these frameworks (that is needed for the achievement of a common understanding of what is STEM) even more complicated.
Finally, at the national level, the lack of systematic governmental support either in terms of research funds for formulating STEM education research groups or for monitoring their functioning does not form the conditions for their uninterrupted operation.

The role of the IDENTITIES project

The IDENTITIES Erasmus+ project gave prominence to many useful practices regarding the operation of STEM education research groups.
At first, the IDENTITIES project offered a context for collaborating researchers in didactics of different disciplines. It has allowed us to "build" a common understanding of interdisciplinarity through the lenses of different disciplines and a common framework/ culture to approach interdisciplinarity in the design and in the analysis of disciplinary and interdisciplinary practice. This framework has provided different tools that have been

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re-formulated in the context of the project: boundary zones and objects, boundary-crossing mechanisms, and epistemological and linguistic activators, among others. In order to achieve this, researchers in didactics of a scientific discipline or in STEM education continuously exchanged perspectives to clarify their own and contribute to the development of a common understanding.
Moreover, the IDENTITIES project constituted a context for education researchers of different disciplines to compare and agree on methodologies concerning teacher education for interdisciplinarity, as well as guidelines on developing STEM contexts/ modules. The shared methodology to rethink and design teacher education modules has helped the research groups involved in the project to make explicit, compare and disseminate research (implicit) tools for the epistemological and didactical questioning of interdisciplinarity (see Intellectual Output 4 https://identitiesproject.eu/identities-final-intellectual-outputs/).
The scientific results of the interdisciplinary educational research and STEM education carried out within the project (see Intellectual Outputs 2 & 3, https://identitiesproject.eu/modules/, https://identitiesproject.eu/identities-final-intellectual-outputs/) can be disseminated in a disciplinary-based context (conferences and summer school for PhD students in Mathematics Education, Physics Education etc.) highlighting and questioning the boundaries between disciplines, but also clarifying the role played by the disciplines in such a process. This dissemination can lead to encouraging a process of "recognition" of the relevance of such interdisciplinary research approaches to issues posed within the disciplinary communities, which hopefully will result in an increased value of interdisciplinary and STEM education research (see Intellectual Output 4 https://identitiesproject.eu/identities-final-intellectual-outputs/).
Finally, at a local level, the IDENTITIES project provided the "authority" and the validity of a European project in order to influence governance.

Final conclusions as recommendations

To foster interdisciplinary research groups, institutional policymakers should consider:

- Developing spaces for the establishment of communication channels among education researchers of different disciplines. These environments should take into consideration the similarities and differences among diverse S-T-E-M communities and disciplinary practices. Furthermore, these environments should ensure circumstances suitable for collaboration and exchange among researchers from different departments, in order to formulate a ground upon which researchers can develop a common culture that is based on interdisciplinarity.
- Establishing a formalised scientific sector for disciplinary didactics in order to bridge the gap between different disciplinary didactic traditions and provide opportunities for interaction and development of common theoretical frameworks. These opportunities could take the form of cross-disciplinary seminars and interdepartmental post-graduate or PhD programmes.

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- Professional development of research staff and recruitment of researchers towards designing and implementing new interdisciplinary curricula. This shared goal can constitute an incentive for education researchers and researchers from disciplinary departments to collaborate, share perspectives and build a common framework to approach interdisciplinarity.

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Chapter 3: Recommendations for research policymakers responsible for STEM professional development programmes (European & national levels)

Good practices

Trying to designate the current state of professional development programmes offered in countries of the IDENTITIES project partner institutions, we focus at first on the good practices related to the interdisciplinary contexts that frame these programmes.

As far as actions for pre-service teachers are concerned, programmes in terms of professional Master's or post-graduate tertiary courses take place in order to recruit and form secondary school teachers. These programmes are spread over disciplinary didactics courses (that are offered by specialisation in a discipline), but also include common courses as psycho-pedagogical, school practicum etc.

Moreover, curricular reforms in primary and secondary school education that include STEM education, also constitute drivers for reforming primary and secondary pre-service teacher education in a respective interdisciplinary STEM direction.

As regards actions for in-service teachers' professional development in STEM education, they are also on the political agenda in many countries but have not yet been realised. However, up to now, good practices may be drawn from research programmes, local or international, on in-service primary and secondary teachers' professional development in STEM education. These projects, apart from introducing theoretical principles of STEM, also engaged teachers in designing and developing STEM teaching materials.

Key Strategies & Barriers

In order for the aforementioned good practices to be established in the countries of partner institutions, specific key strategies were employed. These strategies mainly aimed at formulating suitable contexts for these STEM education professional development programmes to thrive and are revolved around three axes:

I. ensuring collaborative settings,
II. enhancing the development of a STEM teacher professional profile, and
III. wider curricular reforms.

Particularly, promoting the collaboration of teachers with diverse disciplinary backgrounds was of great importance in order to effectively develop and implement interdisciplinary pre-service teacher training programmes. This collaboration was achieved through the participation of teachers in learning groups with shared aims (in specific cases in common

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groups along with academics and experts in the field), discussing and sharing knowledge and practices, as well as reflecting on their teaching practice.
Furthermore, the professional development process assisted teachers to develop Pedagogical Content Knowledge for STEM teaching (by engaging them with problem-solving in real-world contexts, themes and/or problems, assisting them to develop 21st-century skills and implement educational innovations) and therefore recognise cultural, balanced and scientifically strong professional profile in primary and secondary education on STEM.
At the national level, the plans and actions for curricula reforms with specific reference to STEM education as well as the entailed need for reforms in initial and continuous training of teachers also formed a context that contributed to the effectiveness of STEM education professional development programmes.

On the other hand, the interdisciplinary teacher education programmes of the partner institutions have also encountered barriers in their operation that are mainly related to:

I. the deficient understanding of interdisciplinarity by school teachers and teacher educators and of the opportunities it can provide,
II. the monodisciplinary background of teachers,
III. the lack of interaction between universities/STEM education researchers, primary & secondary school institutions and responsibles for curricula reforms,
IV. the limited evaluation of teacher professional development programmes, and
V. limitations in the participation of in-service teachers in these programmes.

To begin with, the perception of interdisciplinarity by teacher educators simply as a fusion of one discipline with another leads to mistakenly characterised “interdisciplinary” practices of providing some “extra courses” from other disciplines in order for pre-service teachers to gain an interdisciplinary view of a given subject. Moreover, teacher educators’ interpretation of interdisciplinarity as something additional to the already huge amount of work that students have to face at school, inevitably intensifies the lack of recognition by the school and university teachers of interdisciplinarity as an opportunity to deeper understand the particular disciplines. This misinterpretation of the interdisciplinarity concept also creates institutional and disciplinary identity tensions among teacher educators and disciplinary science education researchers as regards the needed (inter)disciplinary didactic competencies and knowledge that teachers should be equipped with.
As regards teachers’ background, teachers are trained mostly in a monodisciplinary way, therefore disciplinary barriers coming from their orientation and experience take place. Additionally, limitations due to the time that the professional development programmes take place as well as due to teachers’ low motivation occur. Particularly, in-service teachers are short in having the needed time to participate in professional development programmes and lack funding and resources that could facilitate their participation in such programmes.
Moreover, the frequent changes in the national teacher professional development programmes make it difficult to evaluate their effectiveness after several years of application and therefore even if a program looks successful, in terms of introducing interdisciplinarity, it is difficult to provide evidence for it and of its effectiveness in teachers’ practice.

Finally, barriers to interdisciplinary pre-service teacher development programmes are encountered due to the lack of interaction and operative links between universities and primary & secondary school institutions. This stereotyped dichotomy between theory and practice is due to the low transferability of educational research into school practice given that there do not exist so far specific institutions that would practically interpret and transform the outputs of educational research into teaching practice. This lack reflects weaknesses in the political process regarding (i) the necessary decisions and actions towards the establishment of such institutions and (ii) the overall low level of interaction between researchers in Mathematics and Science Education with politicians and responsibles for curricula reforms.

The role of the IDENTITIES project

The IDENTITIES Erasmus+ project gave prominence to many useful practices regarding STEM professional development programmes.

At first, the IDENTITIES project offered a context for collaborating researchers in didactics of different disciplines. Particularly, it provided a theoretical framework as well as tools and guidelines on how to establish a teacher training program on interdisciplinary subjects where their interdisciplinarity is highlighted and explored (see Intellectual Output 4 https://identitiesproject.eu/identities-final-intellectual-outputs/).

In specific, the IDENTITIES project has adopted and elaborated on theoretical frameworks that can inform teachers' practice and provide guidelines to adopt STEM teaching approaches. In specific, teacher professional development programmes can take examples from the developed IDENTITIES modules for tertiary education (see Intellectual Outputs 2 & 3, https://identitiesproject.eu/modules/, https://identitiesproject.eu/identities-final-intellectual-outputs/), assimilate elements from them, implement and/or further elaborate on them. All the designed modules can be easily adapted to local conditions for pre-service teacher education at secondary, and some, to primary school education.

In addition, the constructs of boundary objects and boundary crossing as well as the epistemological and linguistic activators can inspire professional development program designers in designing and implementing informed STEM professional development programmes for in-service teachers.

Moreover, definitions regarding interdisciplinarity and STEM can establish informed and common communication channels among teacher educators and in-service teachers. Methodological guidelines on designing STEM modules can also assist professional development designers in developing and implementing STEM modules in both contemporary/advanced and curricular topics (see Intellectual Output 4).

Finally, the IDENTITIES project has considered the "institutional" obstacles, difficulties or constraints for interdisciplinarity, derived from scholarly communities, local governments, teacher education programmes, curriculum, traditions of teachers' communities, etc. This has been called the "ecological dimension" of interdisciplinarity, analyzing the conditions

that are necessary and the constraints that can hinder the implementation of interdisciplinarity in real classrooms.

Final conclusions as recommendations

To support STEM professional development programmes, research policymakers should consider:

- Formulating and systematically evaluating professional development programmes for pre-service and in-service teachers that aim at developing a cultural, balanced and scientifically strong profile of teachers that keeps together the different stakeholders, knowledge and competences. Particular focus should be given to the development of teachers' Pedagogical Content Knowledge for STEM teaching.
- Informing the design of professional development programs with the theoretical constructs proposed from the IDENTITIES project that highlight interdisciplinarity, boundary objects, and epistemological and linguistic activators.
- Establishing "intermediate" institutions that render links and interactions between universities and primary & secondary school institutions more easy and fluent and their collaboration productive. These institutions will help to bridge the gap between theory regarding interdisciplinary STEM education (produced in university institutions) and school practice by transforming the outputs of STEM educational research into practical guidelines to adopt STEM teaching approaches.

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Conclusions

The IDENTITIES project as a cross-national and cross-departmental initiative responds to the gap of informed interdisciplinary teaching and learning at the tertiary level, by providing insights and good practices on the design, development and implementation of interdisciplinary teaching modules. In specific, the IDENTITIES project designed teaching modules in both contemporary advanced STEM topics and 'traditional' curriculum topics that highlight interdisciplinarity. The innovative and transferable teaching modules were disseminated in a complete and ready-to-use form, along with teaching materials, examples and hints from their implementation. Hence, the project provided content-specific exemplar modules that can guide the development of STEM modules and can facilitate STEM teaching. Moreover, the project provided theoretical and methodological guidelines for designing teaching modules that highlight interdisciplinary thinking. The developed teaching modules were also tested and evaluated throughout the duration of the project. Additionally, the project revealed barriers from the implementation of the modules at the local and national levels, as well as key strategies to overcome them.

Therefore, the IDENTITIES project provides recommendations as follows:

- Regarding content and topics of teacher training modules, the project recommends the use of both traditional curriculum topics and contemporary advanced STEM topics for interdisciplinary teaching. The project evaluates that there is learning potential in both categories of topics, although the process of highlighting interdisciplinarity differs in each case. In the former, interdisciplinarity should be revealed e.g. by making use of historical and/or philosophical approaches, while in the latter the intrinsic interdisciplinarity should be identified and interconnected with existing disciplinary knowledge.
- Regarding the design methodologies of teacher training modules, the project recommends the use of an adaptation of Study and Research Paths for Teacher Education for STEM teaching. In specific, the pre-service teachers/trainees can experience different phases of interdisciplinary explorers, students and analysts in order to cultivate informed views of interdisciplinarity.
- As concerns the development of interdisciplinary thinking to teachers, the project recommends the use of theoretical constructs such as the metaphors of boundary objects and boundary crossing and the epistemological and linguistic activators for the development of the teaching modules. These constructs can act as 'lenses' that can assist pre-service teachers to perceive and develop interdisciplinary thinking in the modules.
- In relation to research, the project recommends the creation and persistence of interdisciplinary research structures and partnerships of academics from diverse disciplinary backgrounds, traits and experiences in order to foster effective STEM integration, multivoiceness, and diversity in STEM.
- Finally, concerning institutional structure, the project proposes the creation of interdisciplinary spaces (courses, short-termed training, seminars, minor programs) for pre-service and in-service teacher educational settings. Therefore, the existing

contextual barriers and deficits could be overcome more easily and there would be more opportunities for interdisciplinary teaching and learning.