Pedagogical framework, design principles, recommendations, and guidelines for a STEM learning environment design

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Pedagogical Framework, Design Principles, Recommendations and Guidelines
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Introduction

This document presents the pedagogical framework for designing hybrid (virtual, physical, formal, and informal) learning environments (LEs). The pedagogical framework was created as a part of STIMEY (Science Technology Innovation Mathematics Engineering for the Young) project (2016-2019), which is an European Union project financed by Horizon2020, the Framework Programme For Research and Innovation.

The framework consists of

1. **design principles** created based on the theoretical and empirical understanding of teaching and learning,
2. **recommendations and guidelines** for considering these principles in the LE design, and
3. **concrete examples** of how these principles have been considered in the STIMEY LE design and how they can be considered when using the STIMEY LE in teaching and learning.

The special focus is on science, technology, engineering and mathematics (STEM) related studies at primary, lower and upper secondary school levels (10-to-18-year-old learners), and the design of hybrid LEs. Most of the design principles can be, however, applied in the design of any personal, social, virtual, or physical LEs.

We hope that the framework can guide both educators and developers in the LE design, e.g., in the selection of efficient teaching and learning methods, task and activity types, i.e., ways of teaching and learning (how), and of teaching and learning contents (what), particularly in the context of STEM subjects, cross-curricular key competences for lifelong learning, and ICT-enhanced teaching and learning for the target age groups. Instead of passive LE users, educators are here considered as active LE designers, who design both LEs and how they are used.

When designing LEs or teaching and learning sequences, one can choose the most relevant design principles to be considered each time, based, e.g., on the specific learning objectives, instead of trying to keep all principles in mind. Teachers can also choose to focus on specific design principles based on their personal professional development needs, for instance.

Background

The STIMEY project researched and developed a hybrid LE aiming to connect various stakeholders in shared efforts to engage and increase both female and male students’ interest and motivation in STEM education, innovations, and careers from a young age. The key stakeholders in STIMEY are students, teachers, parents, schools, and STEM professionals. STIMEY LE developed during the project consists of the following components:
● **STIMEY Digital Platform** (see Figure 1) for students, teachers, parents, professionals and organizations with features such as
  - course editor for teachers to build lessons and courses (i.e., Missions and Worlds)
  - social media components to connect everyone on the platform (Community, Chat, Discussion, Profile, Wall)
  - e-radio for STEM learning and enjoyment (Radio STIMEY)
  - gamification (Points System)
  - serious games for learning (Lab)
  - e-portfolio feature for students to record and reflect on their learning journey.

● **STIMEY Socially Assistive Robotic Artefacts (STIMEY SARA)** (see Figure 2) for students to use when using the platform, to motivate and support them in their learning.

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**Figure 1** STIMEY platform: Home view and account creation screen for different types of users: Explorer (student), Leader (teacher), Ambassador (parent or STEM professional), Incubator (school)
Researchers of the Finnish Institute for Educational Research at the University of Jyväskylä (Finland) were in charge of the pedagogical framework development closely supported by educational researchers at the University of Macedonia (Greece). Kompetenzzentrum Technik-Diversity-Chancengleichheit E.V., which is a center promoting equal opportunities for women and men and diversity as a principle of success in business, society and technological development based in Germany, was in charge of the development of design principles related to gender inclusion. Representatives of all project partners (the University of Cadiz, Spain; Hochschule Emden/Leer, Germany; Polotsk State University, Belarus; MLS Multimedia AD, Greece; and Baby Radio SL, Spain) also actively collaborated in the work. The pedagogical framework, design principles, recommendations and guidelines is a result of efforts during years 2016-19 consisting of

- a literature review (documentary analysis);

- comparative STEM curriculum analysis in Belarus, Finland, Germany, Greece and Spain;

- focus group 1 (FG1) discussions (participatory co-design): students’, teachers’, directors’, parents’, and STEM professionals’ (total of participants in all countries: n = 132) wishes on teaching, learning, motivation, and assessment, in general, and in relation to cross-curricular skills and STEM subjects, in particular (see Figure 3);

- FG2 discussions with the key stakeholders (total of participants in all countries: n = 137) presenting the results of FG1, confirming their validity, and collecting further feedback in relation to integration of pedagogical design principles into the overall STIMEY LE design;

- FG3 discussions involving 20 experts of local curriculum, STEM, educational policy or educational technology representing all project countries verifying the framework validity, and whose feedback was considered in the final framework version;
● experiences of the use of STIMEY LE in teaching and learning during its piloting (see Figure 4); and

● collaborative work with the STIMEY project’s pedagogical researchers and developers focusing specifically on the platform, social media, e-portfolio, radio, serious games, and robot development.

Special thanks to representatives of key stakeholder groups in all participant countries for their contributions. This work would not have been possible without their insights and input.

For more information about the STIMEY, see: http://promostimey.uca.es

Visit the STIMEY platform at https://stimey.eu

Figure 3 Pictures of FG sessions in STIMEY project countries.
Framework structure

Figure 6 visualises the pedagogical framework and its design principles. The design principles have been divided into the following categories:

1. **General principles**: Pedagogical principles which can be applied generally in the LE design and use.
2. **Cross-curricular skills**: Cross-curricular competencies considered relevant particularly for STIMEY LE design and use.

3. **Ways of teaching and learning**: Pedagogical models and ways of teaching and learning considered essential particularly for the STEM LE design.

4. **Socio-emotional aspects**: Principles referring to aspects that enhance socio-emotional skills, interest, motivation, engagement, and wellbeing.

5. **Educational compatibility**: Assuring that LE is educationally compatible in the local contexts of use.

6. **Gender inclusion**: Assuring that LEs are attractive and functional for all students.

Most of the principles are based on the wishes collected by the key stakeholder groups in all STIMEY project countries during the FG1 sessions. The relevancy of these principles was also confirmed in the FG2 and verified in an expert review during the FG3 sessions. The design principles selected to the framework based on the literature are related to 4. Socio-emotional aspects (“sense of belonging”, “teacher-student and peer relations”, and “home-school and wider community relations”). Also the principles in category 5. Educational compatibility are based on the previous literature. Their importance was also verified in FG3 sessions. Finally, feedback gathered in FG3 led to some modifications such as merging principles “versatility”, “novelty”, and “conventionality” into one principle, and including principles “learning outside the school” as a part of principle “bridging formal, non-formal and informal learning”. Also some principles were renamed (e.g., Creativity -> Creativity and innovation, Project-based learning -> Project-based STEM learning). Further, principle “social and emotional skills” was added to the framework based on the feedback received in the FG3. In relation to 6 Gender inclusion, in FG1, the most frequent wishes were related to gender equality, gender neutrality, gender bias (i.e., preferring one gender), and diversity and cooperation. These aspects were included in the final gender principles created based on the FGs, and literature, which were then confirmed during FG3 and further developed based on the feedback received.
Of the theoretical considerations, the design principles are very much in line with Dewey’s (Dewey, 1907; 1916) educational philosophy viewing learning as **learner-centred, active, experiential, and reflective activity**. Further, they are in line with socio-cultural and socio-constructivist paradigms inspired particularly by the work of Vygostky (1978) viewing **social environments and the mediating artefacts** as essential for learning. Connections can also be found with Bronfenbrenner’s (1979) ecological model viewing **human development taking place in reciprocal interaction with people, objects, and symbols, particularly through proximal processes in an individual’s immediate environment**.
Particularly student-centred pedagogical principles (see O’Neill & McMahon, 2005) have been guiding the framework development. The conceptualisation of student-centred learning is influenced by authors such as Hayward, Dewey, Froebel, Piaget, Rogers, and Knowles (see O’Neill & McMahon, 2005). It appears to relate primarily to the constructivist view emphasizing the importance of places on activity, discovery and independent learning but also cognitive theory highlighting the activity. It also has connections with social constructivist views emphasising the importance of peer interaction in learning. O’Neill and McMahon (2005) view student-centred and teacher-centred learning as a continuum:

- Low level of student choice - High level of student choice,
- Student passive - Student active,
- Power is primarily with teacher - Power primarily with the student.

In the following chapters, we will present pedagogical framework categories and their design principles, recommendations and guidelines, as well as some examples of how these aspects have been considered in the STIMEY LE design and how they can be considered when using the STIMEY LE.

**Introduction - References**


1 General principles

This framework category refers to general design principles which can be applied in the LE design and use. For a more detailed description of the principles, see Mäkelä et al. (2017).

1.1 Connectedness with learners’ experiences

**Pedagogical principle:** Creating connections between learners’ past, present, and future knowledge and authentic experiences.

**Recommendations and guidelines:** Connect learning with personally, culturally, and socially meaningful and relevant problems, and scientific development. Provide authentic contexts where knowledge can be used in real-life and authentic activities, incidents or simulations. Use the e-portfolio for storing, reflecting, and displaying personal experiences (see also 3.8 Reflective learning). For using experiential learning as a method, see 3.4 Learning through experiences.

**Concrete example:** A student who likes to play football is asked to create a simulation with STIMEY Physics Engine (see Figure 7). Based on the simulations, the student can calculate the energy needed to be generated to kick a ball to reach a certain velocity or distance. The student can then write down the results and reflect their connection with their hobby using STIMEY e-portfolio’s Learning Journal (see Figure 8).

![Figure 7 STIMEY Physics Engine](image)

![Figure 8 STIMEY e-portfolio](image)
1.2 Personalisation

**Pedagogical principle:** Considering each student’s competence levels, rhythm, preferences, interests, and special needs.

**Recommendations and guidelines:** Create possibilities to monitor students’ work and provide additional support and guidance for individuals who seem to struggle with learning tasks or who seem to need more challenging tasks. Give opportunities for students to choose ways of working and grouping based on their personal preferences. Provide many different representations, activities and so on as it allows choosing between various options based on own preferences, interests, and competence level (see also 1.5 Versatility in both novel and conventional tools and methods, and 3.11 Multiple Representations).

**Concrete example:** The STIMEY platform provides various STEM-related contents and applications, which students can choose according to personal preferences, interests, and level of understanding. Additionally, a student can choose to be engaged in easier, intermediate or more challenging missions, tasks, etc. facilitating their personal competences and learning rhythm (see Figure 9). Learners can also progress in their own speed. They can highlight and reflect on their personal preferences and experiences on a STIMEY e-portfolio (Figure 8). Teachers and students can personalise scripts for STIMEY SARA robots for every student or student groups with specific needs and interests (Figure 10).

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*Figure 9* STIMEY Search engine  
*Figure 10* STIMEY SARA Customization tool
1.3 Support for teaching and learning

**Pedagogical principle**: Providing support and guidance for the teachers and learners in the LE use.

**Recommendations and guidelines**: Provide both technical and pedagogical instructions for the LE use. Create possibilities to scaffold learning, and to provide feedback as well as tools for structuring and coordinating activities. Use, e.g., peer tutoring between teachers. Also assure that learners know how to contact their teacher for help, when needed.

**Concrete example**: *STIMEY platform* includes clear instructions and examples of the different features of the platform, how to use them, and for what purpose. It is possible to review these instructions when desired. For instance, there is an instructional video and hints for using *STIMEY e-portfolio* (Figure 11). *STIMEY SARA* robots can be programmed to give hints for completing tasks.

![Figure 11 Instructions for the use of STIMEY e-portfolio](image-url)
1.4 Flexibility and adaptability

**Pedagogical principle:** Ensuring that the LE adapts to varied ways of teaching and learning and that there is spatial and temporal flexibility.

**Recommendations and guidelines:** Design flexible and adaptable LEs supporting, e.g., 1.2 Personalisation, 1.5 Versatility in both novel and conventional tools and methods, and modifications based on user’s changing needs and requirements. Assure that the LE is adaptable to different age groups and different educational and socio-cultural contexts (see also 5 Educational compatibility).

**Concrete example:** It is possible to combine the use of STIMEY LE with other learning materials. Teachers can copy and adapt the existing missions and tasks to fit their student groups and different curricular requirements.

1.5 Versatility in both novel and conventional tools and methods

**Pedagogical principle:** Enabling and supporting the versatile use of both novel and conventional tools and methods for learning.

**Recommendations and guidelines:** Combine novel digital LE with conventional tools and methods. Enable use of various digital tools, file formats, apps and links that serve as an open digital LE and assure that they can be used in dynamic interaction with the offline teaching tools and methods (see also 3.11 Multiple representations).

**Concrete example:** Teacher could create a Mission on gravity which utilizes different media explaining the physical phenomenon (text, video, pictures). Teacher could also use STIMEY lab tools such as Physics Engine simulation to demonstrate the topic to students. Students can also test gravity’s effect on different objects by dropping them from a table to get a physical learning experience. Radio STIMEY (Figure 12) allows, for example, using music to create a calm atmosphere to enhance concentration in learning. It is also possible to create podcasts to support learning. STIMEY activities can be combined with the paper textbooks and tests as well as with the experiments in physical laboratories (Figure 13), if so wished.
**Figure 12** Radio STIMEY program and podcast created by users

**Figure 13** Combining digital STIMEY LE with physical experiments

### 1.6 Bridging formal, non-formal and informal LEs

**Pedagogical principle:** Supporting the connections between formal, non-formal, and informal outside the school LEs.

**Recommendations and guidelines:** Allow bridging non-formal LE (e.g., visit to a science centre) and informal learning (e.g., games as an extra activity, hobbies) with formal school learning. Enable the use of the platform on mobile devices. Use e-portfolio to save evidence of different types of meaningful out-of-school learning experiences.
**Concrete example:** Teacher may contact local STIMEY *ambassador* (i.e., STEM professionals connected to STIMEY LE) to organise a field visit to a local observatory. Students document the visit by taking photos and videos and upload the media to the platform, when back at school and produce a report of what they learned during the visit. Because STIMEY platform can be accessed anytime by the students, students can review the learning material anytime they need to. It is possible for the students to view their tasks and upload content to the platform from their mobile devices while they are observing different real-life phenomena outside the classroom.

**General principles - Further reading**

**Introduction**


**1.1 Connectedness with learners’ experiences**


Novak, J. D. (2002), Meaningful learning: The essential factor for conceptual change in limited or inappropriate propositional hierarchies leading to empowerment of learners. Science Education, 86, 548-571.


**1.2 Personalisation**


**1.3 Support for teaching and learning**


**1.4 Flexibility and adaptability**


1.5 Versatility in both novel and conventional tools and methods


1.6 Bridging formal, non-formal and informal LEs


2 Cross-curricular skills

Cross-curricular skills selected for the framework represent competences considered relevant particularly for STIMEY LE. These cross-curricular skills are typically included in frameworks defining Key competences for lifelong learning (European Commission, 2018) or 21st century skills (see e.g., Binkley et. al 2012).

2.1 Professional skills

**Pedagogical principle:** Connecting learning with the professional life and STEM professionals.

**Recommendations and guidelines:** Provide authentic contexts and simulations that reflect the way knowledge will be used in professional life. Create connections with STEM professionals by enabling virtual or physical visits from professionals to schools and visits to their workplaces.

**Concrete example:** Professionals can sign in to STIMEY as Ambassadors. Student’s tasks can be reviewed by a representative of a company that operates in a field where the studied theme is relevant. Students can choose a profession and career they want to follow in the STIMEY serious games (Figures 14, 15 and 16). Radio STIMEY provides program related to STEM professions (Figure 12).

2.2 Entrepreneurial skills

**Pedagogical principle:** Fostering entrepreneurial skills and the creation of both profit and non-profit opportunities.

**Recommendations and guidelines:** Support learners in taking initiative, turning ideas into action solving problems that arise unexpectedly, adjusting to novel circumstances, being perseverant, and coping with uncertainty (see also 2.3 Creativity and innovation). Promote healthy competition and understanding of how to manage a business.

**Concrete example:** STIMEY Issue market (entrepreneurial tournaments) can be used for practicing and promoting entrepreneurial skills (Figure 14). Students can play serious games like STIMEY Business Incubator (Figure 15) for simulating the complex process of developing and making a successful startup; or STIMEY Rocket Scientist (see Figure 16) for experiencing the complexity and exciting details of managing their time while pursuing a STEM career in an innovative field of research and application.
2.3 Creativity and innovation

**Pedagogical principle:** including activities that foster creativity and innovation.

**Recommendations and guidelines:** Foster creativity by encouraging learners to combine multiple different tools (e.g. posters, videos, images, various scientific and creative models) to present their ideas and to search various sources of verified information to enrich their learning content. Encourage them to try complex pedagogical approaches to go beyond the subject-based knowledge and combine various perspectives provided by e.g. Science, Technology, Engineering, Arts and Mathematics (STEAM). Implement various ways of working (e.g. individual and collaborative problem-solving, inquiry-based methods) in the learning process to explore the studied phenomenon or topic from multiple aspects (see 1.5 Versatility in both novel and conventional tools and methods). The LE should allow students to efficiently integrate innovative technologies, solutions and contents and share them with each other during the learning process.

**Concrete example:** By using the** STIMEY e-portfolio, students can track various learning paths and compare different learning outcomes to discuss their efficiency. They can also identify creative and innovative ways and previously unknown results of learning. For instance, task could be given to small groups where they have to produce a multimedia story in which they demonstrate their learning on the given subject and present it to the rest of the class and store it in their e-portfolio. Digital storytelling can contribute to implement imagination in the creative learning process. Digital storytelling can also become a tool for creative assessment of what has been learnt.
2.4 Sustainability

**Pedagogical principle:** Promoting skills related to social, economical and environmental sustainability.

**Recommendations and guidelines:** Encourage inclusion of issues related to social (e.g., how to create democratic communities), economical (e.g., long-term economic planning) and environmental (e.g., reducing waste and pollution) sustainability in learning contents and resources.

**Concrete example:** Creating a **STIMEY Mission** where the objective is to enhance the classroom use of resources by studying how much paper, plastic, etc. is wasted and what changes would increase sustainability. A mission on Warka towers (see Figure 17) demonstrates how water can be collected in countries with lack of water. Working with **STIMEY SARA** robots foster skills needed in future societies and prepares them to continuously increasing use of robotics.

![Figure 17 Screenshots of Warka Water tower STIMEY Mission](image-url)
2 Cross-curricular skills - Further reading

Introduction


2.1 Professional skills


2.2 Entrepreneurial skills


2.3 Creativity and innovation


2.4 Sustainability


3 Ways of teaching and learning

This framework category refers to pedagogical models and ways of teaching and learning which are considered essential particularly for the STEM LE design. The principles in this category consider, on one hand, the role of educators in support of learning, and on the other hand, learners’ active agency in learning. For a more detailed description of the principles, see Mäkelä et al., 2017.

3.1 Active knowledge construction

**Pedagogical principle:** Supporting learners’ knowledge construction instead of teacher-centered memorization.

**Recommendations and guidelines:** Support learners in tasks related to, e.g., selecting, evaluating and interpreting, categorising and relating, rephrasing and summarising information. Employ strategies such as brainstorming and mind maps to facilitate students in knowledge construction.

**Concrete example:** Learners are asked to read a scientific text and summarise it in their own words using STIMEY e-portfolio and its Learning Journal. They use a mindmap to structure the information. Then they publish their texts in Community and evaluate and comment on their peers’ summaries. It is also possible to construct and share knowledge by creating podcasts for Radio STIMEY (Figure 18).

![Figure 18 Proposing content for Radio STIMEY podcasts](image-url)
3.2 Participation and involvement

**Pedagogical principle:** Fostering learners’ participation, involvement and self-expression.

**Recommendations and guidelines:** Foster learners’ active participation, involvement, and self-expression, e.g., through interactive tasks and social media tools. Give them opportunities to influence in the decision making.

**Concrete example:** Creating a *STIMEY mission* that addresses mathematics in everyday life. Students are given a task to demonstrate a topic they wish in a way they desire utilizing the opportunities provided by the *STIMEY platform*. Teacher guides in the choosing of the topic and as students progress, they give feedback to one another and improve their work based on the feedback. Social media tools such as *STIMEY Communities* are used to participate in sharing ideas and being involved in the participatory decision making related to their learning. Working with *STIMEY SARA* robots prepare learners to the future societal participation and involvement including the use of robotics. *STIMEY SARA* can also be used to encourage learners to take part in discussions.

3.3 Collaborative learning

**Pedagogical principle:** Acquiring knowledge and skills as a result of collaboration and knowledge sharing.

**Recommendations and guidelines:** Foster collaboration and collaborative knowledge construction and sharing (see also 3.1 Active knowledge construction). Enable, team, group, and pair work and support knowledge, tool and skill sharing in the LEs for solving problems, completing tasks, or creating products. Vary settings (homogeneous and heterogeneous groups, mixed gender groups, girls and boys separately, etc.).

**Concrete example:** Students can collaborate together in a *STIMEY platform* within a *Mission* by using the *Discussion* or *Community* features and provide their solutions, or feedback on provided solutions (Figure 19). They can also create or join communities or group chat to discuss mission topics with their peers privately and work on assignments together. Also *STIMEY e-portfolio* can be used for peer assessment (see also 5.7 Assessment system and practices).
3.4 Learning through experiences

**Pedagogical principle:** Employing everyday or real-life experiences and learning by doing.

**Recommendations and guidelines:** Find ways to connect learning with real-life experiences and phenomenon with both physical and virtual tools such as simulations. Use experiential learning methods consisting of “hands-on learning” and “learning through reflection on doing”. For connecting learning with learners’ personal experiences, see 1.1 Connectedness with learners’ experiences.

**Concrete example:** Taking advantage of many existing physical building kits that can be used to demonstrate different phenomena. STIMEY platform’s integrated virtual applications such as STIMEY Chemistry Engine (Figure 20) create experiences that are connected to real life. For instance, Molecule builder (Figure 20) can be used together with the physical molecule scale model construction (See also 1.5 Versatile both novel and conventional tools and methods). Examples of real-life phenomena can also be included in STIMEY Missions.
3.5 Experiments and inquiry

**Pedagogical principle:** Integrating problem- and inquiry-based learning that foster experiments and discoveries.

**Recommendations and guidelines:** Model processes of a scientific inquiry (e.g., setting up research questions, constructing working theories, critical evaluation, searching deepening knowledge). Experiment and discover matters in science labs (virtual or physical).

**Concrete example:** Teachers can use a template created for inquiry-based learning when creating a Mission on the STIMEY platform (Figure 21). STIMEY Physics Engine (see Figure 7) and Chemistry Engine (see Figure 20) can be used as virtual labs to carry out various scientific experiments and demonstrations.
3.6 Project-based STEM learning

**Pedagogical principle:** Learning science, technology, engineering, and mathematics in a cross-curricular project aiming at solving a real-world problem.

**Recommendations and guidelines:** Support project- and phenomenon-based learning to make connections between different subjects, to understand complexity, and to gain knowledge applicable in real-life situations. Integrate STEM (and STEAM) in teaching of other subjects. Include aspects such as modeling and reflection on the nature of science and technology in STEM learning. Employ interdisciplinary topics such as communication, medicine, mobility, environment, and food, which promote interest of those who are not STEM enthusiastic per se.

**Concrete example:** The STIMEY LE includes several innovative STEM learning tools (e.g. Chemistry and Physics engines, STEM-related serious games) and supports to link these various different sources in the same learning material, which can be processed collaboratively during the learning process. For instance, a Mission that concentrates on thunderstorms can include tasks from geography (where thunderstorms occur most frequently and why), physics (explain the physics behind lightning), arts (create a visualization of a lightning or thunderstorm). Concrete project outcomes can be presented and shared in Stimey Communities (Figure 22).

![Figure 22 Example of a STIMEY community](image-url)
3.7 Self-regulated learning

**Pedagogical principle:** Enabling autonomous work and awareness of one’s own progress.

**Recommendations and guidelines:** Provide learning material which is accessible at all times to enhance autonomous work. Create tools for tracking own progress and support also emotional self-regulation including, e.g., coping with frustration or failure (see also 4.1 Social and emotional skills).

**Concrete example:** *STIMEY Missions*, which include clear instructions on how to move on, can be studied autonomously. Gamification points and rewards as well as a chart for daily goals (Figure 23) in STIMEY LE support tracking one’s learning. The three points system of knowledge, social skills, and creativity, can give the student’s a quick overview to reflect on which of these learning skills he/she must further improve and which activities to focus on to do so. Further, organising *STIMEY e-portfolio* (see Figure 8) based on one’s work can be used to support self-regulation.

![Figure 23 STIMEY chart for daily goals](chart)

3.8 Reflective learning

**Pedagogical principle:** Encouraging reflective approach, deep thinking, and understanding.

**Recommendations and guidelines:** Foster self-evaluation and peer evaluation in addition to utilizing tools such as an e-portfolio in reflection of one’s own work (see also 5.7 Assessment system and practices).

**Concrete example:** *STIMEY e-portfolio* (see Figure 8) can be used to support reflection on one’s work, e.g., by providing reflective questions to be responded using e-portfolio. In some tasks, also
evaluation could be done by other students instead of the teacher by using the e-portfolio tool. *STIMEY SARA* robots can be programmed to provide feedback to trigger reflection.

### 3.9 ICT-enhanced learning

**Pedagogical principle:** Utilizing ICT tools to foster learning with technology and learning about technology.

**Recommendations and guidelines:** Integrate various types of ICT solutions to the LE to facilitate learning. Use challenges with the technology as an opportunity to solve problems and learn about technology.

**Concrete example:** STIMEY LE offers varied ways of using ICT in learning. For instance, the use of *Communities* and *Chat*, etc. support learning of 21st century digital skills including social media skills. *Mental calculator* as well as *Physics and Chemistry engines* can be used in STEM learning. STIMEY is also integrated to external tools such as Khan Academy and materials available in Scientix (Figure 24). *STIMEY SARA* robots are technological tools which will enhance both learning with and about technology (e.g., basics of coding, programming and robotics).

![STIMEY search in Scientix and use of Khan Academy browser for inserting videos.](image)

### 3.10 Games and gamification

**Pedagogical principle:** Using games and gamified elements in learning.

**Recommendations and guidelines:** Use games and gamification (e.g., badges, levels) to facilitate and engage students in their learning. Create LEs which include elements such as stories, imagination, challenges, simulations, and rewards.

**Concrete example:** STIMEY serious games entail, for instance, a *Rocket Scientist* (see Figure 16), which is a playful simulation of the management of the life of a STEM-researcher and *Business Incubator* (see Figure 15), which is a simulation of managing a startup company. Gamification is
offered through points, which can be achieved by completing different kinds of activities on the platform. (see Figure 25).

![STIMEY Achievements and badges](image)

**Figure 25** STIMEY Achievements and badges

### 3.11 Multiple representations

**Pedagogical principle:** Presenting information through both digital and non-digital media and using various types of representations.

**Recommendations and guidelines:** Use (e.g., video, audio, images, diagrams) of both digital and non-digital media. Support understanding, interpreting and relating different representations. Allow storing digital and non-digital but posteriorly digitalised representations.

**Concrete example:** Creating a **STIMEY mission** which is about mixing different liquids. The process can be demonstrated in a real-world experiment. Students record the experiment and add digital information to the video and share the video on the platform. **Radio STIMEY** podcasts can be created for providing instructions and examples of the phenomenon.

### 3 Ways of teaching and learning - Further reading

**Introduction**


**3.1 Active knowledge construction**


### 3.2 Participation and involvement


### 3.3 Collaborative learning


### 3.4 Learning through experiences


### 3.5 Experiments and inquiry


### 3.6 Project-based STEM learning


3.7 Self-regulated learning


3.8 Reflective learning


3.9 ICT-enhanced learning


3.10 Games and gamification


3.11 Multiple representations

4 Socio-emotional aspects

The design principles of this category refer to aspects that enhance socio-emotional skills, interest, motivation, engagement, and wellbeing. For a more detailed description of the principles, see Mäkelä et al., 2017.

4.1 Social and emotional skills

Pedagogical principle: Exercising social and emotional skills.

Recommendations and guidelines: Support learning emotional and social awareness, emotional and behavioural regulation, empathy, team and relationship skills. Create space for expressing emotions and for caring and empathetic words. Remind of the importance of thinking before expressing emotions in shared forums. Support team building between learners with different characteristics and skills.

Concrete example: Use Discussions and Communities in STIMEY platform to form groups, share one’s emotions and to provide constructive feedback. Interaction with STIMEY SARA robots will support learners’ social skills. For instance, STIMEY SARA can be used to giving learners turns when working as a group. STIMEY SARA can be also programmed to be a mediator between students. It can encourage and offer emotional support to students and help to develop empathy.

4.2 Joy of learning

Pedagogical principle: Creating feelings of enjoyment, accomplishment and satisfaction of learning.

Recommendations and guidelines: Create an attractive LE design with gamified and playful elements that foster the joy of learning, enjoyment and satisfaction. Support experiencing success, accomplishment, and sharing positive emotions.

Concrete example: STIMEY LE enables sharing one’s achievements and providing positive feedback to one another. It is possible to reward success in learning with points and badges. STIMEY SARA robots’ playful facial expressions, speech and behaviour can be used to enhance the joy of learning. STIMEY Setla serious game include little tests after which learner can enjoy relaxing game for collecting elements needed for water molecules (see Figure 27).
4.3 Extrinsic motivation

**Pedagogical principle:** Creating attractive and interesting LE for all types of learners.

**Recommendations and guidelines:** Utilize positive feedback, encouragement, and rewards to increase external motivation. Create inspiring and motivational LEs. Support learners in perceiving personal importance and value of learning so as to move towards more intrinsic forms of motivation (See 4.4 Intrinsic motivation).

**Concrete example:** In STIMEY platform, learners collect achievements (brain, heart and spirit points) and earn badges and receive certificates based on their work. In the future, Energy Orbs gained based on one’s achievement can be used to buy items such as Robot Upgrades in StimeyStore. Learners can also see the best results in a Leaderboard (Figure 27). STIMEY SARA robots can also be used to congratulate (both orally and using facial expressions and gestures) learners when completing their tasks successfully, or to encourage them to try more.
4.4 Intrinsic motivation

**Pedagogical principle:** Fostering learners’ internal curiosity and inner desire to learn.

**Recommendations and guidelines:** Guide learners towards autonomy, intrinsic regulation and self-determined behaviour by encouraging them to choose personally relevant tasks they want to study and to self-evaluate their work (see also 1.3 Personalisation and 3.7 Self-regulated learning). Support their feelings of competence by providing constructive and positive feedback, and relatedness, by assuring that learners feel part of the learning community (see also 4.6 Sense of belonging and 3.3 Collaborative learning).

**Concrete example:** Instead of the same task for the whole class, in *STIMEY Mission*, students can be given multiple options to choose from based on learners personal interests. Allow the creation of *Communities* in the STIMEY LE based on shared interests. Intrinsic motivation may also be supported by encouraging learners to set their personal daily goals and reflect the visualisation of their weekly daily goal progress (see Figure 23).

4.5 Inclusion, justice and equity

**Pedagogical principle:** Ensuring inclusion, fair treatment and equal access for all.

**Recommendations and guidelines:** Assure that the LE is easy to use and as accessible as possible and it promotes fair treatment and equity. Promote inclusion and participation of all learners
regardless of their physical or cognitive capability, ethnicity, culture, language, belief system, socio-economic status, gender (see also 6. Gender inclusion), or any other aspect of an individual’s identity that might be perceived as different.

**Concrete example:** Teacher encourages participation to STIMEY Communities and Chats based on shared interests regardless of learners’ backgrounds and assures that all individuals are given opportunities to participate and belong to communities of their interests (see also 4.6 Sense of belonging). Teacher could also initiate a discussion related with accessibility being motivated by the limitations and deficits that the STIMEY SARA and other robots themselves have and then proceed to transfer the issue to humans by taking into account cultural, social and gender differences.

### 4.6 Sense of belonging

**Pedagogical principle:** Fostering a sense of belonging including emotional attachment and caring for others.

**Recommendations and guidelines:** Use social media tools to enable the creation and belonging to networks based on one's interests or experiences. Include visible signs of the community (e.g., group picture, shared work) to shared spaces and e-portfolios.

**Concrete example:** The STIMEY LE allows creating Communities (see Figure 22) for different learning groups. Students can develop their sense of belonging by joining a group they like. Teachers can support this by assuring that there are groups shared by everyone and that everyone belongs to a specific community of their interest.

### 4.7 Teacher-student and peer relations

**Pedagogical principle:** Promoting good teacher-student and peer relations in order to support learning and wellbeing.

**Recommendations and guidelines:** Enable fluent communication between teachers and students and between peers by using communication channels that both teachers and students are familiar with. Use shared activities and communication in order to foster student cohesiveness and social engagement.

**Concrete example:** The STIMEY platform enables that the teachers and the students communicate with each other by using the chat tool or Communities. It is also possible to contact the teachers or peers outside the classroom.
4.8 Home-school and wider community relations

**Pedagogical principle:** Fostering good relations and shared understanding between the school, families, and the wider society.

**Recommendations and guidelines:** Provide parents and external experts access to the specific areas at the LE and possibility to communicate with teachers and students. Create access to the school community to actively participate in the wider surrounding community.

**Concrete example:** STIMEY Ambassadors (parents and external experts) can participate at the STIMEY platform, e.g., by means of social media tools for evaluating, or moderating the student’s work in Missions or Communities. STIMEY e-portfolio can be used to present one’s work both to parents and to external experts.

4.9 Safety

**Pedagogical principle:** Assuring that the LE is physically, virtually, emotionally and socially safe.

**Recommendations and guidelines:** Focus both on safety prevention (e.g., clear code of conduct and rules) and effective interventions when safety is in danger. For instance, in a case of cyber bullying, make sure that it is possible to identify the bullies, save evidence, and then to remove the harmful content. Make sure that everyone’s right for privacy is respected. Aim at creating a welcoming atmosphere where everyone can feel safe (see also 4.6 Sense of belonging). Assure that issues with personal security and data protection are adequately considered.

**Concrete example:** STIMEY LE can be used to practice respectful and polite communication in social media. Teacher can, for instance, analyse together with the students the feedback given to one another in communities and discussion forums. STIMEY platform also includes clear Privacy Policy guidelines to support security and safety (Figure 28).
4 Socio-emotional aspects - Further reading

Introduction


4.1 Social and emotional skills


4.2 Joy of learning


4.3 Extrinsic motivation


4.4 Intrinsic motivation


4.5 Inclusion, justice and equity


4.6 Sense of belonging

4.7 Teacher-student and peer relations
4.8 Home-school and wider community relations


4.9 Safety

5 Educational compatibility

This category refers to the importance of assuring that LE is educationally compatible to the local contexts of use. Compatibility to different system levels such as regional, national, local, school and classroom levels should be considered in the LE design. The design principles in this category are part of the evaluation framework created for identifying globally shared and locally specific requirements for the design and use of educational technology, which in addition to “educational compatibility”, entails evaluation criteria related to “culture and society” and “design and use of technological learning solution” (see Mäkelä, 2015).

5.1 Educational needs and challenges

**Pedagogical principle:** Addressing contemporary local and global educational needs and challenges.

**Recommendations and guidelines:** Create learning activities, which support local educational needs (e.g., low performance or engagement levels). Provide activities which focus on both cognitive (e.g., conceptual change, prediction, anticipation of consequences) and affective (e.g., interest, engagement, teacher-student relations) dimensions of learning.

**Concrete example:** STIMEY platform’s serious games (Figure 29) may be used to increase student’s motivation and awareness of possible STEM careers. Resources such as Mental calculation tool (Figure 30) can be used to improve the performance in this area.
5.2 Educational system

**Pedagogical principle:** Assuring that the LE fits to different educational systems.

**Recommendations and guidelines:** Indicate the appropriateness of learning activities for different school levels and age groups. Consider, for instance, country-differences in the age children start schooling, and in the duration primary, lower and upper secondary school. Support the creation of user-generated activities which fit to local system.

**Concrete example:** The *Mission editor* on the STIMEY platform makes it possible to create and modify learning content that is in line with the local educational system. For instance, the difficulty level can be adapted considering the age- and development-related differences in the maturity level depending on the age children start primary or secondary school in each country.

5.3 General curricular goals and contents

**Pedagogical principle:** Matching the learning goals and contents with general local curricular requirements

**Recommendations and guidelines:** Design keywords, tags, peer review systems with ratings, etc. for indicating the appropriateness of learning activities within a specific curriculum. Support the creation of user-generated activities which fit to local curriculum. Consider, for instance, country-differences in ways that cross-curricular or transversal competences are included in the curriculum (see also 2 Cross-curricular skills).

**Concrete example:** The local curriculum is considered when designing learning contents to STIMEY platform. Tags are created to indicate the age and curriculum appropriateness of the materials. Content created in other countries can be used as template (Figure 31), which can then be adapted to local requirements. It is possible to create a World (i.e., a short curriculum) on the platform encompassing aspects of general curricular goals and contents in order to facilitate teacher collaborations and creating meaningful connections between the different subjects in a curriculum.
5.4 Subject-specific goals and contents

**Pedagogical principle:** Assuring that the LE promotes acquisition of learning objectives of the specific subject/s.

**Recommendations and guidelines:** Describe clearly the subject-specific goals, contents, and expected outcomes. Allow modifying the goals and contents depending on the local requirements. Take into account that there are country-difference, for instance, in the ways science, technology, engineering, and mathematics are taught (e.g., as separate subjects, as part of environmental studies, or as cross-curricular themes).

**Concrete example:** STIMEY LE’s content search engine (Figure 32) is supporting topic- and subject-based searches, which makes it easy to find specific topic- and subject-related materials on the platform. The description of subject-specific goals, contents, and expected outcomes are included in the STIMEY Mission creation templates. Shared missions can be adapted to local requirements.
5.5 Organisational practices

**Pedagogical principle:** Fitting LE to the local institutions’ everyday organizational practices and operations.

**Recommendations and guidelines:** Assure that the LE can be used also in educational organisations where teachers have, e.g., less development opportunities, collaboration amongst teachers, or very big classroom sizes. LE should be easy to use for teachers and guidance should be provided for its use (see also 1.3 Support for teaching and learning). Enable and encourage collaboration between teachers so as to share their experiences and good practices related to the LE use.

**Concrete example:** STIMEY LE can be used by individual teachers alone or in collaboration between teachers. It also entails instruction and guidance for teachers in its use. STIMEY LE also enables creating teacher communities to discuss and share teaching and learning related concerns.

5.6 Educational practices at group level

**Pedagogical principle:** Considering differences related to educational practices at group level.

**Recommendations and guidelines:** Enable varied ways of using the LE based on local practices, for instance, related to teacher and learner roles or instructional practices and strategies. Provide how to use guidance for LE in student-centred or personalized learning (1.3 Support for teaching and learning).

**Concrete example:** STIMEY LE allows local variation in ways of teaching and learning. It also provides templates guiding educators in the use of different pedagogical approaches. This can support teachers to move towards more innovative and versatile ways of teaching and learning (see 1.5 Versatile both novel and conventional tools and methods).
5.7 Assessment system and practices

**Pedagogical principle:** Considering local assessment system and practices.

**Recommendations and guidelines:** Enable versatile both conventional and novel assessment types (e.g., diagnostic, formative, summative, numeric, descriptive, personalised, self and peer evaluations, multiple choice tests, open ended questions). Guide teachers in the use of novel evaluation methods (1.3 Support for teaching and learning). Use embedded assessment (e.g., automatic points, progress tracking), social feedback, and eportfolio in evaluations. Aim at authentic assessment which also considers learning in informal and non-formal LEs.

**Concrete example:** By using the STIMEY e-portfolio, the teachers have an opportunity to give descriptive feedback and evaluation of the students’ work. It will also foster reflection (see 3.8 Reflective learning) and self-evaluation and self-regulation (see, 3.7 Self-regulated learning) by making learning visible for learners themselves. Learners can provide feedback to one another using social media features such as Communities and Discussion.

5.8 Task and activity types

**Pedagogical principle:** Considering how the LE matches locally typical task-types and activities.

**Recommendations and guidelines:** Include versatile task and activity types to the platform and guidance for the use of more novel task types, such as the use of robots in teaching and learning (see also 1.5 Versatility in both novel and conventional tools and methods and 1.3 Support for teaching and learning).

**Concrete example:** The STIMEY LE offers a variety of task templates and tools, but users can create their own task types based on their preference. The platform allows saving outcomes representing different activities to STIMEY e-portfolio. The STIMEY LE encourages including the use of STIMEY SARA robots to teaching and learning.

5 Educational compatibility - Further reading

**Introduction**

5.1 Educational needs and challenges


5.2 Educational system


5.3 General curricular goals and contents


5.4 Subject-specific goals and contents


5.5 Organisational practices


5.6 Educational practices at group level


5.7 Assessment system and practices


5.8 Task and activity types


6 Gender inclusion

The gender-sensitive approach in the LE design and use is about creating equal learning opportunities for all students and creating LEs that provide suitable learning conditions for all learners. For gender- and diversity-conscious teaching, two didactic principles are particularly helpful: a wide variety of methods and activation of students. The design principles in this pedagogical framework such as 1.5 Versatility in both novel and conventional tools and methods, 1.2 Personalisation, and 3.3 Collaborative work support gender- and diversity-conscious teaching and learning.

The well-known early drop-out of girls from STEM subjects requires a particularly sensitive approach to socially rooted gender stereotypes in these subjects. The early stereotyping of children in STEM, the lack of female STEM-Role Models and self-confidence among girls leads to an early loss of engagement and motivation of many female students for STEM-subjects.

The focus of these pedagogical principles is on the well-balanced combination of explorative and communicative interaction and technology-based learning. These creative teaching and learning opportunities support teachers to reflexively deal with the particularities and learning requirements of both girls and boys in STEM. The feedback received from the participant stakeholders gave a clear hint that an open and welcoming culture based on clear ground rules is an important issue for the LE design.

As an example, there are four missions with gender topics among the missions at STIMEY LE, addressing as well pupils with regard to gender stereotypes and professional role models as teachers with regard to how to conduct school lessons without gender clichés.

6.1 Gender-sensitive teaching and learning

**Pedagogical principle: Addressing and motivating all genders.**

**Recommendations and guidelines:** Consider various components related to didactics, setting, contents, and communication to contribute to more nuanced gender perceptions and avoid stereotypical representations of men and women in STEM. These include (visual) language, learning themes/topics, and ways of teaching. In addition to gender, take into account country-specific differences and differences in learners’ background, culture, beliefs, age, etc. to contribute to an individual learning support where diverse interests and competencies are praised and addressed (see also 1.2 Personalisation, 1.4 Flexibility and adaptability, and 4.5 Inclusion, justice and equity).
Concrete example: A gender- and diversity-sensitive didactic approach implemented in STIMEY LE ensures that all students have equal opportunities: LE and atmosphere influence positively their motivation and willingness to learn. Gender and Diversity awareness of teachers, which is supported in STIMEY LE, is crucial for motivating female students for STEM studies and careers. There are also exemplary gender-sensitive STEM missions on the platform (see Figure 33).

Figure 33 Gender-related missions on STIMEY platform

6.2 Encouraging STEM careers beyond traditional gender-roles

**Pedagogical principle:** Opening up individual resources beyond stereotypical role perceptions.

**Recommendations and guidelines:** Avoid current notions of "male" and "female", especially in the STEM subjects, which restrict the chances of free development and individuality. Aim at giving young people the opportunity to feel competent in the STEM subjects beyond gender stereotypes so that they can choose their future profession according to their talents and inclinations.
Concrete example: Female role models are included in STIMEY promotion. STEM becomes more accessible for girls when they see that other women have found their way into technology and science and are successful. Women specialists and STEM students are invited to share their STEM-Experience in STIMEY and to make students aware of future prospective in STEM. In STIMEY LE, all students are addressed as Explorers, regardless to their gender differences.

6.3 Empowering LE

Pedagogical principle: Empowering by strengthening girls’ self-confidence in their capacities in the STEM field.

Recommendations and guidelines: Empower and strengthen especially girls’ self-confidence in STEM as they tend to underestimate themselves and their STEM abilities. The confidence in being successful in STEM is an important factor for girls to get involved with STEM studies.

Concrete example: STIMEY LE offers the chance to become a supportive learning community. Social interaction on the platform shapes the user’s self-confidence and perceptions of self-efficacy when different ways of learning are possible and respected, and action-oriented challenges are just as important as the possibility of working in a "creative mode" (see 2.3 Creativity and Innovation). Empowering feedback in STIMEY platform and performance-based recognition, as well as giving equal attention to different needs and not controlling the work too much, inspire students to improve their personal or group performance. STIMEY LE offers opportunities to experiment and to create gender mixed groups or single gender groups. STIMEY SARA robots can be programmed to provide empowering and strengthening feedback.

6.4. Emphasizing relevance of STEM in every-day life

Pedagogical principle: Showing the purpose of STEM learning and its relevance in everyday-life.

Recommendations and guidelines: Include cultural and social aspects in STEM teaching at schools in order to increase the relevance of STEM for real world problems (see also 1.1 Connectedness with learners’ experiences). Use creative and interdisciplinary approaches (see 2.3 Creativity and innovation and 3.6 Project-based STEM learning) to stop student’s self-selection out of technology and engineering activities and contribute to attract and motivate multiple and diverse talents.

Concrete example: Women have more success when they can see the purpose of what they are learning and how it influences the external world. Creating a STIMEY Mission "STEM - something for me?" which includes building e.g., a simple paper bridge to experiment with. Creating something like this requires very little material but a lot of creativity. Girls are significantly more interested in science activities that include societal, real-life, and creative aspects. And such real-life topics also
helps to introduce interdisciplinary topics in STEM, which promote the interest of those who are not STEM enthusiasts per se.

6 Gender inclusion - Further reading

6.1 Gender-sensitive teaching and learning

The toolbox Gender and Diversity in Teaching of Freie Universität Berlin has been proven in practice and provides numerous suggestions. https://www.genderdiversitylehre.fu-berlin.de/.

The Hypathia toolkit (2016): A ready-to-use digital collection of modules aimed at teenagers to be used by teachers, informal learning organisations, researchers and industry. Hypatia Project is carried out by 19 partners from 15 countries: http://www.expecteverything.eu/hypatia/toolkit/2016


6.2 Encouraging STEM careers beyond traditional gender-roles

Microsoft (2018). Why Europe’s girls aren’t studying STEM. Region-wide research of 11,500 women reveals how we can get more young women into science, technology, engineering and math.


6.3 Empowering LE


6.4. Emphasizing relevance of STEM in every-day life


Conclusions

The pedagogical framework and its design principles gather a wide range of teaching and learning related aspects that can be used in the LE design and use both by the instructional designers/developers and educators designing and using different LEs in their teaching. It is not, however, meant to be an exhaustive collection of design principles. On the other hand, not all principles necessarily apply to every LE design. The relevancy of these design principles depends on the LE design focus and purpose, and some new design principles may need to be added. We hope that the pedagogical framework, design principles, recommendations and guidelines described in this publication support both the use of STIMEY LE and the design and use of any other hybrid LEs for STEM and other studies.
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