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stimey

Science Technology Innovation Mathematics Engineering for the Young

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Contents

Introduction

This publication presents the pedagogical framework for designing hybrid (virtual, physical, formal and informal) learning environments (LEs). The pedagogical framework was created as part of the **STIMEY (Science Technology Innovation Mathematics Engineering for the Young) project** (2016–2021), which is a European Union project financed by Horizon 2020, Framework Programme for Research and Innovation.

As a result of difficulties in organising education during the COVID-19 pandemic, it has become more evident than ever that there is a need to design hybrid or blended LEs. In the context of STIMEY, a hybrid LE is defined as an LE that combines face-to-face teaching and learning interaction, physical tools and environments with technology-enhanced teaching-learning interaction in virtual environments and also connects formal, non-formal and informal LEs.

The STIMEY 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 STIMEY LE design and how they can be considered when using STIMEY LE in teaching and learning.

The special focus is on **science, technology, engineering and mathematics (STEM)-**related studies at the **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**, for example, in the selection of efficient teaching and learning methods, task and activity types – in other words, 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, for example, on the specific learning objectives instead of trying to keep all the 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 learners' interest and motivation in STEM education, innovations, and careers** from a young age. The key stakeholders in STIMEY are learners, teachers, parents, schools, and STEM professionals. The STIMEY LE developed during the project consists of the following components:

- **STIMEY Digital Platform** (see Figure 1) for learners, teachers, parents, professionals and organisations with features such as the following:
  - **course editor** for teachers to build lessons and courses (i.e. Missions and Worlds)
  - **lab** including various STIMEY resources and also links to resources available in SCIENTIX (see also http://www.scientix.eu/resources)
  - **social media components** to connect everyone on the platform (Community, Chat, Discussion, Profile, Wall)
  - **e-radio** for STEM learning and enjoyment (Radio STIMEY)
  - **gamification** (playful elements, achievements, labelling system)
  - **serious games** for learning (part of Lab)
  - **e-portfolio** feature for learners to record and reflect on their learning journey
- **STIMEY Socially Assistive Robotic Artefacts (STIMEY SARA)** (see Figure 2) for learners to use when using the platform to motivate and support them in their learning. *Note: At the time of publishing the framework, STIMEY SARA prototypes are available in participant countries for their testing and piloting. We hope to have them manufactured and to be offered to schools in the future.*

To test the STIMEY platform, sign up at https://stimey.eu.

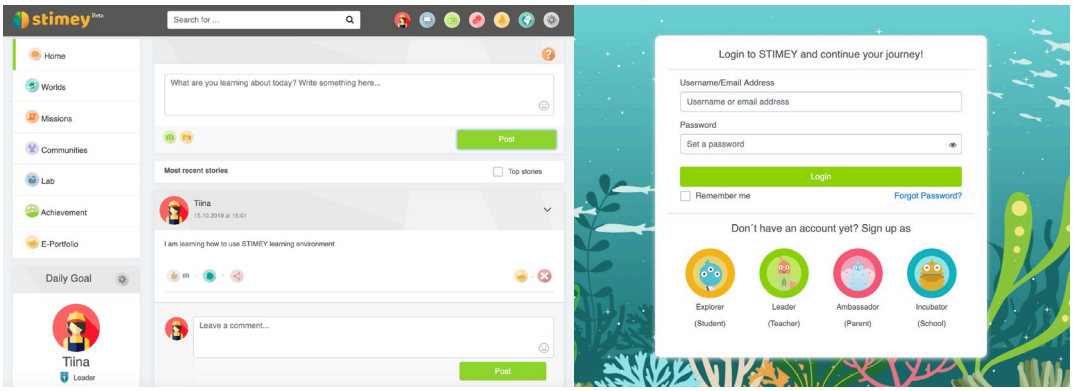

Figure 1 *STIMEY platform (graphic design by Babyradio): Home view and account creation screen for different types of users: Explorer (learner), Leader (teacher), Ambassador (parent or STEM professional), Incubator (school)*

Figure 2 *STIMEY SARA robots*

Researchers of the *Finnish Institute for Educational Research* at the University of Jyväskylä (Finland) were in charge of the pedagogical framework development and closely supported by educational researchers at the *University of Macedonia* (Greece). *Kompetenzzentrum Technik-Diversity-Chancengleichheit E.V.*, which is a centre 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 the design principles related to gender inclusion. Representatives of all the 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 are the result of collaborative efforts during 2016–2021 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): learners', teachers', directors', parents' and STEM professionals' (total of participants in all countries: n = 132) wishes on teaching, learning, motivation and assessment both 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 the integration of pedagogical design principles into the overall STIMEY LE design;
- **FG3 discussions** involving 20 experts on local curricula, STEM, educational policy or educational technology representing all project countries verifying the framework's 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 and dissemination (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.

Figure 3 *Pictures of FG sessions in STIMEY project countries*

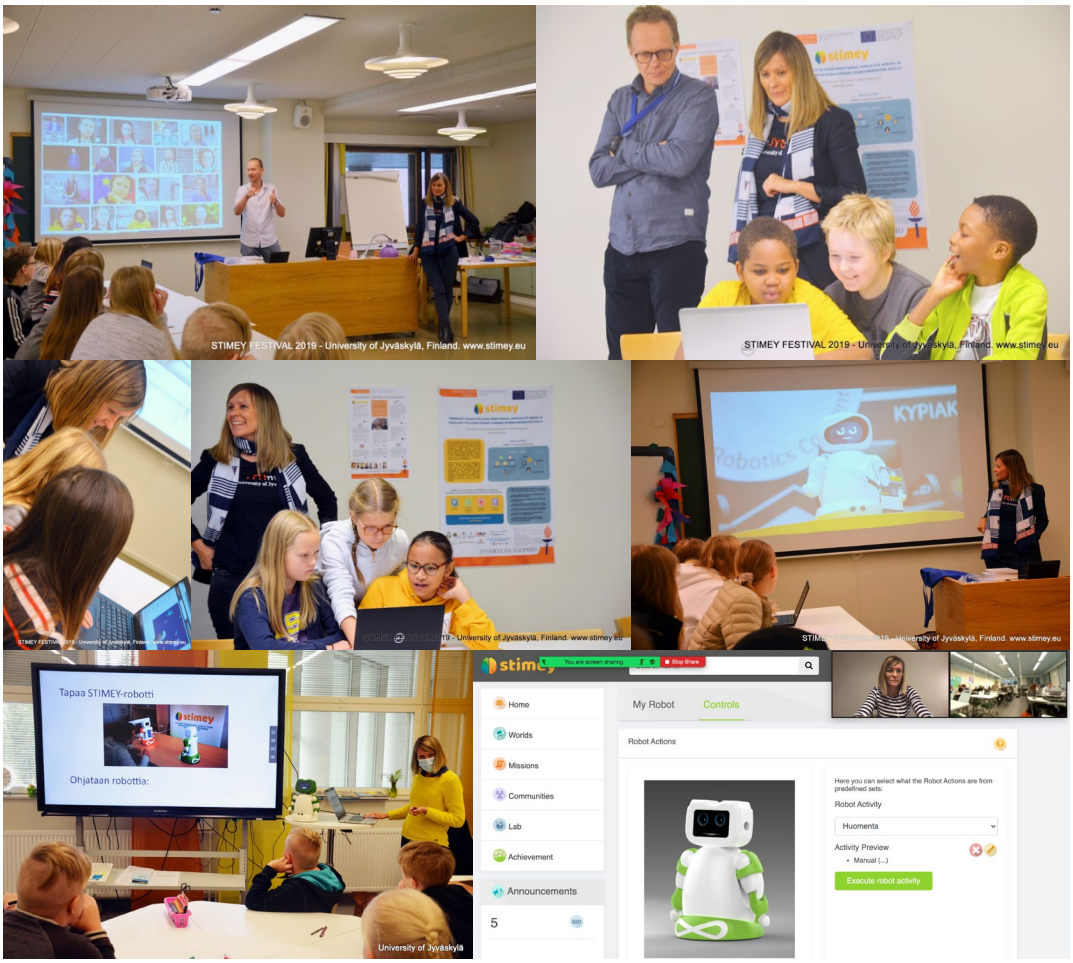

Figure 4 *Final STIMEY LE pilots*

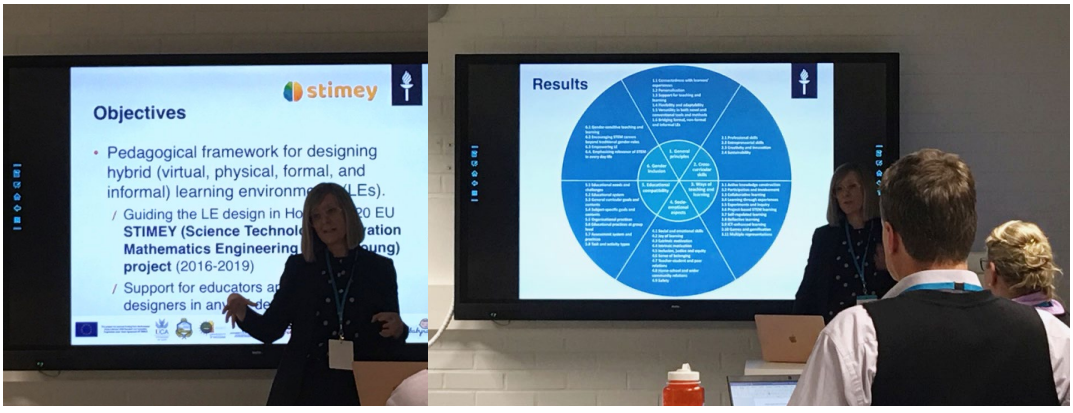

Figure 5 *Presenting the framework to stakeholder groups*

Special thanks to the 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 STIMEY, see: **http://promostimey.uca.es**
Visit the STIMEY platform at **https://stimey.eu**

Framework structure

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

- **General principles:** Pedagogical principles which can be applied generally in the LE design and use.
- **Cross-curricular skills**: Cross-curricular competencies considered relevant particularly for STIMEY LE design and use.
- **Ways of teaching and learning:** Pedagogical models and ways of teaching and learning considered essential particularly for the STEM LE design.
- **Socio-emotional aspects:** Principles referring to aspects that enhance socio-emotional skills, interest, motivation, engagement and wellbeing.
- **Educational compatibility**: Principles to assure that LE is educationally compatible in the local contexts of use.
- **Gender inclusion:** Principles to support that LEs are attractive and functional for all learners.

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 FG2 and verified in an expert review during the FG3 sessions. Some of the principles related to 4. Socio-emotional aspects ('sense of belonging', 'teacher–student and peer relations' and 'home-school and wider community relations') and principles in category 5, Educational compatibility, were added to the framework based on the specific STIMEY LE objectives and supported by the literature. The importance of these principles was also verified in the FG3 sessions. Finally, feedback gathered in FG3 led to some modifications, such as merging the principles 'versatility', 'novelty' and 'conventionality' into one principle and including the principle 'learning outside the school' as a part of the 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, the principle 'social and emotional skills' was added to the framework based on the feedback received in FG3. In relation to 6. Gender inclusion, in FG1, the most frequent wishes were related to gender equality, gender neutrality, gender bias (i.e. prefer-

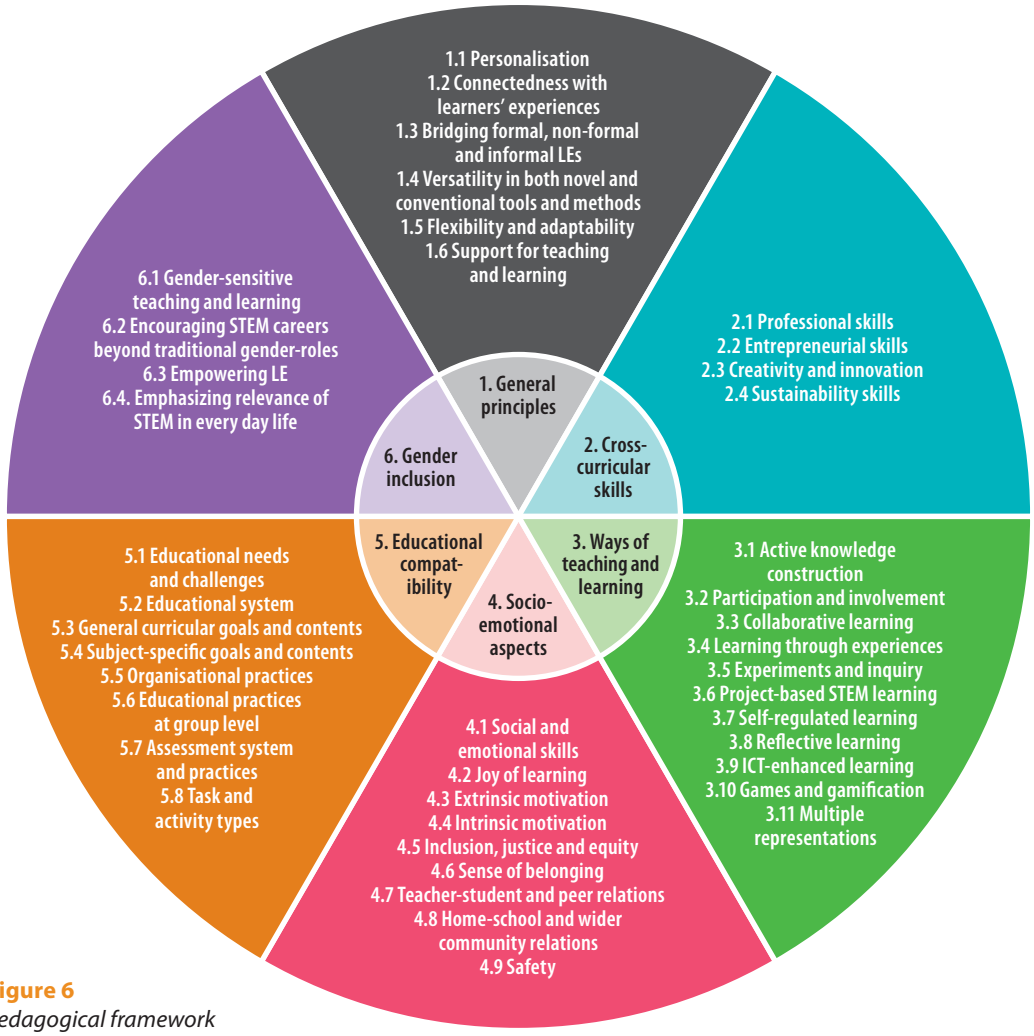

Figure 6
Pedagogical framework

ring one gender) and diversity and cooperation. These aspects were included in the final gender principles created based on the FGs and the literature, which were then confirmed during FG3 and further developed based on the feedback received.

Regarding the theoretical considerations, the design principles are very much in line with Dewey's (Dewey, 1907, 1916) educational philosophy viewing learning as **a learner-centred, active, experiential and reflective activity**. Further, they are in line with the 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.

Particularly student-centred pedagogical principles (see O'neill & McMahon, 2005) have guided the framework development. The conceptualisation of student-centred learning is influ-

enced by authors such as Hayward, Dewey, Froebel, Piaget, Rogers and Knowles (see O'Neill & McMahon, 2005). Student-centred learning is related primarily to *constructivist theories* emphasising the importance of places on activity, discovery and independent learning but also to *cognitive theory* highlighting the activity. It also has connections with *social constructivist theories* emphasising the importance of peer interaction in learning. O'Neill and McMahon (2005) view teacher-centred and student-centred learning as a continuum:

- Low level of student choice – high level of student choice;
- Student passive – student active;
- Power is primarily with the teacher – power primarily with the student.

In the following chapters, we will present the 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 STIMEY LE.

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General principles

General principles

This framework category refers to **general design principles which can be applied in the LE design and its use**. For a more detailed description of the principles, see Mäkelä et al. (2017) and Mäkelä, Fenyvesi and Mäki-Kuutti (2020).

1.1 Personalisation

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

Recommendations and guidelines: Create possibilities to monitor learners' 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 learners to choose ways of working and grouping based on their personal preferences. Provide alternative representation (see also 3.11 Multiple representations) activities, tools and ways of working (see also 1.5 Versatility in both novel and conventional tools and methods) as it allows a choice among various options based on one's own preferences, interests and competence level.

Concrete example: The *STIMEY platform* provides various STEM-related contents and applications, which learners can choose from according to personal preferences, interests and level of understanding. Additionally, a learner can choose to be engaged in easier, intermediate or more challenging missions, tasks, etc., facilitating their personal competences and learning rhythm (see

Figure 7). Learners can also progress at their own speed. They can highlight and reflect on their personal preferences and experiences on the *STIMEY e-portfolio* (Figure 10). Teachers and learners can personalise scripts for *STIMEY SARA* robots for every learner or learner groups with specific needs and interests (Figure 8).

Maria, a teacher at primary school in Spain, lets learners in her class practise with the STIMEY Mental Calculator (Figure 31) in their own rhythm. She recommends particularly learners with difficulties in arithmetic to watch the 'tips for strategies' section. For more advanced learners, she recommends having a playful competition related to time and correct responses in order to rank high in the Leaderboard.

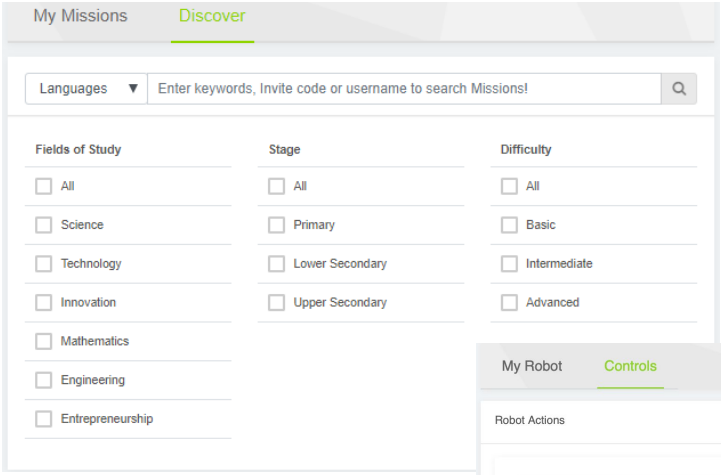

Figure 7 *STIMEY search engine*

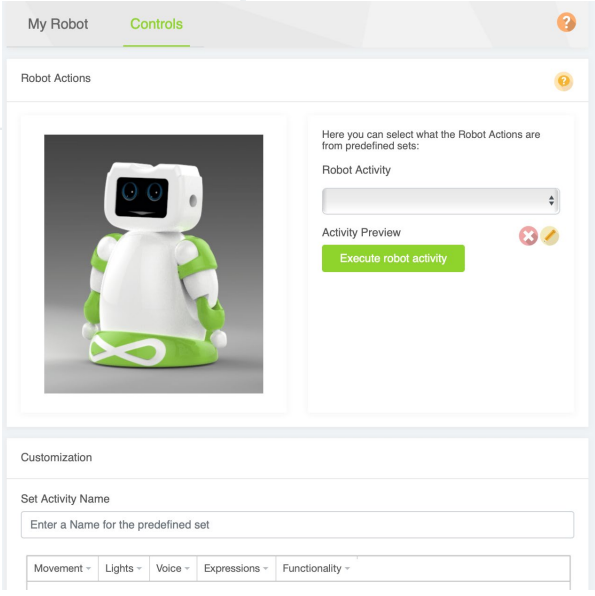

Figure 8 *STIMEY SARA customisation tool*

1.2 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 on and displaying personal experiences (see also 3.8 Reflective learning). On using experiential learning as a method, see 3.4 Learning through experiences.

Concrete example: A learner who likes to play football is asked to create a simulation with the *STIMEY Physics Engine* (see Figure 9). Based on the simulations, the learner can calculate the energy needed to be generated to kick a ball to reach a certain velocity or distance. The learner can then write down the results and reflect on their connection with their hobby using *STIMEY e-portfolio's Learning Journal* (see Figure 10).

Saara, a Finnish secondary school teacher, encourages her 13-year-old students who love to play ice hockey to use the STIMEY Physics Engine to create a simulation of the perfect force from different angles to smash the puck to the net. In this way, their real-life passion is connected to the physical phenomena they are studying at school.

Figure 9 *STIMEY Physics Engine*

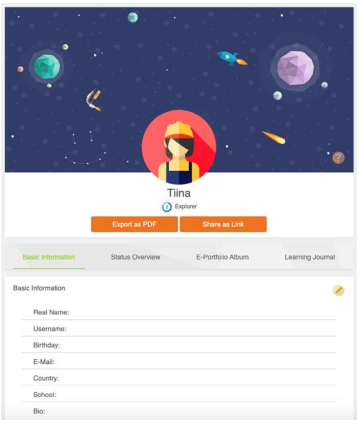

Figure 10 *STIMEY e-portfolio*

1.3 Bridging formal, non-formal and informal LEs

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

Recommendations and guidelines: Allow bridging a 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 for mobile learning. Use the e-portfolio to save evidence of different types of meaningful out-of-school learning experiences.

Concrete example: Teacher may contact a local *STIMEY Ambassador* (i.e. STEM professionals connected to *STIMEY LE*) to organise a field visit to a local observatory. Learners document the visit by taking photos and videos and upload the media to the platform when back at school and produce a report on what they learned during the visit. Because the STIMEY platform can be accessed anytime by learners, the learners can review the learning material anytime they need to. It is possible for the learners 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. The *STIMEY Platform Profile Showcase Event Planner* has been designed for displaying different events organised virtually or physically outside the school environment.

A group of science teachers in a secondary school in Germany contacted local STEM organisations in order to create connections with outside-of-school STEM environments. A local laboratory accepted the invitation and agreed that their 35-year-old Biochemist Michael could become a STIMEY Ambassador. Michael used the STIMEY Platform Profile Showcase Event Planner to display the laboratory location, days and times he would be available for presential and virtual field trips. As a chemistry teacher, Sacha started following him and, after Michael had accepted his invitation, they agreed on the 9th grade laboratory visit using STIMEY chat. After the visit, students were asked to share their experiences in the discussion section in the Mission that Sacha had created in order to connect the field trip with the chemistry class. Michael was also invited to participate in that discussion.

1.4 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 a novel digital LE with conventional tools and methods. Enable the 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: Teachers could create a *Mission* on gravity which utilises different media explaining the physical phenomenon (text, video, pictures). Teachers could also use *STIMEY lab* tools such as the *Physics Engine* simulation to demonstrate the topic to learners. They can also test gravity's effect on different objects by dropping them from a table to get a physical learning experience. *Radio STIMEY* (Figure 11) 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 12) if desired.

Aksana, a Belarussian secondary school teacher who is accustomed to using textbooks in her classes, was introduced to STIMEY LE by her colleague. She learned that she can combine the use of STIMEY LE with textbooks by creating a World and Missions following the structure of the textbooks and including textbook activities into Missions. However, her classes would now be enriched, for instance, by online discussion in Communities and the different integrated resources offered, such as the Khan Academy.

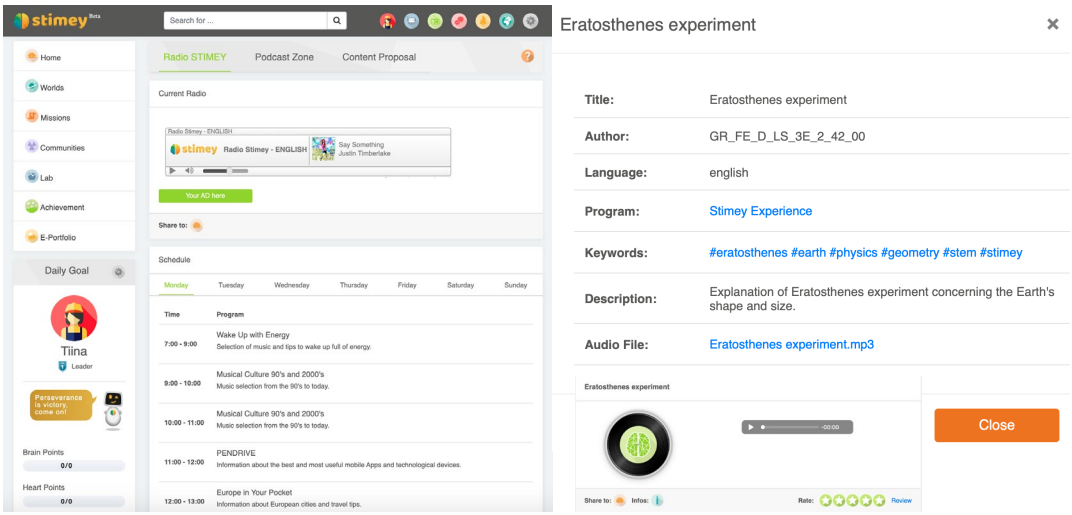

Figure 11 *Radio STIMEY programme and podcast created by users*

Figure 12 *Combining digital STIMEY LE with physical experiments*

1.5 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, for example, 1.2 Personalisation, 1.5 Versatility in both novel and conventional tools and methods and modifications based on the user's changing needs and requirements. Flexibility in time and space is also needed when organising education in exceptional circumstances, such as the COVID-19 crisis. Also assure that the LE is adaptable to different age groups and different educational and sociocultural contexts (see also category 5, Educational compatibility).

Concrete example: It is possible to combine the use of STIMEY LE with other learning materials. Teachers can use existing Missions as templates and adapt them to fit their learner groups and different curricular requirements. STIMEY LE can also be used in online learning both synchronously with the whole group connected in a videoconference or asynchronously, either individually or in small groups.

Heike, a German secondary school biology teacher, browsed the Biology Missions available on the STIMEY platform. She came across the Mission 'Animal Cell' and was intrigued with the content and design of the Mission even though it was a bit advanced for her students. She made a copy of the Mission, and since it had more than she needed to practise the topic with her 8th grade students, she tailored the Mission to fit her group.

1.6 Support for teaching and learning

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

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

Concrete example: The *STIMEY platform* includes clear instructions and examples of the different features of the platform, how to use them and for what purpose. It includes, for instance, tutorials both for teachers and learners. It is possible to review these instructions when desired. For instance, there is an instructional video and hints for using the *STIMEY e-portfolio* and tutorials for both teachers and learners on how to use the *STIMEY platform* (Figure 13). Also, *STIMEY SARA* robots can be programmed to give hints for completing tasks.

Teachers in Finland agreed with the school direction that they could spend one teachers´ weekly meeting becoming familiar with STIMEY LE. They went through a Mission called 'Platform Teacher's Tutorial' as well as 'Platform Student´s Tutorial'. This way they felt ready to use STIMEY LE in their own teaching.

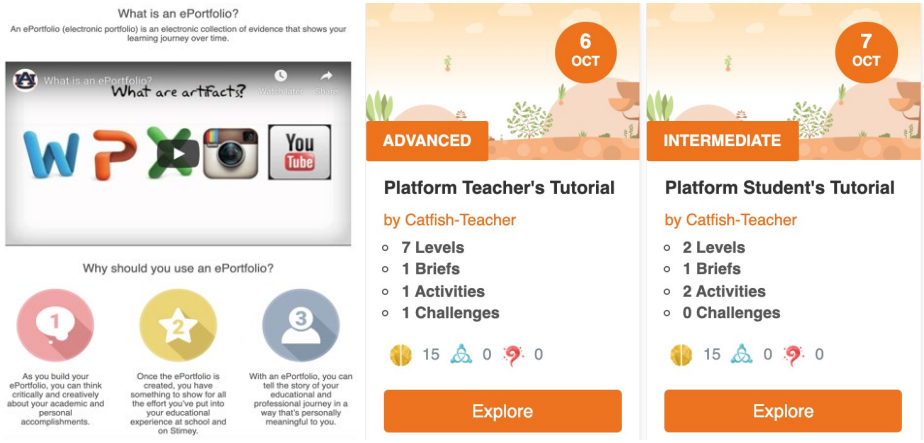

Figure 13 *Instructions for the use of the STIMEY e-portfolio (left), Platform Teacher´s Tutorial Mission (middle) and Student´s Tutorial (right)*

GENERAL PRINCIPLES – FURTHER READING

Introduction

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Cross-curricular skills

Cross-curricular skills

Cross-curricular skills selected for the framework represent transversal 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). For a more detailed description of these principles, see Mäkelä, Fenyvesi and Mäki-Kuutti (2020).

2.1 Professional skills

Pedagogical principle: *Connecting learning with 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*. They can be verified by teachers based on their experiences of collaboration with the Ambassadors. Learners' tasks can be reviewed by a representative of a company that operates in a field where the studied theme is relevant. Learners can choose a profession and career they want to follow in the *STIMEY serious games* (Figures 14, 15 and 16). *Radio STIMEY* provides programs related to STEM professions (Figure 11).

A German science teacher, Sacha, was happy with the collaboration he had had with the local laboratory and their biochemist Michael. He verified Michael so that as a verified Ambassador other teachers would be encouraged to contact him in order to plan virtual or in-person laboratory visits. Michael also accepted an invitation to create a podcast for Radio STIMEY in order to present his work as a biochemist for STIMEY users.

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 and 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 an understanding of how to manage a business.

Concrete example: The *STIMEY Issue Market* (entrepreneurial tournaments) can be used for practising and promoting entrepreneurial skills (Figure 14). Learners can play serious games such as *STIMEY Business Incubator* (Figure 15) for simulating the complex process of developing and making a successful start-up 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.

Alexis, an upper secondary school student in Greece, was introduced to the STIMEY Business Incubator Serious Game challenge by his teacher, Penelope. The month-long challenge led Alexis to take an entrepreneurial course and attend several workshops as optative studies for which he could get credit. Alexis didn't win the competition, but he was inspired and motivated as he discovered his true entrepreneurial spirit. This motivated him to apply for business school after finishing upper secondary school.

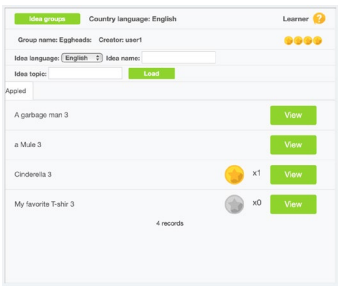

Figure 14 *STIMEY Issue Market*

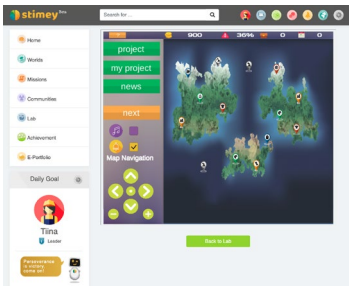

Figure 15 *Business Incubator*

Figure 16 *STIMEY Rocket Scientist*

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 create and 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, for example, 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 learners to efficiently integrate innovative technologies, solutions and contents and share them with each other during the learning process (see 3.9 ICT-enhanced learning).

Concrete example: By using the *STIMEY e-portfolio*, learners 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, a 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 implementing imagination in the creative learning process. Digital storytelling can also become a tool for the creative assessment of what has been learnt. *STIMEY Settlers Fantasy* game supports both creativity and its assessment (Figure 17). Also, the *STOC (Science and Technology-Oriented Creativity) test* can be used both to practice and evaluate learners' science- and technology-related creativity and innovation (Figure 17).

Jorge, a Spanish biology teacher, familiarised with STIMEY Settlers Fantasy game. After watching the tutorials, he created a sample Fantasy for his students choosing the ocean background and selecting Active Points including information and quizzes related to sea animals. After trying out the sample Fantasy, small groups of students were asked to select their own ecosystem and create a Fantasy related to their topic. Jorge reviewed students' works and published them in STIMEY LE. Each group then played Fantasies created by the other groups.

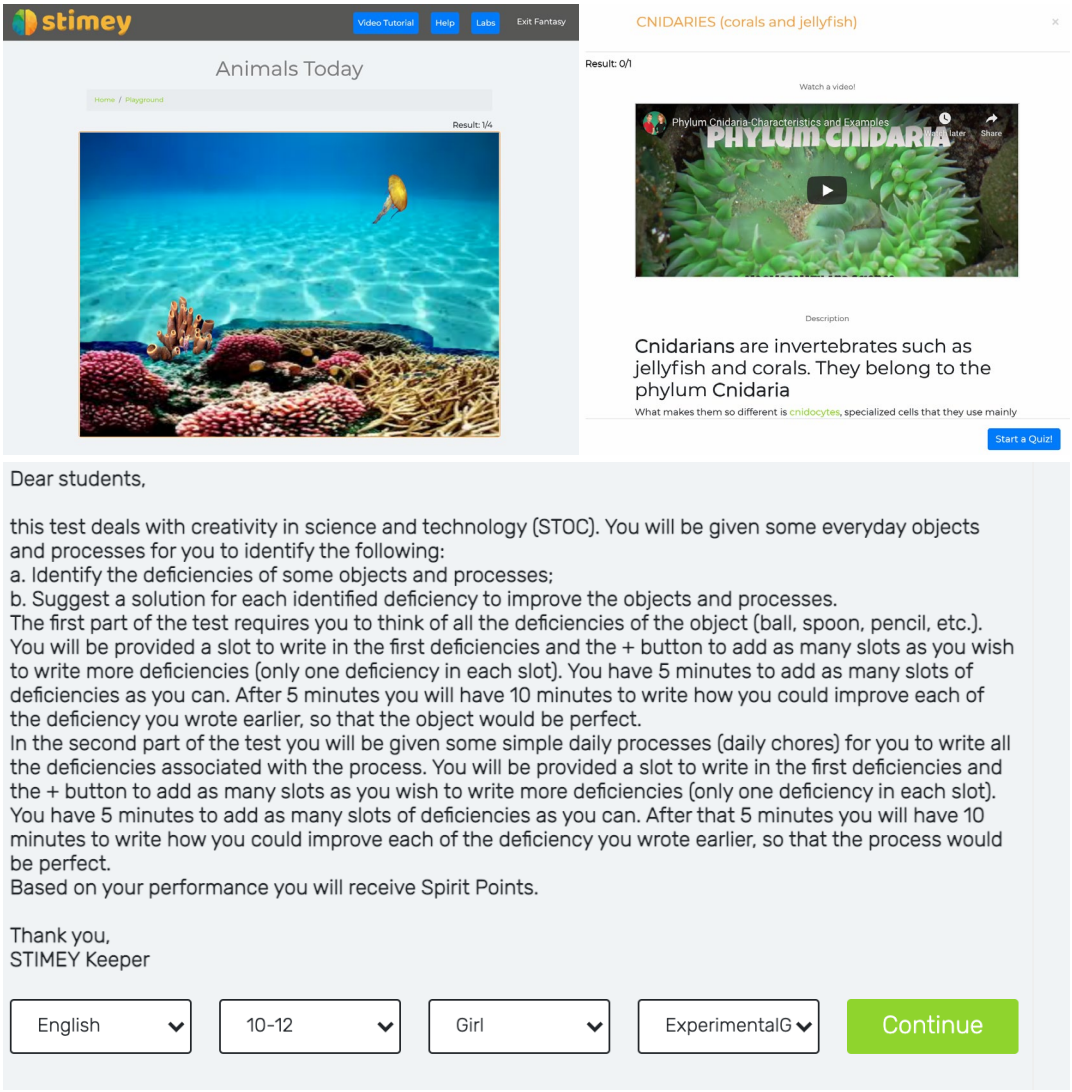

Figure 17 *STIMEY Settlers Fantasy game (top) and STOC test (bottom)*

2.4 Sustainability

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

Recommendations and guidelines: Encourage the 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* in which 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 the Warka Water Tower (see Figure 18) demonstrates how water can be collected in countries lacking sufficient water supply. Working with *STIMEY SARA* robots fosters skills needed in future societies and prepares them to continuously increase the use of robotics.

At the top of the list of Hot Missions is the 'WARKA WATER TOWER: Condensing water from air' Mission. Jukka, a Finnish primary school teacher, decided to use that Mission as a template when creating an activity for his 5th grade pupils related to water consumption. The mission included short videos and instructions for using tangible material to build a physical structure. As a final task, Jukka's group created a podcast for Radio STIMEY explaining what they learned about sustainable water consumption during the Mission. This way, the 'WARKA WATER TOWER' Mission gained even more popularity amongst other STIMEY users.

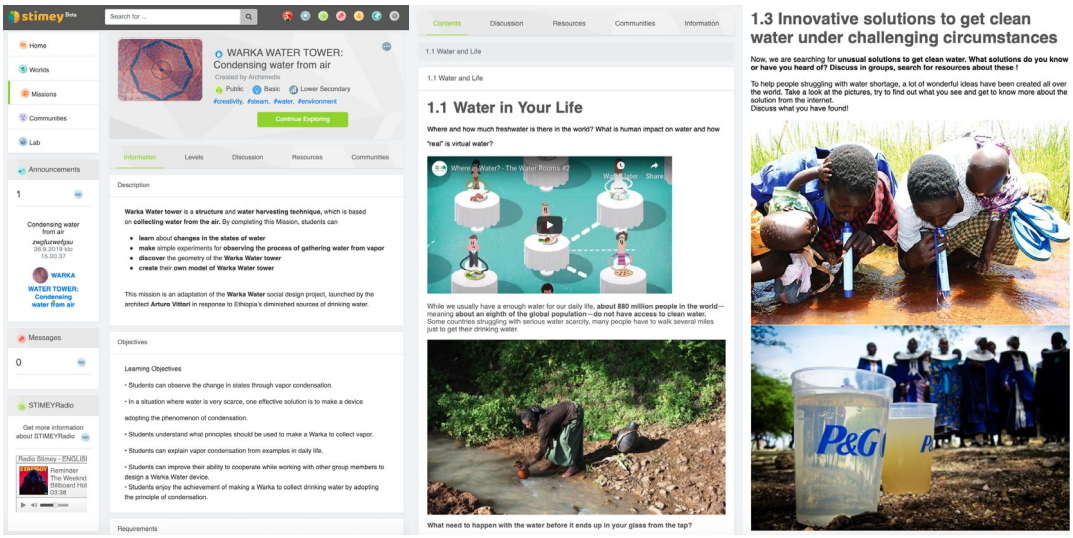

Figure 18 *Screenshots of the Warka Water Tower STIMEY Mission*

2 CROSS-CURRICULAR SKILLS – FURTHER READING

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2.2 Entrepreneurial skills

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Ways of teaching and learning

Ways of teaching and learning

This framework category refers to **pedagogical models and ways of teaching and learning which are considered essential specifically for the STEM LE design**. The principles in this category consider, on one hand, the role of educators in the 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) and Mäkelä, Fenyvesi and Mäki-Kuutti (2020).

3.1 Active knowledge construction

> ***Pedagogical principle:*** *Supporting learners' knowledge construction instead of teacher-centred memorisation.*

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

Concrete example: Learners are asked to read a scientific text and summarise it in their own words using the *STIMEY e-portfolio* and its *Learning Journal*. They use a mind map to structure the information. Then they publish their texts in *Community* and evaluate and comment on their peers' summaries. The *STIMEY Settlers Fantasy* (Figure 17) game can also be used to actively create and construct knowledge. Additionally, It is possible to construct and share knowledge by creating podcasts for *Radio STIMEY* (Figure 19).

Jukka discovered that his group of 5th graders could construct knowledge on sustainability using the STIMEY Settlers Fantasy game. He divided his class into small groups and gave each group one sustainability goal (e.g. life below water, life on land, climate action). Groups searched for information about their topic and included them in their Fantasy together with some quiz questions. When finished, Jukka reviewed each Fantasy, after which other learners could play them. Feedback about each Fantasy was then given in the 5th grade Community.

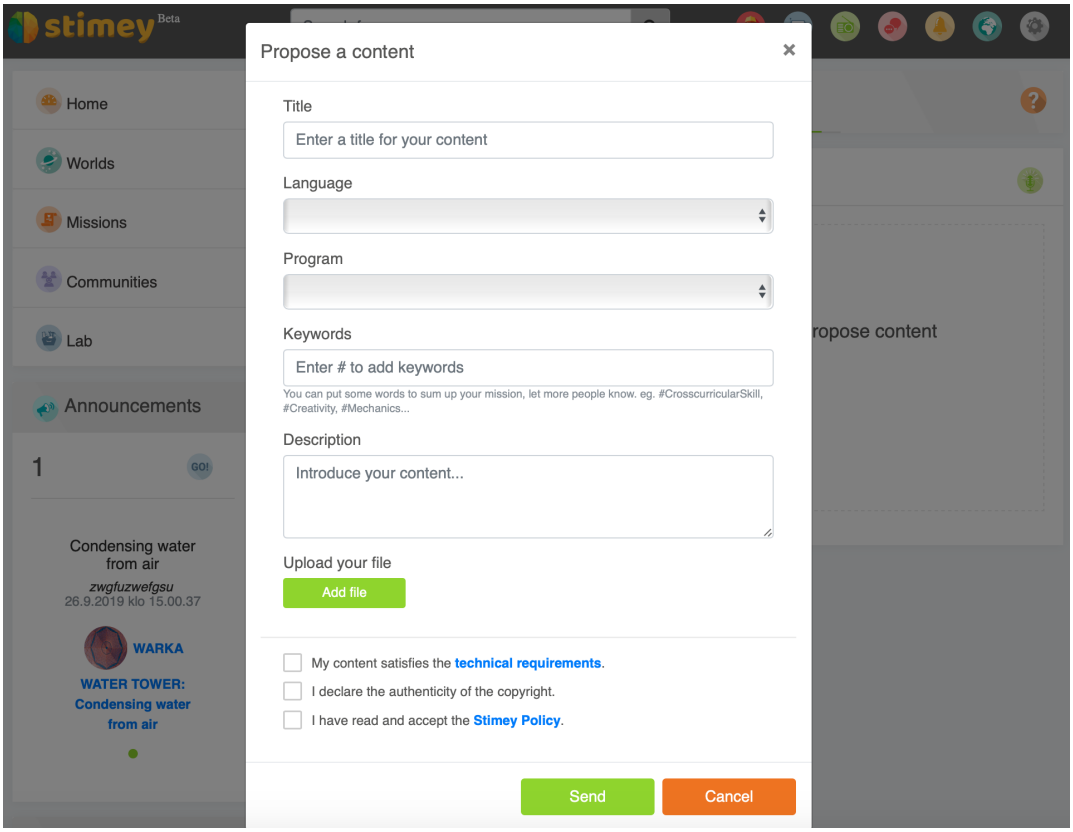

Figure 19 *Proposing content for Radio STIMEY podcasts*

3.2 Participation and involvement

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

Recommendations and guidelines: Foster learners' active participation, involvement and self-expressions, for instance, through interactive tasks and social media tools. Give them opportunities to influence decision making.

Concrete example: It is possible to create a *STIMEY Mission* that addresses mathematics in everyday life. Learners are given a task to demonstrate a chosen topic in a way they desire utilising the opportunities provided by the *STIMEY platform*. The teacher guides in the choosing of the topic, and as learners 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 prepares learners for future societal participation and involvement including the use of robotics. *STIMEY SARA* can also be programmed to encourage learners to take part in discussions, such as by calling them by names in turns.

Berta used a STIMEY Community with her 6th graders in Spain in order to propose a class project related to environmental protection. The best proposal was voted for by the number of 'thumbs' given to it. Learners were involved in the project design. They presented their outcomes in a Radio STIMEY podcast and also invited other learners to create challenges related to environmental protection.

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 by creating homogeneous and heterogeneous groups, mixed gender groups, working with girls and boys separately and so on.

Concrete example: Learners can collaborate together on the *STIMEY platform* by using the *Discussion* or *Community* features and provide their solutions or feedback on provided solutions (Figure 20). They can also create or join communities or group chats (Figure 20) to discuss Mission topics with their peers privately and work on assignments together. Also, the *STIMEY e-portfolio* can be used for peer assessment by agreeing that peers will review one another's portfolios and give feedback on them (see also 5.7 Assessment system and practices).

David, a secondary school science teacher in Germany, found a Mission created initially by the STIMEY pedagogues named 'Nanotechnology clothes that make our life easier', and he wanted to adapt it for his students. In that Mission, students were given instructions on how to create superhydrophobic clothes. They worked in small groups using STIMEY Group Chat in discussions. Each group then posted pictures and explanations of their final work in Community, where they could give feedback and send questions to one another.

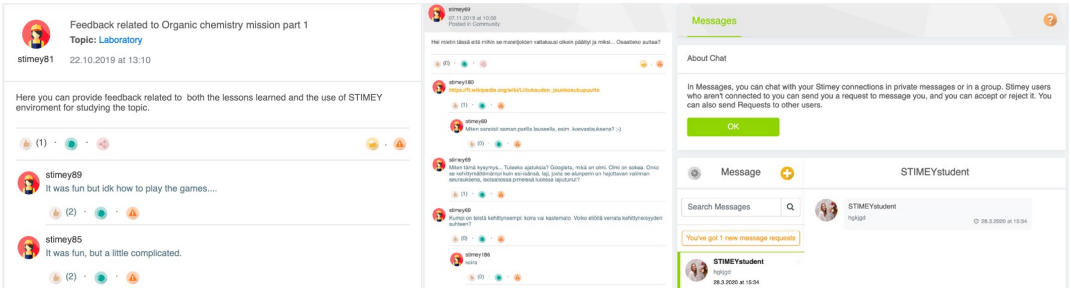

Figure 20 *Examples of collaboration in STIMEY Discussion (left), Community (middle) and Chat (left).*

3.4 Learning through experiences

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

Recommendations and guidelines: Find ways to connect learning with real-life experiences and phenomena 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. The *STIMEY platform*'s integrated virtual applications, such as the *STIMEY Chemistry Engine* (Figure 21), create experiences that are connected to real life. For instance, *Molecule Builder* (Figure 21) can be used together with the physical molecule scale model construction (see also 1.5 Versatility in both novel and conventional tools and methods). Examples of real-life phenomena can also be included in *STIMEY Missions*.

David, a secondary school science teacher in Germany, was delighted to discover how the 'Nanotechnology clothes that make our life easier' Mission helped him to connect science class with t-shirt fabrication. With his student group, they also found lots of videos and web pages with information about these fabrics. These materials were shared and published in their Community.

3.5 Experiments and inquiry

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

Recommendations and guidelines: Model processes of a scientific inquiry, including (1) creating context, (2) setting up research questions, (3) constructing working theories, (4) conducting critical evaluation, (5) searching deepening knowledge, (6) generating subordinate questions and (7) constructing new working theories. 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 22). The *STIMEY Physics Engine* (see Figure 7) and *Chemistry Engine* (see Figure 21) can be used as virtual labs to carry out various scientific experiments and demonstrations.

Helena, a Greek secondary school teacher, created a Mission on organic chemistry. She introduced the topic in a Radio STIMEY podcast. Students then learned to construct molecule structures using the Chemistry Engine. They took screenshots of their molecule structures, named them and saved the pictures in their e-portfolios.

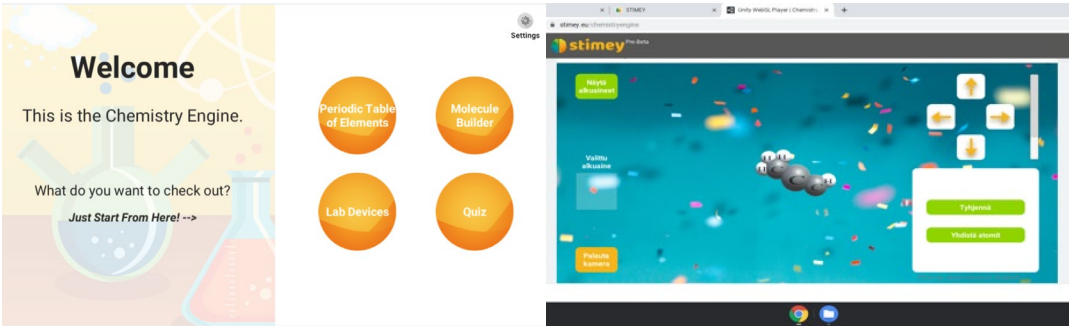

Figure 21 *STIMEY Chemistry Engine (left) and Molecule Builder (right)*

Progressive inquiry model template

Created by Tiina
Inspired by FinlandCrew

Public Advanced Upper Secondary

Update

Information | Levels | Discussion | Resources | Communities | Results

Mission Description

The *progressive inquiry model* (Hakkarainen & Sintonen, 2002; Muukkonen et al., 1999; see also Assaad & Mäkelä, 2017), considers the need to connect learning with real-world problems meaningful to learners. Further, this model can be employed in computer-supported collaborative learning thus combining the elements of inquiry, use of ICT, and collaboration. Some of the principles in progressive inquiry are:

- Students should be guided to search for answers for authentic open questions.
- Focus is on understanding and explaining the phenomenon (significance, interrelations), the most important concepts and big ideas.
- Students learn to examine critically the information and their preconceptions.
- Information is searched individually but new knowledge is constructed socially in a group.
- Information is searched in varied ways considering various disciplines.
- Students learn to solve problems collaboratively distribute their expertise.
- Teacher's' role is to support and encourage as a mentor the development of students' metacognitive skills such as
  - critical thinking towards information,
  - teamwork,
  - scientific thinking,
  - reasoning,
  - self-regulation,
  - reflection, and
  - Problem-solving.
- There is a concrete project outcome, actual results.

Figure 22 *STIMEY progressive inquiry model template*

3.6 Project-based STEM learning

Pedagogical principle: *Learning science, technology, engineering and mathematics in a cross-curricular project aimed 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 the teaching of other subjects. Include aspects such as modelling and reflection on the nature of science and technology in STEM learning. Employ interdisciplinary topics such as communication, medicine, mobility, the environment and food, which promote interest in those who are not STEM enthusiastic per se.

Concrete example: STIMEY LE includes several innovative STEM learning tools (e.g. chemistry and physics engines, STEM-related serious games) and supports links to these different sources in the same learning material, which can be processed collaboratively during the learning process. Concrete project outcomes can be presented and shared in *STIMEY Communities* (Figure 23).

Vladimir, a Belarussian secondary school teacher, agreed with his colleagues that they would create a Mission that concentrates on thunderstorms. It included tasks from geography (where thunderstorms occur most frequently and why), physics (explain the physics behind lightning) and the arts (create a visualisation of a lightning or thunderstorm).

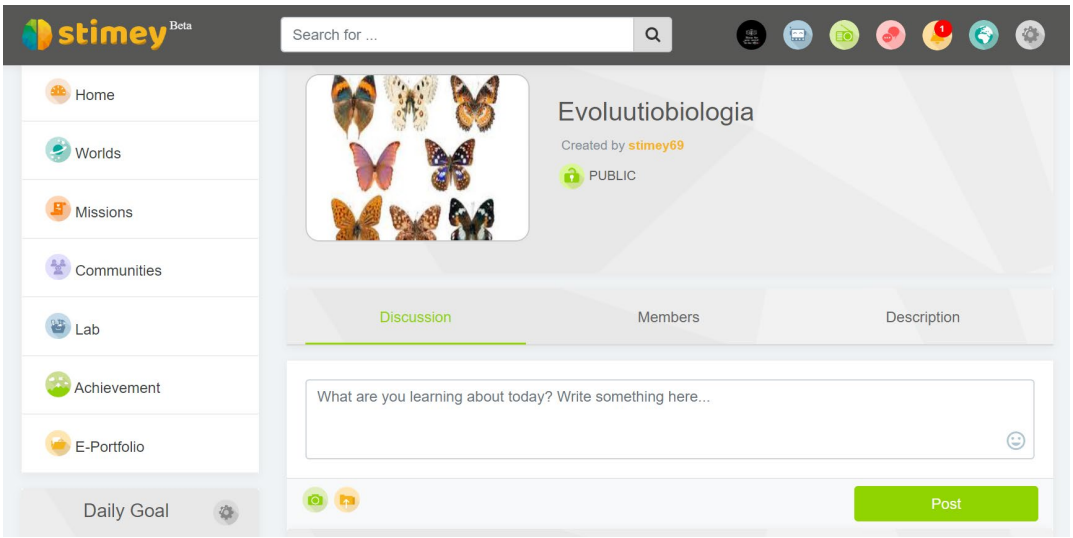

Figure 23 *Example of a STIMEY community*

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 one's own progress and help learners to improve their self-regulation skills, including emotional self-regulation consisting of, for example, coping with frustration or failure (see also 4.1 Social and emotional skills). Provide opportunities particularly for autonomous and self-directed learners with good self-regulation and time management skills for independent online learning not only in exceptional times, such as learning during the COVID-19 pandemic, but also in other circumstances.

Concrete example: *STIMEY Missions*, which include clear instructions on how to progress, can be studied autonomously. Gamification points and rewards as well as a chart for daily goals (Figure 24) in STIMEY LE support tracking one's learning. The three-points system of knowledge ('brain points'), social skills ('heart points'), and creativity ('spirit points') can give the learner 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 a *STIMEY e-portfolio* (see Figure 10) based on one's work can be used to support self-regulation.

A Spanish primary school teacher, Ana, found out that she could support her learners' self-regulated learning by helping them set their own goals using the STIMEY Daily Goal and Achievements chart. She also encouraged her group to achieve brain, spirit and heart points. Ana saw first-hand the power of STIMEY Gamified and the effect it had on her students. Achieving a point the moment they made a post on their Wall in Communities and commenting on their classmates' posts were rewarding for her group.

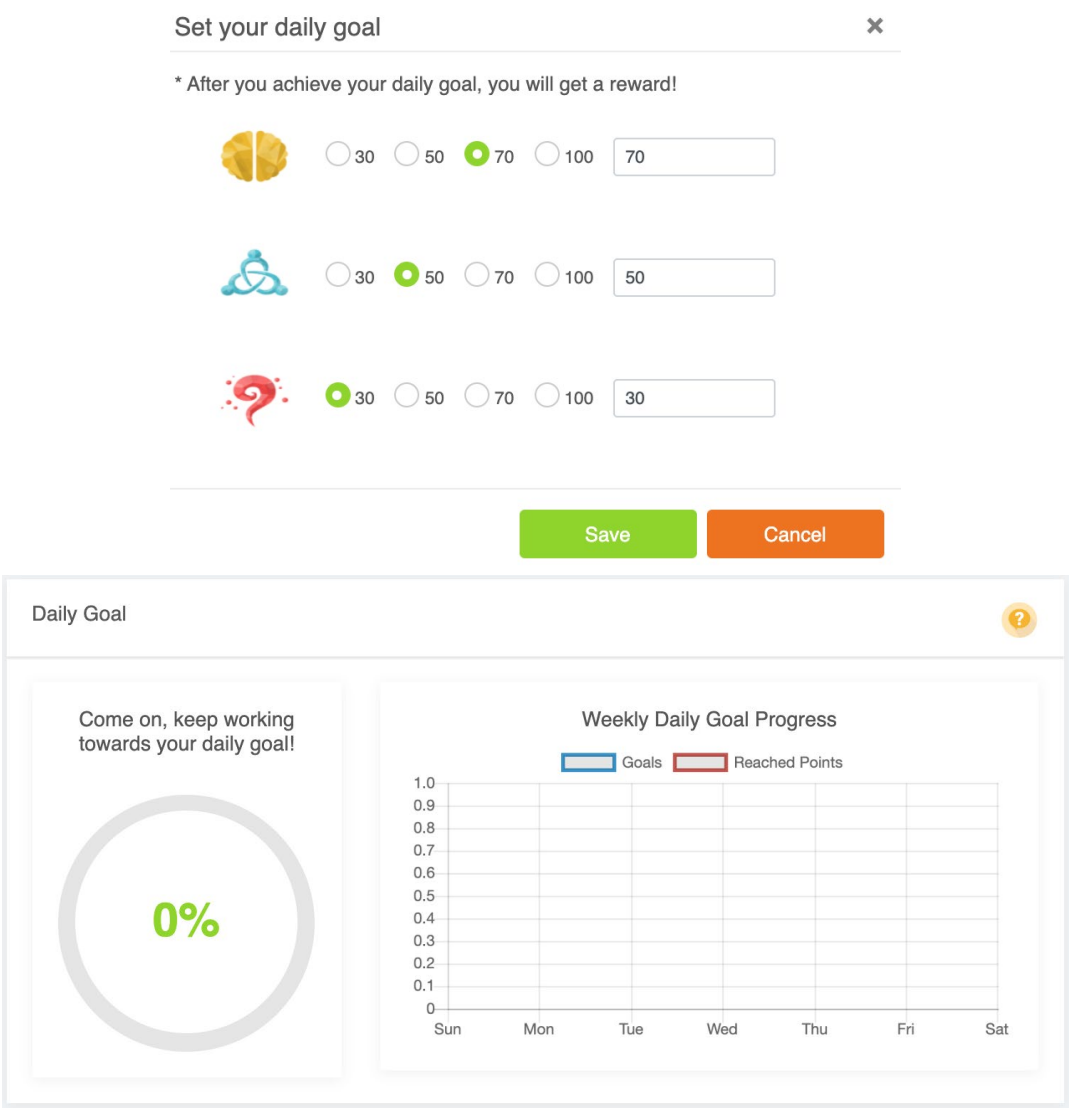

Figure 24 *Setting daily goals (left) and STIMEY chart for daily goals (right)*

3.8 Reflective learning

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

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

Concrete example: *STIMEY e-portfolio* (see Figure 10) can be used to support reflection on one's work, such as by providing reflective questions to be responded to. In some tasks, evaluation can also be done by other learners instead of the teacher by agreeing on the use of peer evaluations for each other's e-portfolios. *STIMEY SARA* robots can be programmed to provide feedback to trigger reflection.

Antti, a Finnish 5th grade teacher, invited his group to use STIMEY e-portfolio's Learning Journal to write down their goals, endeavours and difficulties as well as to collect their accomplishments there. Antti guided each learner in that work, and as a homework, they were asked to present their Learning Journal to their parents and to discuss their personal goals with them. At the end of the term, learners were asked to self-evaluate how well they think they had accomplished their goals.

3.9 ICT-enhanced learning

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

Recommendations and guidelines: Integrate various types of ICT solutions into the LE to facilitate learning. Use challenges with technology as an opportunity to solve problems and learn about technology. Be aware of opportunities that the use of ICT in learning also has for distance learning. Alternatively, it is recommendable to limit the number of various ICT tools in one subject due to the various ways to operate them, which may confuse both teachers and learners.

Concrete example: STIMEY LE offers various ways of using ICT in learning. For instance, the use of *Communities* and *Chat* (Figure 20) support the learning of 21st-century digital skills, including social media skills. The *Mental Calculator* as well as the *physics and chemistry engines* can be used in STEM learning. STIMEY is also integrated with external tools such as the Khan Academy and materials available in Scientix (Figure 25). *STIMEY SARA* robots are technological tools which will enhance both learning with and about technology (e.g. basics of coding, programming and robotics). STIMEY unifies different ICT tools in one LE in order to limit the potential problems related to combining various tools.

Dimitris, a Greek secondary school teacher, found out that his students would enjoy customising and then executing STIMEY SARA activities. This served as an introduction to coding. Students loved observing how the robot moved and talked based on the commands they created for it.

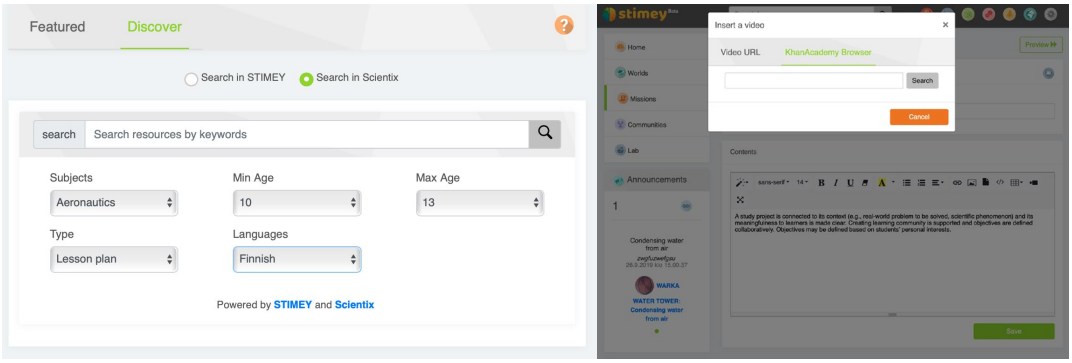

Figure 25 *STIMEY search in Scientix and the use of the Khan Academy browser for inserting videos*

3.10 Games and gamification

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

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

Concrete example: STIMEY serious games entail, for instance, *Rocket Scientist* (see Figure 15), which is a playful simulation of the management of the life of a STEM researcher, and *Business Incubator* (see Figure 16), which is a simulation of managing a start-up company. Also, STIMEY Settlers Fantasy game allows both creating and playing games (Figure 17). Gamification is offered through points, which can be achieved by completing different kinds of activities on the platform (see Figure 26).

Natalia, a Belarussian secondary school teacher, used Business Incubator in order to simulate managing a start-up company. Students could select businesses to buy based on the available resources and their research into businesses' profits and losses. They could also see how their income fluctuates. By watching the news, they would be more aware of potential strikes that can affect their fortune. After playing the game, students first wrote down what they learned about the business using their e-portfolio and then discussed their ideas by using the Community.

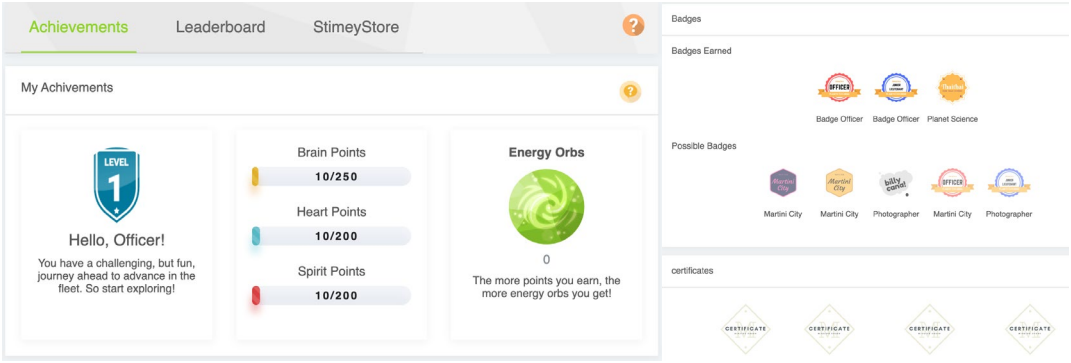

Figure 26 *STIMEY achievements and badges*

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 both digital and non-digital media (e.g. video, audio, images, diagrams). Support understanding, interpreting and relating different representations (see also 1.4 Versatility in both novel and conventional tools and methods). Allow storing digital and non-digital but posteriorly digitalised representations.

Concrete example: *STIMEY Mission* can focus, for example, on mixing different liquids. The process can be demonstrated in a real-world experiment. Learners 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.

Maria, a German primary school teacher, created a Mission related to saving the planet. In addition to text, the Mission included a podcast and lots of illustrative images and videos, such as on recycling. Maria also brought different materials to the classroom which learners needed to classify to different containers found at school. They were asked to take pictures of how materials were classified and save them in their personal e-portfolios.

3 WAYS OF TEACHING AND LEARNING – FURTHER READING

Introduction

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3.1 Active knowledge construction

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Socio-emotional aspects

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) and Mäkelä, Fenyvesi and Mäki-Kuutti (2020).

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 and 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. Social networking that fosters supporting networks and caring relationships with peers (social wellbeing) as well as support for learners' emotional wellbeing can also be facilitated in collaborative online LEs and are highly relevant particularly in socially and emotionally challenging times.

Concrete example: Use *Discussions* and *Communities* (Figure 20) in the STIMEY platform to form groups, share one's emotions and provide constructive feedback. Interaction with *STIMEY SARA*

robots will support learners' social skills. For instance, *STIMEY SARA* can be used to give learners turns when working as a group. *STIMEY SARA* can be also programmed to be a mediator between learners. It can encourage and offer emotional support to learners and help to develop empathy.

A Finnish primary school teacher, Sami, programs STIMEY SARA to use the names of each learner to encourage them to participate in the group quiz. When the response is not correct, the robot says: 'Don't worry. All of us make mistakes at times. Just don't give up trying'. This cheers the whole class up and sets a good example for peer communication.

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 and 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. The *STIMEY* serious game *Setla* includes a short test after which the learner can enjoy relaxing games for collecting elements needed for water molecules (see Figure 27).

A Belarussian primary school teacher, Arina, discovered the power of STIMEY SARA in making learning a more joyful experience for her group. She used the robot to greet her group at the beginning of the class, to cheer them up during activities and to give final words of encouragement at the end of the class.

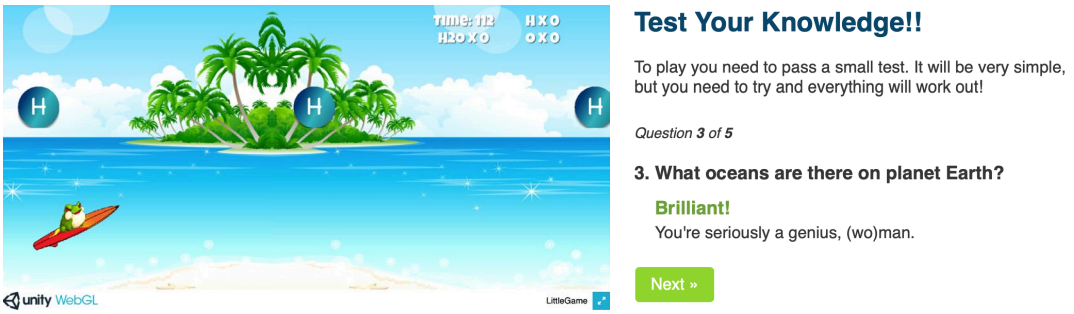


Figure 27 *Example of a STIMEY games in STIMEY Lab*

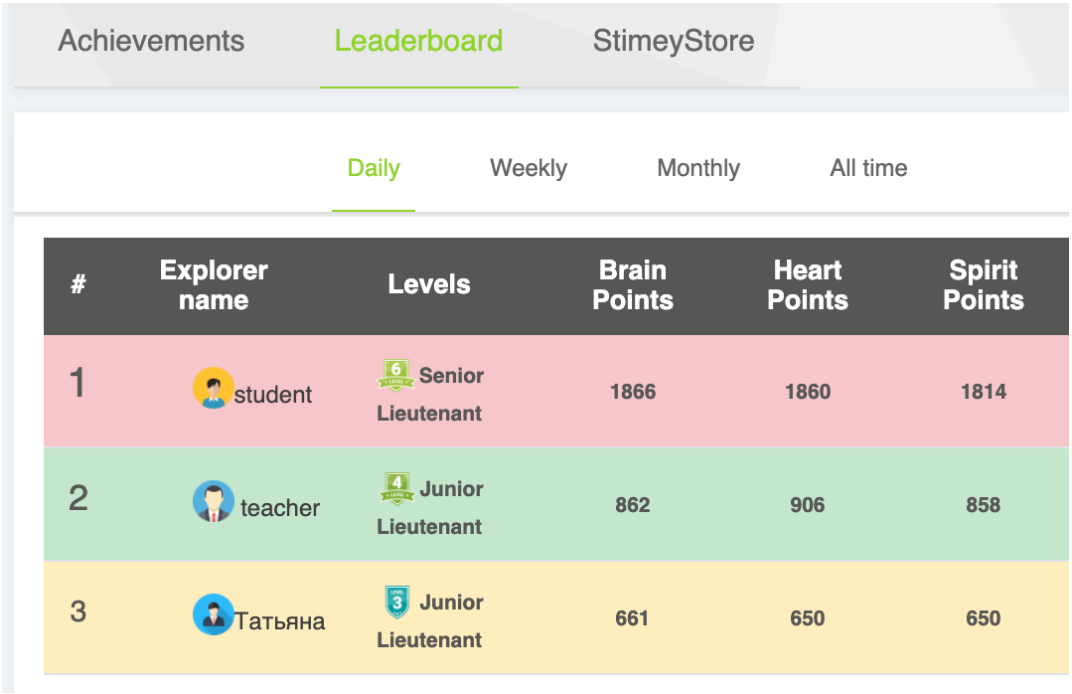
4.3 Extrinsic motivation

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

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

Concrete example: In the *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 achievements will be designed to be used to buy items such as Robot Upgrades in the StimeyStore. Learners can also see the top results in a Leaderboard (Figure 28). *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 harder.

Juan, a Spanish secondary school teacher, was amazed to see how his students got enthusiastic just by observing how different points are accumulated when using STIMEY LE. Also, features such as the Leaderboard motivated them to have a playful competition between themselves.



#	Explorer name	Levels	Brain Points	Heart Points	Spirit Points
1	student	Senior Lieutenant	1866	1860	1814
2	teacher	Junior Lieutenant	862	906	858
3	Татьяна	Junior Lieutenant	661	650	650

Figure 28 *STIMEY Leaderboard*

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 of 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,* learners can be given multiple options to choose from based on their personal interests. Also, *STIMEY Settlers Fantasy* can be used to elaborate the contents of one's own interest. STIMEY LE allows the creation of *Communities* (Figure 20) based on shared interests. Intrinsic motivation may also be supported

by encouraging learners to set their personal daily goals and reflect on the visualisation of their weekly daily goal progress (see Figure 26).

Helena, a Greek secondary school teacher, found out that giving students the possibility to set their own daily goals and reflect on their weekly daily goal progress was a good tool for supporting intrinsic motivation. While STIMEY LE provided them rewards for achieving the goals, the idea was, nonetheless, to help students to find achieving goals as intrinsically rewarding.

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 that 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: Teachers can encourage participation in STIMEY *Communities* and *Chats* (Figure 20) 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). Teachers could also initiate a discussion related to 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.

Ludmila, a Belarussian secondary school teacher, noticed that her students were communicating more freely with one another in STIMEY LE when they were allowed to use nicknames and not to reveal their personal details. She thought that this helped them to treat everyone without discrimination and to get rid of prejudices towards their classmates.

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 of and belonging to networks based on one's interests or experiences. Include visible signs of the community (e.g. group picture, shared work) within shared spaces and e-portfolios (Figure 10).

Concrete example: STIMEY LE allows creating *Communities* (see Figure 23) for different learning groups. Learners 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.

German secondary school teacher Sacha noticed that his students had taken their own initiative in creating Communities to discuss different STEM-related topics. They were keen to select group pictures for their own Community. Students used their Communities to ask for support from their peers when they had doubts.

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 learners and between peers by using communication channels that both teachers and learners are familiar with. Use shared activities and communication in order to foster learner cohesiveness and social engagement.

Concrete example: The STIMEY platform enables teachers and learners to communicate with each other directly in real time by using the *Chat* tool or *Communities* (Figure 20). It is also possible to contact teachers or peers outside the classroom.

Jukka, a primary school teacher from Finland, noticed that he could use the personal chat tool to ask how his learners were doing. Particularly shyer learners also seemed to contact him more easily by chat than by raising their hands to ask questions. Group chats were also used in communication when doing group work.

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 of the LE and the possibility to communicate with teachers and learners. Create access to the school community to actively participate in the wider surrounding community.

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

Berta, a Spanish primary school teacher, was amazed to see how enthusiastic children's parents were to become STIMEY Ambassadors. They represented many different STEM-related professions. Berta agreed with volunteering parents that they would take turns in presenting their work in a videoconference.

4.9 Safety

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

Recommendations and guidelines: Focus both on safety (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 remove the harmful content. Make sure that everyone's right to 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. Teachers can, for instance, analyse together with the learners the feedback given to one another in *Communities* and *Discussion* forums (Figure 20). The STIMEY platform also has a verification system that can be used for verifying schools, teachers, students, parents and Ambassadors, adding credibility and trust to users' accounts. The STIMEY platform includes the possibility to report improper contents and has clear privacy policy guidelines to support security and safety (Figure 29).

Juana, a Spanish secondary school teacher, noticed that before starting to use STIMEY LE with her students, it was important to go through the Platform Student´s Tutorial (Figure 13), also including some references to how to act in a case where one finds misuses in the STIMEY LE. She also orally emphasised the importance of assuring everyone´s right to a safe LE.

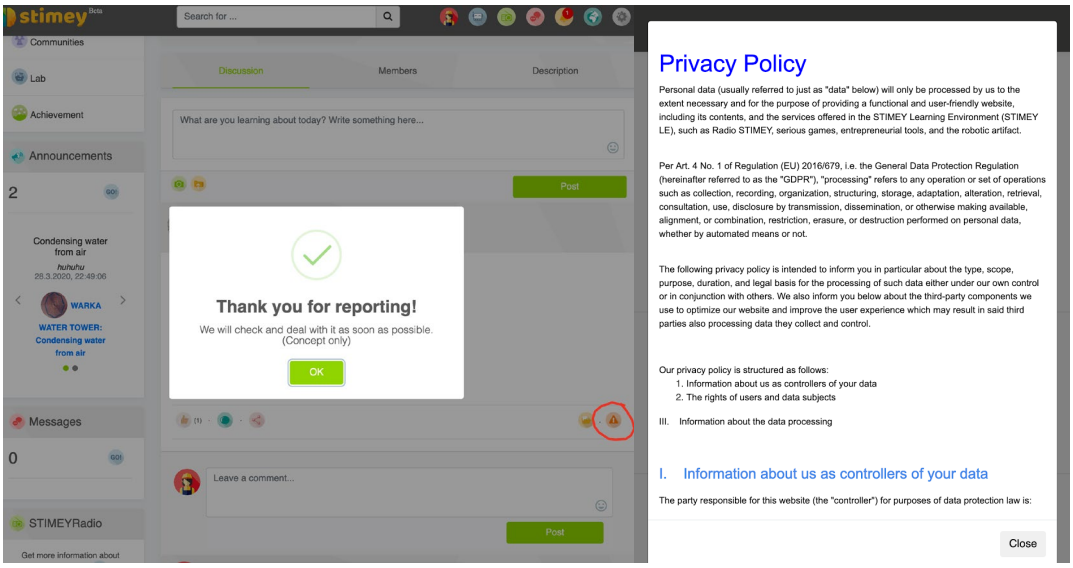


Figure 29 *STIMEY reporting system (left) and Privacy Policy (right)*

4 SOCIO-EMOTIONAL ASPECTS – FURTHER READING

Introduction

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4.1 Social and emotional skills

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Humphrey, N., Kalambouka, A., Wigelsworth, M., Lendrum, A., Deighton, J., & Wolpert, M. (2011). Measures of social and emotional skills for children and young people: A systematic review. *Educational and Psychological Measurement*, *71*(4), 617–637.

4.2 Joy of learning

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Csikszentmihalyi, M. (1997). Happiness and creativity. *The Futurist*, *31*(5), S8.

Rantala, T., & Määttä K. (2012). Ten theses of the joy of learning at primary schools. *Early Child Development and Care*, *182*(1), 87–105.

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4.3 Extrinsic motivation

Deci, E. L., & Ryan, R. M. (2002). Overview of self-determination theory: An organismic dialectical perspective. In E. L. Deci & R. M. Ryan (Eds.), *Handbook of self-determination research* (pp. 3–33). The University of Rochester Press.

Loukomies, A., Pnevmatikos, D., Lavonen, J., Kariotoglou, P., Juuti, K., & Spyrtou, A. (2013). Promoting students' interest and motivation towards science learning: The role of personal needs and motivation orientations. *Journal of Research in Science Education*, *43*(5), 2517–2539.

4.4 Intrinsic motivation

Deci, E. L., & Ryan, R. M. (2002), Overview of self-determination theory: An organismic dialectical perspective. In E. L. Deci and R. M. Ryan (Eds.), *Handbook of self-determination research* (pp. 3–33). The University of Rochester Press.

Loukomies, A., Pnevmatikos, D., Lavonen, J., Kariotoglou, P., Juuti, K., & Spyrtou, A. (2013). Promoting students' interest and motivation towards science learning: The role of personal needs and motivation orientations. *Journal of Research in Science Education*, *43*(5), 2517–2539.

4.5 Inclusion, justice and equity

Polat, F. (2011). Inclusion in education: A step towards social justice. *International Journal of Educational Development, 31*(1), 50–58.

Qvortrup, A., & Qvortrup, L. (2018). Inclusion: Dimensions of inclusion in education. *International Journal of Inclusive Education*, *22*(7), 803–817.

Wayne K., Hoy, C., & Tarter, J. (2004). Organizational justice in schools: No justice without trust. *International Journal of Educational Management*, *18*(4), 250–259.

4.6 Sense of belonging

St-Amand, J., Girard, S., & Smith, J. (2017). Sense of belonging at school: Defining attributes, determinants, and sustaining strategies. *IAFOR Journal of Education*, *5*(2), 105–119.

4.7 Teacher–student and peer relations

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4.8 Home-school and wider community relations

Lewis, A. E., & Forman, T. A. (2002). Contestation or collaboration? A comparative study of home–school relations. *Anthropology & Education Quarterly*, *33*, 60–89.

Santiago, R. T., Garbacz, S. A., Beattie, T., & Moore, C. L. (2016). Parent-teacher relationships in elementary school: An examination of parent-teacher trust. *Psychology in the Schools*, *53*, 1003–1017.

Zimmerman, H. T., & Bell, P. (2014). Where young people see science: Everyday activities connected to science. *International Journal of Science Education, 4*(1), 25–53.

4.9 Safety

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Educational compatibility

Educational compatibility

This category refers to the importance of assuring that **LE is educationally compatible with the local contexts of use**. Compatibility with **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 the 'design and use of technological learning solutions' (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 the cognitive (e.g. conceptual change, prediction, anticipation of consequences) and affective (e.g. interest, engagement, teacher–student relations) dimensions of learning. Times such as the COVID-19 pandemic show that, in addition to local educational challenges, there are global challenges in education, for instance, in relation to organising hybrid or online learning that need to be tackled.

Concrete example: STIMEY LE offers opportunities for well-guided online learning by means of Missions with instructions. Video recordings can also be embedded within Missions to replace synchronised face-to-face instructions. The STIMEY platform's serious games (Figure 30) may be used to increase learner's motivation and awareness of possible STEM careers. Resources such as the *Mental Calculator* tool (Figure 31) can be used to improve performance in mathematics.

> *Maria, a Spanish primary school teacher, noticed that the use of the Mental Calculator tool had helped her learners to improve their skills. She also included additional math exercises in her Missions for individuals who had more challenges in math in order to get versatile practising opportunities.*

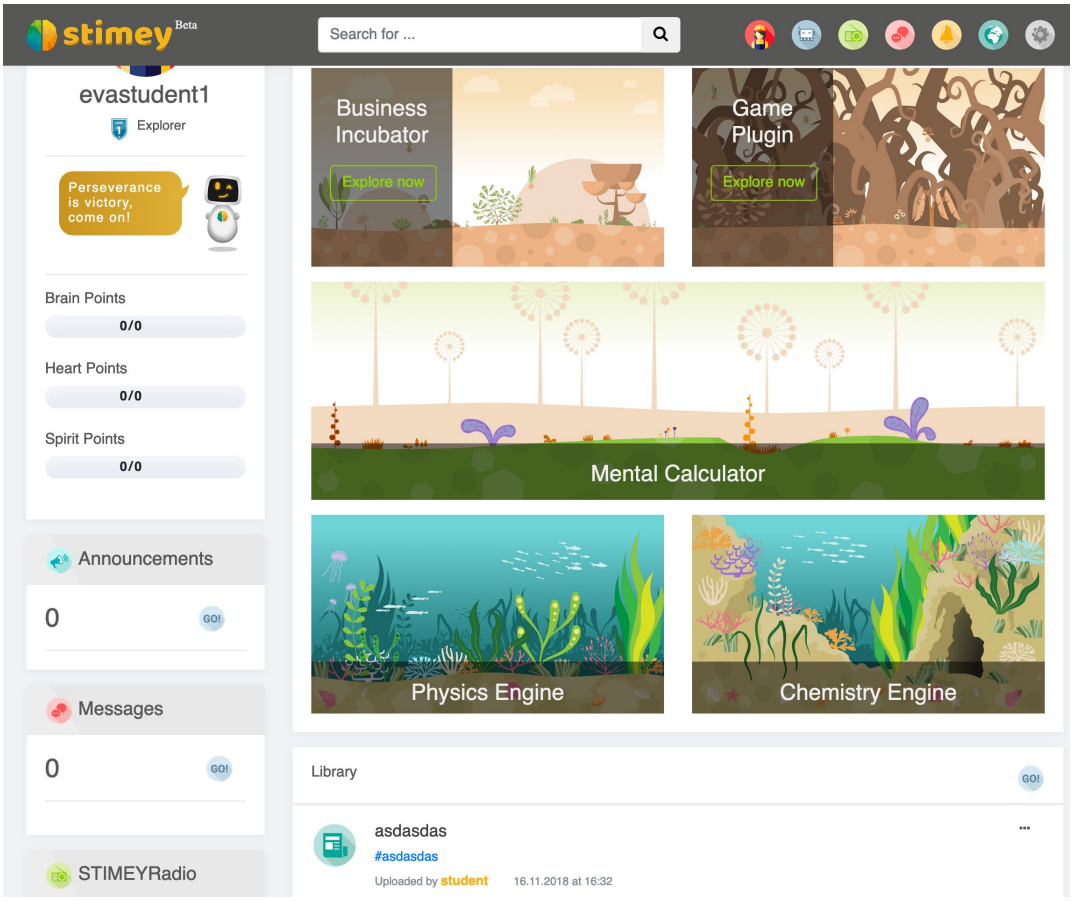

Figure 30 *STIMEY serious games in Lab*

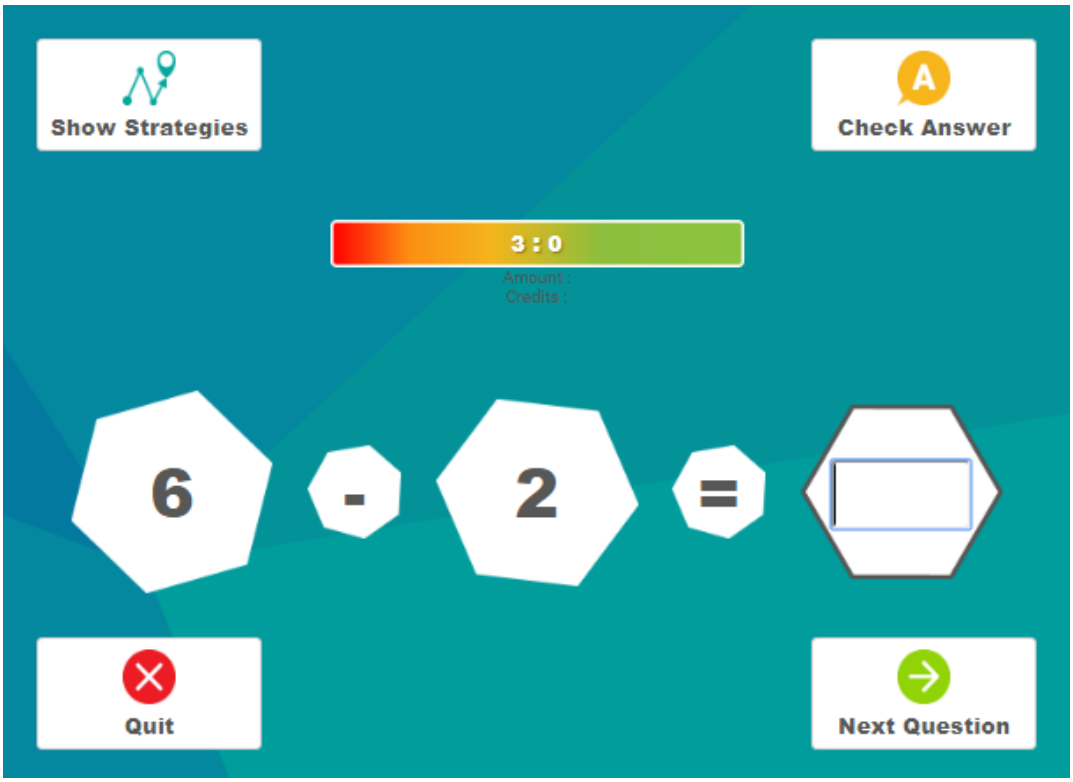

Figure 31 *STIMEY Mental Calculator*

5.2 Educational system

Pedagogical principle: *Assuring that the LE fits with 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 of primary, lower and upper secondary school. Support the creation of user-generated activities which fit the 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 age- and development-related differences in the maturity level depending on the age children start primary or secondary school in each country.

Petri, a secondary school teacher from Finland, was delighted to discover that there were many science Missions created in English in STIMEY LE that he could translate to Finnish and also adapt to the Finnish curriculum.

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 for the STIMEY platform. Tags are created to indicate the age and curriculum appropriateness of the materials. Content created in other countries can be used as a template (Figure 32), 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 create meaningful connections between the different subjects in a curriculum.

Mikko, a secondary school teacher from Finland, created STIMEY Missions for practising math problems for the matriculation examinations that his upper secondary school students were about to have.

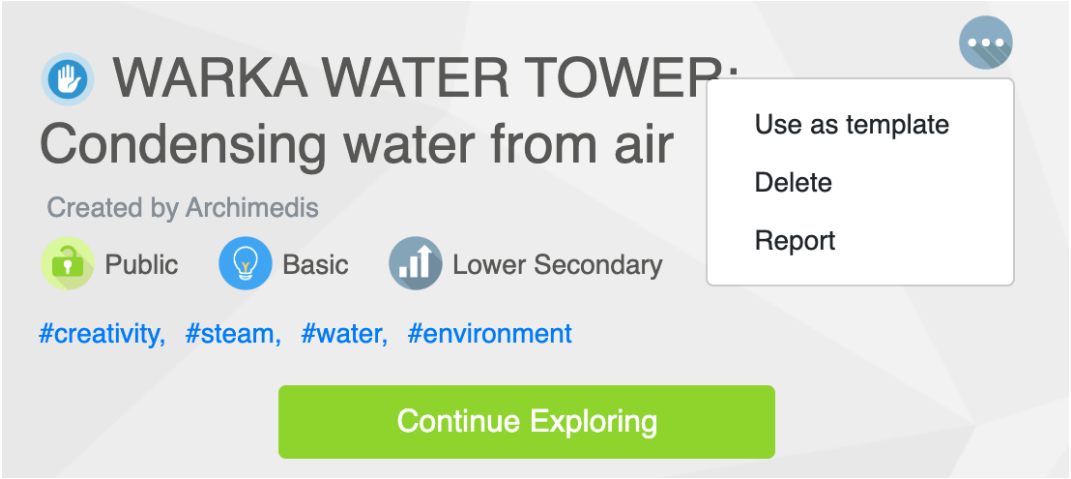

Figure 32 *Use of STIMEY Mission as a template*

5.4 Subject-specific goals and contents

Pedagogical principle: *Assuring that the LE promotes the acquisition of learning the 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 differences, such as 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 33) supports 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.

A Belarussian primary school teacher, Sviatlana, was happy to notice that it was possible to limit the search of Missions for her educational level and also check only the Missions created in her language of instruction.

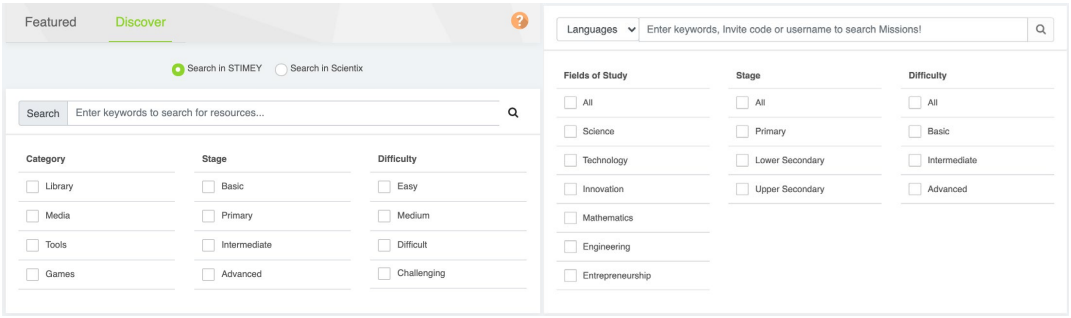

Figure 33 *STIMEY search engines: Lab (Right) and Missions (Left)*

5.5 Organisational practices

Pedagogical principle: *Fitting STIMEY LE to the local institutions' everyday organisational practices and operations.*

Recommendations and guidelines: Assure that STIMEY LE can also be used in educational organisations where teachers have, for example, fewer development opportunities, less collaboration amongst teachers or very large classroom sizes. The 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 they can share their experiences and good practices related to the LE's 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. Additionally, STIMEY LE enables creating teacher Communities to discuss and share teaching and learning related concerns.

Teachers in different countries highly valued the tutorials created for teachers (Figure 13). There were always some teachers who learned quickly how to use STIMEY LE. Their help was found to be valuable for teachers with less experience using similar environments.

5.6 Educational practices at group level

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

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

Concrete example: STIMEY LE allows for local variation regarding 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).

Helena, a Greek secondary school teacher, started to use STIMEY LE by placing the contents of her lectures on the platform, but when she felt comfortable enough with its different components, she started progressively using Communities, Laboratory resources and finally even Radio STIMEY podcasts in her teaching.

5.7 Assessment system and practices

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

Recommendations and guidelines: Enable versatility in 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 (see 1.3 Support for teaching and learning). Use embedded assessment (e.g. automatic points, progress tracking), social feedback and the e-portfolio feature 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 learners' 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 to the learners themselves. Learners can provide feedback to one another using social media features such as *Communities* and *Discussion* (Figure 20).

Jukka, a primary school teacher from Finland, noticed that he could use different data accumulating in the STIMEY platform, such as in the challenges in the Missions he created, the results of the Fantasy games played and the Mental Calculator tool as well as different brain, heart and spirit points to support his evaluation.

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 in 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: 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 the saving of outcomes representing different activities in the *STIMEY e-portfolio*. STIMEY LE encourages including the use of *STIMEY SARA* robots to teach and learn.

Oleg, a Belarussian secondary school teacher, created Missions that, apart from some interactive contents such as videos and challenges, followed the logic of his textbooks. He was, however, encouraged to try out new tools which were introduced in Missions his colleagues were using that he could use as a template for his own classes.

5 EDUCATIONAL COMPATIBILITY – FURTHER READING

Introduction

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Jacobson, M. J. (2015). Education as a complex system: Implications for educational research and policy. *Modeling Complex Systems for Public Policies*, 301–316.

Mikk, J., Krips, H., Säälik, Ü., & Kalk, K. (2016). Relationships between student perception of teacher-student relations and PISA results in mathematics and science. *International Journal of Science and Mathematics Education*, *14*(8), 1437–1454.

5.2 Educational system

Jacobson, M. J. (2015). Education as a complex system: Implications for educational research and policy. *Modeling Complex Systems for Public Policies*, 301–316.

Giménez, V., Thieme, C., Prior, D., & Tortosa-Ausina, E. (2017). An international comparison of educational systems: A temporal analysis in presence of bad outputs. *Journal of Productivity Analysis*, *47*(1), 83–101.

5.3 General curricular goals and contents

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Wyse, D., & Ferrari, A. (2015). Creativity and education: Comparing the national curricula of the states of the European Union and the United Kingdom. *British Educational Research Journal, 41*(1), 30–47.

5.4 Subject-specific goals and contents

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5.6 Educational practices at group level

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Gender inclusion

Gender inclusion

The gender-sensitive approach in the LE design and use is about creating equal learning opportunities for all learners 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 the activation of learners. The design principles in this pedagogical framework include 1.5 Versatility in both novel and conventional tools and methods, 1.2 Personalisation and 3.3 Collaborative work supporting gender- and diversity-conscious teaching and learning.

The well-known phenomenon of girls dropping out from STEM subjects early on requires a particularly sensitive approach to socially rooted gender stereotypes in these subjects. The early stereotyping of children in regard to STEM and the lack of female STEM role models as well as low self-confidence among girls leads to the early loss of engagement and motivation of many female learners in STEM subjects.

The focus of gender-related 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 various Missions with gender topics among the Missions in STIMEY LE addressing 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 learners have equal opportunities; the LE and its atmosphere positively influence their motivation and willingness to learn. The gender and diversity awareness of teachers, which is supported in STIMEY LE, is crucial in motivating female learners towards STEM studies and careers. There are also exemplary gender-sensitive 'Worlds', such as 'Career and study choices free of gender stereotypes' and 'Gender inclusion on STIMEY', with various Missions available on the platform (see Figure 34).

Teachers at a secondary school in Spain discovered the gender-sensitive STEM Missions 'Career and study choices free of gender stereotypes', 'My role model and I', 'What do I want to do for a living', 'Parent-teacher conference: Career and study choice – cliché free support' and 'It's all cliché' as great material, which they then decided to translate and adapt to the Spanish context in order to have sessions with both students and parents about gender in career choices.

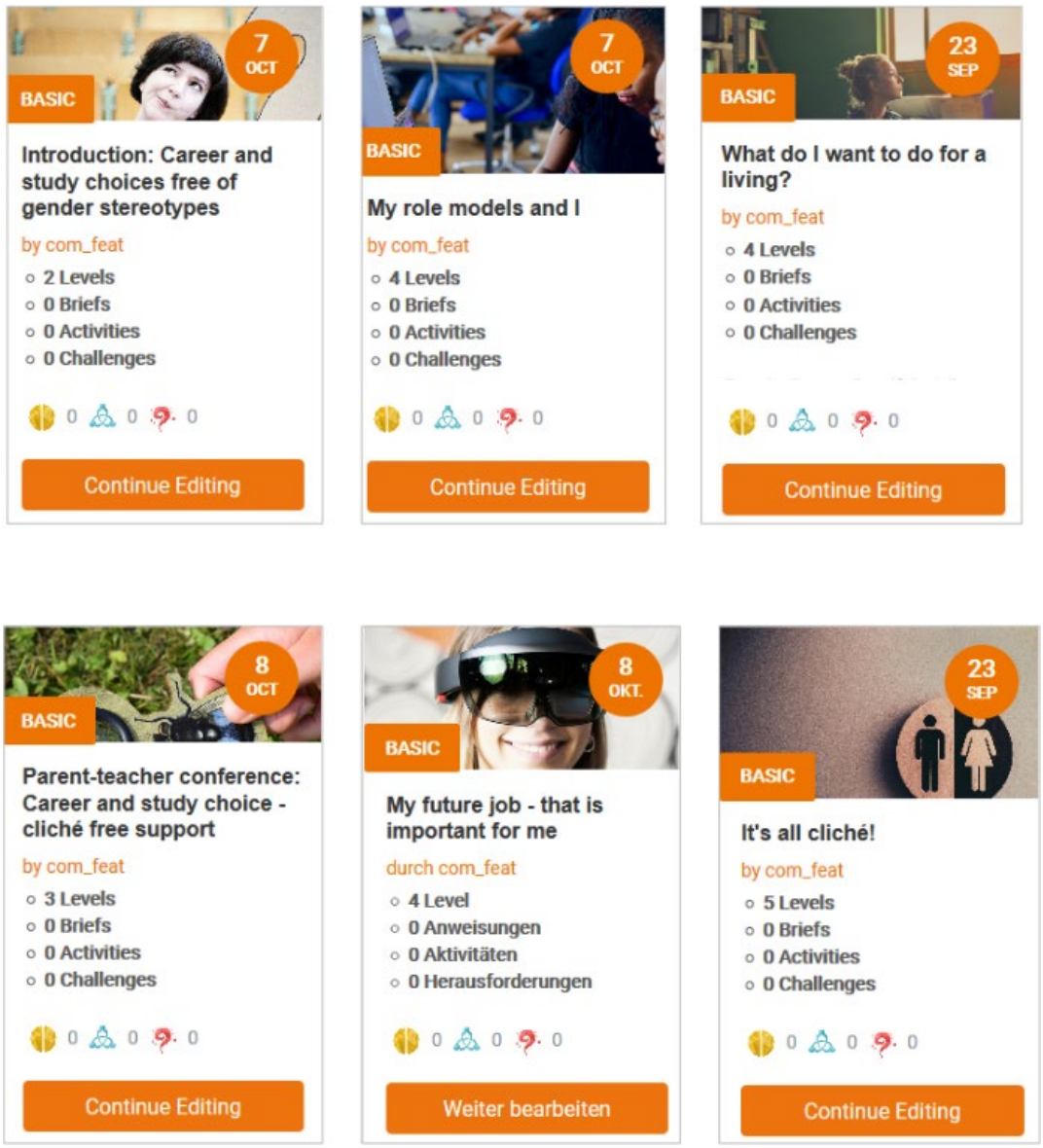

Figure 34 *Gender-related missions on the STIMEY platform*

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, such as by female STEM professionals involved in STIMEY. 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 learners are invited to share their STEM experience in STIMEY and to make learners aware of future prospects in STEM. In STIMEY LE, all learners are addressed as *Explorers* regardless of their gender differences.

In a Finnish secondary school, a special effort was made to invite female STEM professionals to subscribe as STIMEY Ambassadors. Online meetings in which volunteering professionals presented their work helped to get rid of some gender stereotypes in STEM professions.

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 particularly girls' self-confidence in STEM as they tend to underestimate themselves and their STEM abilities. 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 made 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 the STIMEY platform and performance-based recognition as well as giving equal attention to different needs and not controlling the work too much inspire learners to improve their personal or group performance. STIMEY LE offers opportunities to experiment and to create with gender-mixed groups or single-gender groups. *STIMEY SARA* robots can be programmed to provide empowering and strengthening feedback.

Penelope, a Greek secondary school teacher, invited her students to design empowering and strengthening messages particularly for girls that could be programmed into a STIMEY SARA robot.

6.4 Emphasising the relevance of STEM in everyday 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 learners' self-selection out of technology and engineering activities and contribute to attracting and motivating 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. Girls are significantly more interested in science activities that include societal, real-life and creative aspects. And such real-life topics also help to introduce interdisciplinary topics in STEM, which promote the interest of those who are not STEM enthusiasts per se. These topics are considered, for instance, in a STIMEY World named 'STEM – Something for me?' and its Missions (see Figure 35).

Heike, a German secondary school teacher, found out that the girls in her class enjoyed a lot of the STIMEY World 'STEM – Something for me?', which includes building, for example, a simple paper bridge to experiment with that requires very little material but a lot of creativity. It helped the girls to see how STEM is related to very practical and creative issues.

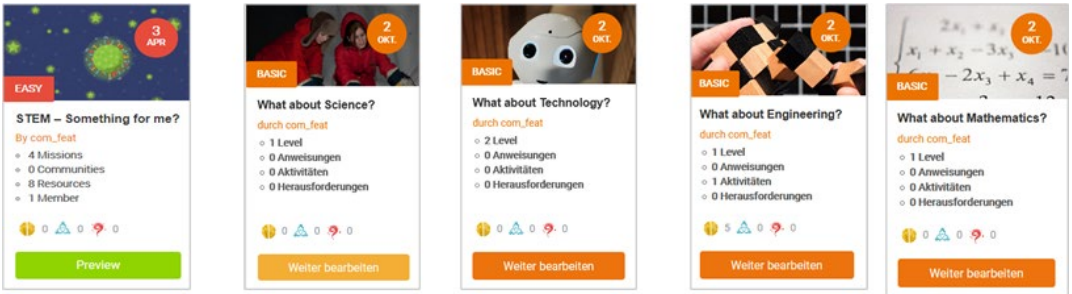

Figure 35 *Gender-related World and its Missions on the STIMEY platform*

6 GENDER INCLUSION – FURTHER READING

6.1 Gender-sensitive teaching and learning

The toolbox Gender and Diversity in Teaching by Freie Universität Berlin https://www.genderdiversitylehre.fu-berlin.de/en/toolbox/index.html

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6.4. Emphasising relevance of STEM in every-day life

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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 used 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 and 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.