

# Solar Village – A Gamified Learning Environment for Higher Energy Engineering Education

Kari Alanne



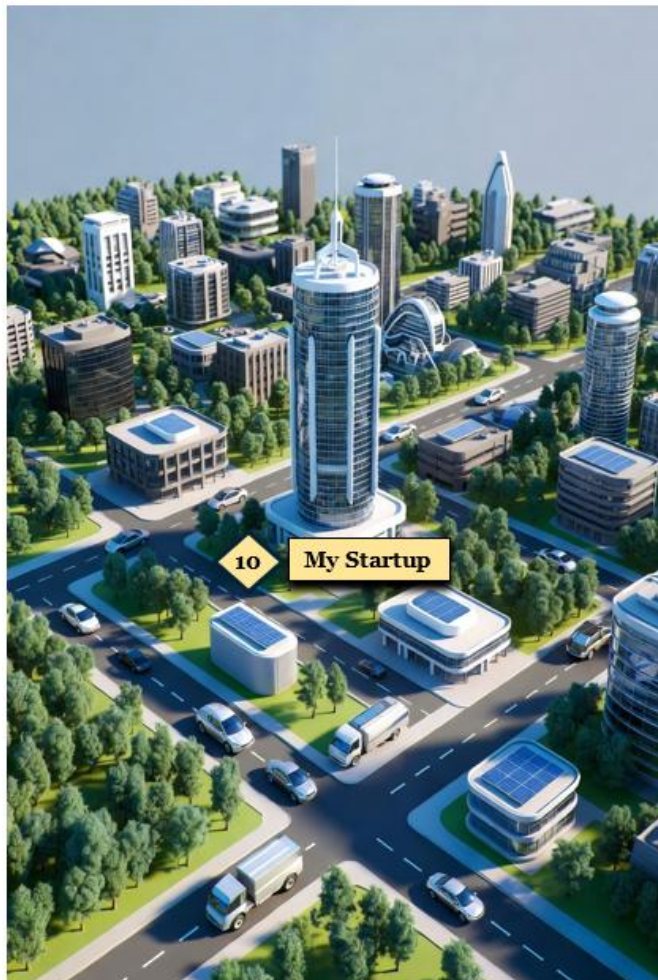


# Solar Village – A Gamified Learning Environment for Higher Energy Engineering Education

November 2025

Author: Kari Alanne

Aalto University Dept. of Mechanical Engineering



Aalto University publication series  
Science, Technology 7/2025

© Kari Alanne

ISBN 978-952-64-2915-1 (paperback)

ISBN 978-952-64-2914-4 (PDF)

ISSN 1799- 4896 (print)

ISSN 1799- 490X (PDF)

<https://urn.fi/URN:ISBN:978-952-64-2914-4>

This work is licensed under CC BY 4.0. To view a copy of this license, visit

<https://creativecommons.org/licenses/by/4.0/>.

[aaltodoc.aalto.fi](http://aaltodoc.aalto.fi)

2025

# Contents

Abstract.....	4
1 Introduction .....	5
2 Gameplay .....	6
2.1 General .....	6
2.2 Establishing a New Startup Company .....	7
2.3 Business Card.....	9
2.4 Headquarters .....	11
2.5 Centre of Competency .....	12
2.6 Event Manager.....	13
2.7 Resources .....	14
2.8 Balance Sheet.....	15
2.9 Projects .....	16
2.9.1 Type 1: General expertise .....	16
2.9.2 Type 2: Problem-solving.....	17
2.9.3 Type 3: Planning & design.....	18
2.9.4 Type 4: Performance assessment .....	20
2.9.5 Type 5: Scientific research .....	21
2.10 Instructions, guidance and counseling.....	22
2.11 Multiplayer activities .....	24
2.11.1 Business Alliance .....	24
2.11.2 Competitions .....	28
2.12 Leaderboards.....	34
3 Hidden elements of the gamified learning environment .....	36
3.1 Protection .....	36
3.2 Variables and databases .....	37
3.3 Assessment.....	40
3.3.1 Reference solutions.....	40
3.3.2 Scoring criteria .....	41
3.3.3 AI-assisted evaluation .....	44
3.4 Settings .....	50
4 Future development of the Solar Village.....	52
4.1 Platform.....	52
4.2 User interface.....	53
4.3 Events.....	56
4.4 Resources .....	61
4.5 Other .....	63
5 Discussion .....	65
5.1 Opportunities and challenges .....	65
5.2 On the university teachers' role in the future.....	67
6 Conclusions .....	68
References .....	69

## **Abstract**

In this report, the novel gamified learning environment “Solar Village” for higher engineering education is described. The principles of gameplay, platform, user interface, and workspaces are explained through commentaries and examples taken from two energy engineering courses provided by the Aalto University. The next steps of the learning environment’s further evolution are discussed. Moreover, the opportunities and challenges of a comprehensive gamified education model are addressed, including the perspectives of student learning and the society plus the teacher’s role in the digitalized and AI-assisted higher education. The report is to encourage university teachers and software developers to consider implementing the presented learning environment in new courses, degree programmes, and disciplines. It is to provide sufficient basis to guide the further development of the learning environment by way of proper game engines.

# 1 Introduction

The learning-promoting effect of games originates from their ability to increase the pleasure of learning, which strengthens the learner's motivation to receive knowledge and skills (Torres & Macedo, 2000). Moreover, the learners can take on different roles, which helps them to reflect on their attitudes to various perspectives (Romanov & Holler, 2021). One of the key challenges in game development is to find a balance between learning and entertainment. Likewise, the games should include elements to promote interaction between the learners (Juan & Chao, 2015). Digital learning games have been utilized in the higher engineering education of energy technology from the early 2000s (e.g., Varano, Patel, Asnani, TsyKalyuk & Idowu (2006); Cetin (2012); Juan & Chao (2015); Toba, Seck & Ngatang (2018); Suzuki, Shibuya & Kanagawa (2021)).

In an educational development project funded by Aalto University, School of Engineering (ENG), a learning game including a design challenge for the course “Energy Systems” was developed, implemented and reported by Alanne et al. (2023). The results of the pedagogic survey implied that the gamification had both enhanced the learning outcome and increased the motivation. The interaction between students had increased remarkably. On the other hand, the teacher’s workload was eased off due to avoiding routine tasks such as scoring. The students experienced the gamified learning to encourage asking “What if?” and “What next?” questions. For the further development of the game, however, the respondents wanted more “intelligence” to guide them forward in situations, where they confronted difficulties. The demand for more “entertaining” or “game-like” features was recognized, too.

In Alanne (2016), a comprehensive gamified educational model was presented, where gamified learning is extended to cover engineering students’ entire study path and an official salary recommendation for graduates is proposed. Motivated by these concepts and prospects, this report is to describe the gamified learning environment “Solar Village” to replace learning assignments, courses, and, over time, the entire curriculum in energy engineering. So far, the ideas have been partly implemented and demonstrated in the Aalto courses “Energy Systems” and “Sustainable Building Energy Systems”.

In Sections 2 and 3 of this report, the central game elements and their implementation are explained and showcased using Microsoft Excel worksheet functions and macros. Section 4 is dedicated to the next steps of the learning environment’s future evolution. In Section 5, the opportunities and strengths of the comprehensive gamified educational model are addressed and the university teacher’s role in the comprehensive gamified educational model with high level of digitalization and AI assistance is anticipated. The aim is to provide motivation and guidelines for the further development of the “Solar Village” environment, including its implementation using game engines other than MS Excel and in contexts other than energy engineering curriculum.

## 2 Gameplay

### 2.1 General

The “Solar Village” learning environment has adopted its idea from survival strategy games, which begin with building a base using minimal equipment, whereas the focus is in developing the base by scavenging resources and crafting items. The games are open-ended, allowing players to set their own goals and playstyles. Both single-player and multiplayer modes are enabled.

The “Solar Village” starts with establishing a new startup company, the market value of which the player tries to increase by participating in various types of events associated with the study path. To that end, the player needs to pursue resources (e.g., an access to advanced simulation tools) during the gameplay. The playfield is a domain the students of one class belong to. A new domain is established for each class at the beginning of their study path (e.g., Aalto ENG students beginning in 2025).

The gameplay can be scaled up to cover entire curricula and include participants from both domestic and international universities. Leaderboards are updated regularly by ranking the players’ achievements and the startup market values. This encourages the student to pursue always higher skill level and market value in comparison with the peers. The “Solar Village” can be “played through” in the sense that a final certificate and recommended salary are unlocked when the student graduates, but the participation in events and market value have no limit. In the multi-player mode, the player can establish or join a business alliance with other players in the same domain (class), which again may partake increasingly challenging events (projects and student competitions). A single student may play various roles in the business alliance.

The user interface of the “Solar Village” is “intuitive”, which means that the player is guided by coloured buttons, and immediate feedback is provided. In MS Excel, buttons and text fonts are marked by **green colour** to guide forward and indicate whether the player’s solution to a given problem is acceptable. Examples will be shown throughout this report. Colour codes are also used to indicate the progress level and the level of difficulty of events. Four main levels (Lvl 0, 1, 2, and 3) can be unlocked in the course “Energy Systems” of Aalto University. They are exemplified with colour codes and descriptions in Table 1.

Table 1. Summary of level-specific colours in the course “Energy Systems”.

<b>Level</b>	<b>Colour code</b>	<b>Description</b>
Lvl 0	RGB (255,255,255) or #FFFFFF	Beginner level of difficulty/achievement
Lvl 1	RGB (221,235,247) or #DDEBF7	Junior level of difficulty/achievement
Lvl 2	RGB (252,228,214) or #FCE4D6	Advanced level of difficulty/achievement
Lvl 3	RGB (255,230,153) or #FFE699	Master level of difficulty/achievement

In contrast to commercial survival strategy games, the incentive to spend money to obtain enhanced resources has been replaced in the “Solar Village” by an incentive to simply study more. In Table 2, selected features of the “Solar Village” are compared with the dystopic survival strategy game “State of Survival” (<https://stateofsurvival.game/en>).

Table 2. Comparison between selected features of “Solar Village” and their counterparts in “State of Survival”.

<b>Feature</b>	<b>Solar Village</b>	<b>State of Survival</b>
The Base	Startup company	Settlement of survivors
Playfield	Domain / Class in Academic / Business world	Dystopic State / World map
Player’s role	Chief executive officer (CEO) of a startup company	Chief of the settlement
Objective(s)	To increase market value To raise HQ / CEO level To learn skills/knowledge	To increase battle power To raise HQ / chief level To acquire resources
Events	Projects Student competitions	Recurring missions Special events
Multiplayer mode	Business alliance	Military alliance
Virtual currency	Solar Credits	Various (e.g., “Biocaps”, “Flawless Pearls” etc.)
Resources	Data tables & nomograms Computational tools Virtual assistants	Buildings War machines & components Heroes & troops

## 2.2 Establishing a New Startup Company

The first time when a player starts the “Solar Village” environment, a welcoming window is launched, where the name “Solar Village” is shown. In MS Excel, the welcoming window is a user form, where an AI-generated photo depicting a 3D map of a solar-powered housing area is used as a background (See: the cover of this document). Each game element of the “Solar Village” has been implemented in a separate Excel worksheet (tab), which is called workspace. In the first workspace (worksheet), a short introduction to the gamified learning environment is shown.

When played first time, the first workspace (introduction) guides the player to the next workspace, where establishing the new startup company is briefly explained and writeable text fields are unlocked for the player’s name, student number, nickname (optional) and the startup company name (with suggestion, e.g., “MyStartup”).

The workspace also contains a suitability test with an aim to challenge the student to seek his/her professional identity and potential role as a team member. In the “Energy Systems” course implementation in MS Excel, the testing has been demonstrated through a simplified and a playful approach using sliders that allow the players to evaluate their identities on a scale 0...10 with respect to five attributes. The attributes are summarized in Table 3.

Table 3. Descriptions of suitability attributes.

<b>Attr.</b>	<b>Description</b>	<b>Expert oriented identity</b>	<b>Sales oriented identity</b>
1	Sociability	I like to work alone.	I like to work in a team.
2	Self-expression	I like to write rather than to talk.	I am talkative.
3	Interaction	I am introverted.	I am extroverted.
4	Decision-making	I am systematic.	I am spontaneous.
5	Detail orientation	I am more interested in detail.	I am more interested in entities.

The slider values are interpreted so that the minimum slider value (0) represents fully “expert oriented” identities, whereas the maximum value (10) is assigned to “sales oriented” ones. The test result is a single number defined as the average of the slider values for the five attributes, which is normalized between 0 and 1. The result is converted to verbal characterizations (startup profile, CEO profile) by comparing it against the range of threshold values as shown in Table 4.

Table 4. Threshold values of a test result and their verbal characterizations.

<b>Ranges of threshold values</b>	<b>Verbal characterizations</b>	
	<b>Startup profile</b>	<b>CEO profile</b>
0...0.25	Design office	Designer
0.25...0.45	“	Foreman
0.45...0.5	Consulting office	“
0.5...0.55	“	Organizer
0.55...0.75	Sales & marketing	“
0.75...0.9	“	Consultant
0.9...1	“	Salesman

Besides acting as the students’ tool to reflect on their professional identities, the result of the suitability test can be employed to assign individually targeted events or related input data to the players. In the course “Energy Systems”, for example, the annual set of weather data was allocated according to the test result. Regarding the verbal characterizations, given that the CEO was profiled as “Designer” and the startup as “Design office”, the weather data of January 1 was provided. One must note that the suitability test presented above is not based on any established scientific theory. It is a “humbug” test just for demonstration purposes. Scientifically more solid approaches will be discussed in Section 4.5 of this report.

When the new startup company has been established, the interface locks the input fields and the suitability test items (sliders), records the player data in a database, declares the sequence completed, assigns the initial market value for the established startup, unlocks workspaces for the newly opened game elements, and guides the player to survey them. In the MS Excel user interface, the recently unlocked tabs are not just made visible but marked by the green colour. The suitability test is rewarded by adding 1000 € to the startup's market value (which was zero) and proclaiming the increment in a message box (+1000 €).

## 2.3 Business Card

The workspace “Business Card” is a simple information board that contains the following data fields:

- Startup name
- Startup profile
- Startup market value
- Name of CEO
- ID of CEO (student number)
- CEO profile (+ CEO level)
- Skills and knowledge (of the CEO)

The variable data recorded by the Business Card is updated automatically during the gameplay. The startup market value increments depend on the extent and difficulty level of the events following specific rules assigned by the game developer. The rules are discussed with more details later in the document.

The CEO level is an integer number attached to the CEO profile. The level can be elevated during the gameplay depending on the skills and knowledge items the student has achieved by participating in events. In the course “Energy Systems”, the maximum available CEO level has been set to three (3). This requires that all the twelve (12) level-ups in ten (10) different categories of skills/knowledge are accomplished. The ten categories of skills and knowledge of the course “Energy Systems” are listed below:

- Professional identity (max. 1 level-up can be obtained)
- Heat loss and heating demand of a building (1)
- Energy consumption of a building (1)
- Saving potential of energy renovations (1)
- Economic viability of energy renovations (1)
- Steam power plant process (1)
- Energy efficiency of steam power plant (1)
- Solar PV generation (2)
- Energy storage modelling (1)
- Matching of energy generation and demand (2)

Moreover, the Business Card presents a picture of the Headquarters (HQ), which evolves during the gameplay. The HQ can be upgraded (to level 3 at maximum, the level is shown as an integer at the bottom right corner of the HQ photo) by investing Solar Credits (the virtual currency) obtained from the events.

Furthermore, there is an embedded image in the bottom left sector of the Business Card to unlock the certificate “approved” when the game is “played through”. In a study path, this refers to graduation (or a passed course). The final grade (and the possible salary recommendation) can be shown on the Business Card, if applicable.

The screenshot in Fig. 1 exemplifies the Business Card workspace of the “Solar Village” environment (version Beta 1.0) implemented in the course “Energy Systems”. Note that the bar on the top of the screen has the brown-yellow background colour “RGB (255,230,153)”, which has been set to manifest the CEO level (Lvl 3). The market value is shown on the top of all the workspaces apart from the welcoming space and the establishment of the new startup. The Business Card is to include the name of the domain through which the player has registered, and the business alliance he or she has joined, but those features are not yet available.



My Startup: Business Card		Market value: 12810 €
	<b>Startup:</b> My Startup <b>Startup profile:</b> Sales & marketing <b>Market value:</b> 12 810 €	
	<b>CEO:</b> CEO.1 <b>ID:</b> 12345 <b>CEO profile:</b> Organizer Lvl 3 <span style="float: right;">***</span>	
	<b>Skills/knowledge:</b> Professional identity	1/1
	Heat loss and heating demand of a building	1/1
	Energy consumption of a building	1/1
	Saving potential of energy renovations	1/1
	Economic viability of energy renovations	1/1
	Steam power plant process	1/1
	Energy efficiency of steam power plant	1/1
	Solar PV generation	2/2
	Energy storage modelling	1/1
	Matching of energy generation and demand	2/2

Figure 1. “Business Card” of the “Solar Village” in the “Energy Systems” course.

## 2.4 Headquarters

The “Headquarters” (HQ) workspace is a completely “game-like” element in the “Solar Village” learning environment. It is to add bonuses that boost the startups’ strength in competitive events. The players use the in-built virtual currency (Solar Credits, SC) to upgrade the HQ toward higher levels and more pompous appearance. By showing the level and appearance of the HQ on the Business Card (which is planned to be visible for the other players, too), the students are challenged to compete – which, in turn, is enabled by participating in more events and by performing as well as possible.

In the Excel implementation, the HQ upgrade requires upgrading its four (4) components, namely, i) real estate, ii), building, iii) workrooms, and iv) equipment. A fixed number of Solar Credits is required to upgrade each component. For the real estate and the building, the cost of one level-up is SC100 and for the workrooms and equipment it is SC50. Correspondingly, one level-up of the real estate/building raises the startup’s market value by 200 € and that of the workrooms/equipment by 100 €. The overall HQ level is equal to the minimum achieved level among the four components. For example, if the real estate level is two (2) and the level of all the rest of the components is three (3), the overall HQ level is two (2). The overall HQ upgrade of one level raises the market value by 500 €.

The implementation of the HQ workspace for the course “Energy Systems” is depicted in Fig. 2. Here, the overall HQ level is two (2), and the upgrade to Lvl 3 requires upgrading the real estate at the cost of SC100. Given that there is enough SC in the cash, the “Upgrade” button has a green background colour. The colours of the various sections of the box at the bottom of Fig. 2 indicate the upgrade status of each HQ component. The only upgradable component is real estate (at the bottom), which has been marked by the light pink colour code of level two, i.e., RGB (252,228,214).

No	Component	Lvl	Cost [S€]	Status
0	Real estate	2	100	<input type="button" value="Upgrade"/>
1	Building	3	100	<input type="button" value="Maxed"/>
2	Workrooms	3	50	<input type="button" value="Maxed"/>
3	Equipment	3	50	<input type="button" value="Maxed"/>

Figure 2. The implementation of the HQ workspace in the course “Energy Systems”.

## 2.5 Centre of Competency

The “Centre of Competency” workspace is a visual representation of the player’s progress in skills and knowledge required by the course or study path/curriculum. The representation is a network structure with an aim not just to list the content items to be learned, but to describe their relationships and pre-requisites. The name and acquired skill/knowledge level is attached to all the content items and equipped with a simple drawing symbol, which is used consistently everywhere in the learning environment.

The Centre of Competency of the course “Energy Systems” is demonstrated in Fig. 3. Here, all the twelve (12) upgrades in the ten (10) categories of skills/knowledge have been accomplished. The progress is made from the left to the right so that the pre-requisite (on the left) must be acquired before moving forward. The final upgrade (from 1/2 to 2/2) in the category “Matching of energy generation and demand” is new. Thus, the text box has a green background color. The color codes representing the difficulty level of each content item have not yet been implemented in the present version of the “Solar Village”. Hence, their background color is white.

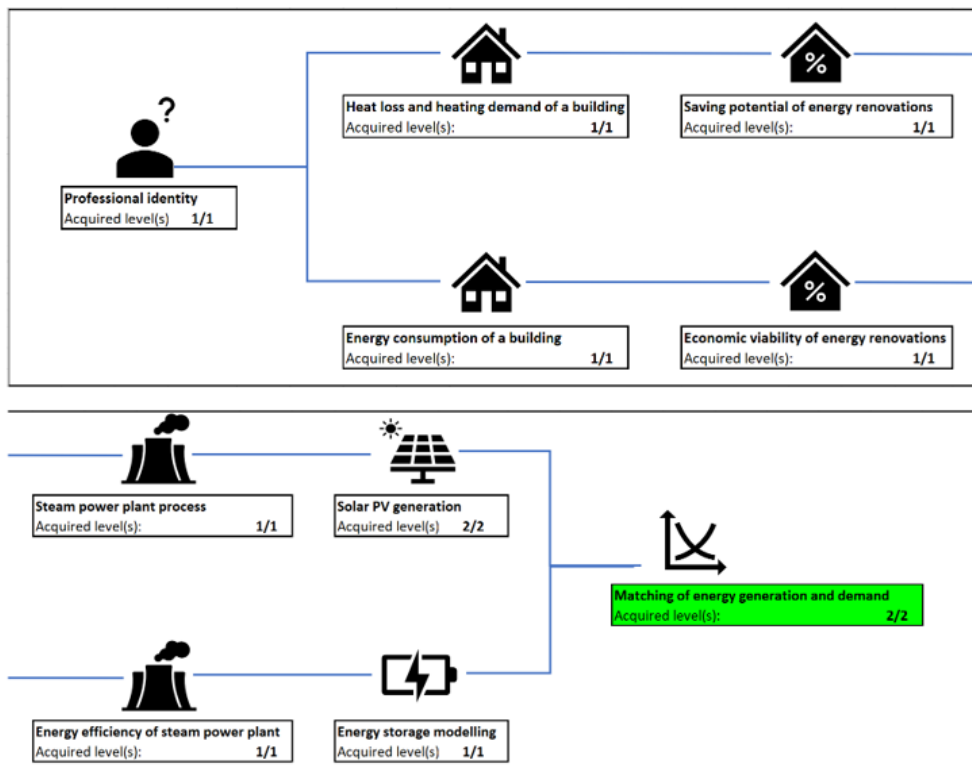


Figure 3. Centre of Competency in the course “Energy Systems”.

## 2.6 Event Manager

The gamified “Solar Village” learning environment is event-based. The student contribution takes place in events (projects and competitions) rather than by assignments and examinations. A key principle is that the access to events is unlocked regularly along the study path, which maintains the excitement and raises the question “What next?” The scheduling of the events is domain specific. The event calendar is reset when a new domain is established, and the launch date and duration of each event is scheduled on daily or weekly basis (e.g., unlocked at the beginning of the week 14).

The “Event manager” workspace is a dashboard of events (projects and competitions) the players can partake via the “Solar Village”. The duty of software developer or an administrator is to continuously update the workspace by with new events and their individual availability dates. The events are recommended to be named with game-like titles rather than just as “exercises”, “assignments”, or “projects”. The event manager also shows a progress indicator to keep the player up to date on the progress. The visibility and status of the events is managed via appropriate control objects.

In Fig. 4, a section of the event manager is exemplified by a screenshot showing two projects from the course “Sustainable Building Energy Systems”. The projects are called “Quest of Resilience” and “Flexi Challenge”. They aim at developing the students’ skills in “Building energy modeling”, “Resilience research”, “Hot water demand profiling”, “Solar collector modeling”, and “Solar thermal system design”. The background color of the project name fields is white (RGB (255,255,255)), which means that no difficulty level has been defined (yet).

In the example, the project “Quest of Resilience” has been already completed (progress 100%, bar color blue), but it can be opened for exploration afterwards, albeit without a possibility to edit the responses (the show/hide button has the caption “Show”). The status button of the project “Flexi Challenge” has been marked with the status “Go” and green, meaning that the project is unlocked for execution (given that by the pre-requisites and availability dates are fulfilled), but not yet started (the show/hide button is disabled, progress 0%, bar color grey).



Project	Status	Progress	Show/Hide
Quest of Resilience	Complete		Show
Flexi Challenge	Go		Not available

Figure 4. An event manager screenshot of the course “Sustainable Building Energy Systems”.

Besides basic information like event name and status, the “Event manager” may provide other information such as event-specific rewards. The “Event manager” of the course “Energy Systems” differs from that of the course “Sustainable Building Energy Systems” in the sense that it lists the expected profits with an aim to help players to predict their workload and to find motivation. In “Energy Systems” (Solar Village Beta v1.0), the total number of projects is eight (8) and the profit is SC300 per project (for now). In other words, the maximum number of solar credits to be earned is SC2400.

## 2.7 Resources

The “Solar Village” learning environment provides an access to a multitude of resources. These are mainly computational tools that are useful or even necessary for participating the events. To that end, there is a database of available resources on the “Resources” workspace where an access to them can be claimed using the Solar Credits. Owning the access to a resource as such raises the startup’s market value.

The table of resources implemented in the course “Energy Systems” is depicted in Fig. 5. The database shows three (3) computational tools, namely, “X Steam Tables”, “Excel Solver” and “TRNSYS Simulation environment”. These tools have been classified according to their value and applicability to missions at various levels of difficulty. The “X Steam Tables” is a simple tool without classification (the resource name field is white (RGB (255,255,255))), whereas the more sophisticated “Excel Solver” tool is an optimization tool considered appropriate for tasks with higher complexity (the color code of Lvl 1, i.e., RGB (221,235,247)). There is no access to the TRNSYS simulation environment in the present implementations of the “Solar Village” environment, but it has been included in the list as an option for the sake of a demonstration.

The acquisition costs for each resource (in SC) are listed in the database, as well as their status of availability. The status button with green background color in Fig. 5 declares that an access to Excel Solver can be claimed (i.e., there are enough solar credits in the cash, and the tool has not been purchased yet). When an access to the tool is claimed, the “Solar Village” automatically activates the Solver Add-in in Excel. The suggested resource-specific market value increments for the “X Steam Tables” and “Excel Solver” are 500 € and 800 €, respectively.

Resource	Cost [S\$]	Status
X Steam Tables	300	Owned
Excel Solver	500	Purchase
TRNSYS simulation environment	2500	Purchase

Figure 5. Database of resources in “Energy Systems” course.

A screenshot of the tool “X Steam Tables” is shown in Fig. 6. Technically, the “Steam Tables” tool is a re-implementation of the publicly available on-line tool by Magnus Holmgren, which has been built in the “Solar Village” environment to test and to demonstrate the integrability of various resources in the Excel platform. The green button “Show h,s-diagram” opens a window (user form) to show an enthalpy–entropy chart, where the player can easily check the thermodynamic state point as a function of a given variable. The button “Return to project” closes the tool and automatically returns the player back to the project from which he or she launched the “X Steam Tables”.

Steam Tables		<input type="button" value="Show h,s- diagram"/> <input type="button" value="Return to project"/>	
Original version: Magnus Holmgren (www.x-eng.com)			
<b>Saturation properties given temperature</b>		<b>Saturation properties given pressure</b>	
Temperature	100.00 °C	Pressure	10.000 bar a
Saturation pressure	1.014 bar a	Saturation temperature	179.89 °C
<b>Liquid</b>		<b>Liquid</b>	
Enthalpy	419.1 kJ/kg	Enthalpy	762.7 kJ/kg
Density	958.35 kg/m <sup>3</sup>	Density	887.13 kg/m <sup>3</sup>
Entropy	1.31 kJ/kgK	Entropy	2.14 kJ/kgK
<b>Vapour</b>		<b>Vapour</b>	
Vapour enthalpy	2675.6 kJ/kg	Vapour enthalpy	2777.1 kJ/kg
Vapour density	0.60 kg/m <sup>3</sup>	Vapour density	5.15 kg/m <sup>3</sup>
Vapour Entropy	7.35 kJ/kgK	vapour Entropy	6.58 kJ/kgK
Evaporation energy	2256.5 kJ/kg	Evaporation energy	2014.4 kJ/kg
<b>Properties given pressure and temperature</b>		<b>Properties given pressure and enthalpy</b>	
Pressure	10.00 bar a	Pressure	10.00 bar a
Temperature	180.00 °C	Enthalpy	485.83 kJ/kg
Enthalpy	2777.4 kJ/kg	Temperature	115.6 °C
Density	5.14 kg/m <sup>3</sup>	Density	946.99 kg/m <sup>3</sup>
Entropy	6.59 kJ/kgK	Entropy	1.48 kJ/kgK
Vapour fraction	100 %	Vapour fraction	0 %
IF97 Region	2	IF97 Region	1
Phase	Steam	Phase	Liquid
Isobaric heat capacity	2.711935 kJ/kg	Isobaric heat capacity	4.237046 kJ/kg

Figure 6. User interface of the “X Steam Tables” tool in “Solar Village”.

## 2.8 Balance Sheet

The “Balance Sheet” workspace simply summarizes the accumulated profits and costs for a given reporting period and stores the number of Solar Credits in the cash at the end of that period. The “Balance sheet” is updated every time when a project is submitted, the HQ is upgraded, or an access to resource is claimed.

In the course “Energy Systems”, the reporting period starts from the first profit, and the present number of Solar Credits is indicated. With these conditions and the assumption that a player has earned the available number of solar credits (SC2400) up to the present, and purchased the “X Steam Tables” tool at the cost of SC300, the “Balance Sheet” would be shown as:

Accumulated profits [S\$]	Accumulated costs [S\$]	Cash [S\$]
2400	300	2100

## 2.9 Projects

Projects constitute the basis for the event repertoire of the “Solar Village”. Technically, the term refers to a largish learning assignment that can be divided into one or more missions with an aim to make the entity easier to tackle. The projects are to simulate common tasks the graduates will confront after they have moved to the working life. The suggested typology to that end is, i) general expertise, ii) problem-solving, iii) planning & design, iv) performance assessment, v) scientific research.

The projects and missions are classified according to their difficulty. To that end, the traditional Bloom taxonomy (Lvl1: memorize, Lvl 2: understand, Lvl 3: apply, Lvl 4: evaluate, Lvl 5: develop) is recommended (Bloom et al., 1956).

Developing new projects is only restrained by the imagination of the developers. The purpose of this section is to share some ideas and suggestions for designing and implementing projects. To that end, examples from the courses “Energy Systems” and “Sustainable Building Energy Systems” are brought up.

### 2.9.1 Type 1: General expertise

The projects and missions representing “General expertise” challenge the player’s knowledge and understanding, which represents the first two levels of the Bloom taxonomy. These require the student to show their ability to recall and seek information and explain concepts, which makes them suitable for “throw-in” missions for beginners.

A simple example from the course “Sustainable Building Energy Systems” is the “Flexi Challenge” project, the first mission of which is to define the domestic hot water demand profile for a three-occupant house on hourly basis. Here, the “Solar Village” simply asks the player to suggest a daily hot water consumption per occupant based on his/her existing knowledge or information search. The data are inserted in a data cell by directly writing the number or as multiple choice, after which the “Solar Village” automatically checks that the input is numerical and within a pre-defined range. If the input is accepted, a green text “OK” immediately appears on the right side of the input cell. The response time or the number of attempts may be controlled and rewarded/penalized according to how iterating the correct value by guessing can be considered affecting learning.

## 2.9.2 Type 2: Problem-solving

A crucial part of learning is expected to happen by solving problems based on the acquired information and knowledge. This requires new realizations on the learners' behalf. In the Bloom taxonomy, applying the knowledge which problem-solving represents, is interpreted as upgrading the skills to the next level. The realization begins from understanding the problem, which, in turn, benefits from visualizing the problem.

One of the keys to success in energy engineering is identifying such system boundaries that best describe the problem as a thermodynamic system. In the course "Energy Systems", the players are asked to solve such a mass flow for the intermediate steam, which results in the best power generation efficiency for a cogeneration plant. To that end, they first need to understand that the pre-requisite is a saturated state in the plant's feedwater tank. Solving the mass flow requires data on the steam properties (provided in terms of a "data package" by the game and, for example, using the tool "X Steam Tables" shown in Fig. 6). Moreover, a specific heat balance is needed, which is identified via multiple choices based on the figure shown as a pop-up window (Fig. 7). Here, the alternative system boundaries are specified with capital letters A...F and dashed lines with varying colors.

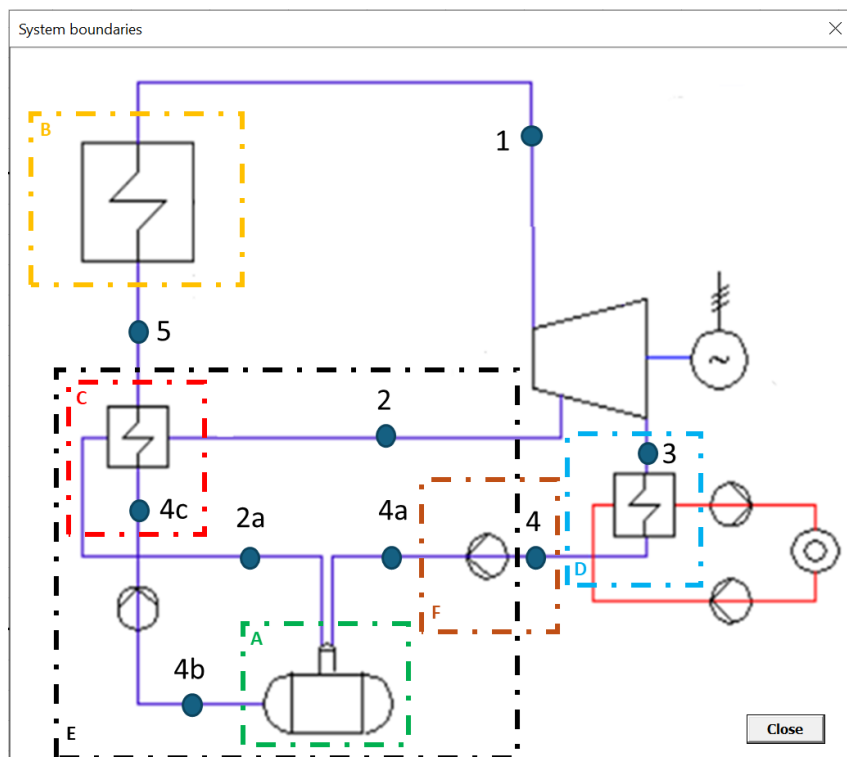


Figure 7. Alternative system boundaries of a power plant shown in a pop-up window.

### 2.9.3 Type 3: Planning & design

Planning and design are usually the first jobs a newly graduated engineer confronts after having stepped into the working life. These include sizing whole systems or their components following pre-defined design criteria and, on the other hand, configuring systems based on experience or optimization subject to given constraints.

The Type 3 projects represent a medium-high difficulty level in terms of the Bloom taxonomy, since they require a capability to apply various theoretical principles, methods and tools. This is not about solving specified problems only, but the student must be able to figure out the problem first and set a solution framework accordingly. Essentially, all the Type 3 projects are computational assignments. They require the implementation of properly chosen mathematical equations but also programming skills enabling complex operations such as iteration loops or logical statements. The MS Excel Solver Add-in is a useful resource for Type 3 projects.

A Type 3 project can be exemplified by the final project of the course “Energy Systems”, which is technically a two-stage event, let it be called “SolAthon”. The aim is to find such a combination of solar PV-collector (combined power & thermal generation) area and battery capacity that fulfills the energy demand of a fictional solar village on annual basis (full self-sufficiency), maintains a feasible state-of-charge, and keeps the project within a given budget.

The project makes use of a system model that is familiar for the players from the first stage of the “SolAthon”. Here, they have built hourly energy balances for the entire system and charge-discharge cycles for the energy storage. In the second stage, a workspace equipped with the user interface shown in Fig. 8 is unlocked. Essentially, this is a simulation exercise, where the player’s task is to seek the best configuration by way of an existing system model, changing the variables “Solar collector area” and “Energy content of the storage at the beginning of year”. The brownish backcolor (RGB (255,204,153)) indicates cells that require a numerical input. In the example, the Solver Add-in has been activated (green button) and the “Submit” button has been enabled.

Assume that a player has set the solar PV-collector area to 1300 m<sup>2</sup> and the initial storage to 80 MWh (which is also the highest charge of the storage during the year, i.e., the storage capacity). In Fig. 8, the consequences of the player’s actions are shown below the input cells in locked cells under the title “Results”. To achieve the present configuration (1300 m<sup>2</sup>, 80 MWh), the player is assumed to have used 30 trials (each change in one of the input cells is recorded), which is shown at the bottom of the interface. The brown-yellowish back color of the cell implies that the current number is reasonable, i.e., in the middle of the color scale red...yellow...green. Instead, the energy balance (i.e., the difference between the energy content of the storage at the end and the beginning of year) is –80 MWh and the annual net demand of electricity (= the annual electrical shortage) is not zero (= 91 MWh), which refers to an imbalanced system (back color bright red). The generated energy is not sufficient to

meet the demand although the degree of self-sufficiency is as high as 75%. Again, the storage is emptied upon the year (the lowest state-of-charge (SOC) reaches the value zero), which is not desirable. The used budget is 990000 €, however, which is clearly below the project budget (2 M€).

Given the conditions above, the player must decide whether to continue pursuing an improved configuration at the cost of penalty due to increasing number of trials or to accept the present configuration and a potentially lower income and reduced increment in the startup's market value. Here, it is worth mentioning that the trials made by the Solver Add-in are also counted.

**Mission: Sizing of solar collector area and seasonal energy storage**

**Data package 4 received including the following data:**

Total budget of the project	2000000 €
-----------------------------	-----------

**Your task: Find correct values to the variables below**

Solar collector area	1300 m2
Energy content of the storage at the beginning of year	80 MWh

**Results:**

Energy balance	-80 MWh
Annual net demand of electricity	91 MWh
Maximum charge of storage (= capacity)	80 MWh
The lowest SOC during the year	0 %
Self-sufficiency	75 %

Used budget	990000 €
Remaining budget	1010000 €

Number of trials	30
------------------	----

Solver
  
  
Submit

Figure 8. User interface of the solar village design project “SolAthon”.

#### 2.9.4 Type 4: Performance assessment

Type 4 projects require analytical skills and extended overall view on the topic studied. The players need readiness to master large entities to investigate the performance of energy systems and their components with respect to aspects other than those related to power or energy, such as life-cycle costs or environmental impacts.

A simplified example of a project including the aspects of the Type 4 performance assessment has been implemented in the course “Energy Systems”. This is a two-stage event, as well. Let it be called by the event name “Renovation Rush” to seek a game-like atmosphere and to demonstrate the pressure that is usually confronted by engineers in real life. This kind of a project needs computationally effective and easy-to-implement, yet accurate modeling approaches.

First, the students are asked to build a mathematical model of an apartment building, including the heat transfer calculations based on conductances, and setting a quick estimate for the energy demand of heating up domestic hot water. The model can be used to solve the annual heating energy consumption (Type 2) and sizing of the heating system (Type 3).

Second, the students are challenged to investigate the financial viability of four (4) energy efficiency investments, namely, i) replacing the old windows, ii) adding heat recovery to the ventilation system, iii) adding mineral wool to improve the thermal insulation of the roof, and iv) replacing the water fixtures. Here, the students need to assess the energy savings in all four scenarios (in comparison with the no-renovation case) and calculate their cost impacts plus draw conclusions on the viability of these investments and provide recommendations using the methods of investment calculations, mainly the net present value (NPV) method.

The implementation of this example does not differ from that of other project types presented in this report. In the first mission, energy savings are calculated for each four renovation scenarios. The second mission entails the calculation of cost savings, which, on the other hand, represents a positive cash flow (revenue). The financial viability analysis is completed in the third mission.

The viability analysis is supported by an interactive visualization depicted in Fig. 9. Technically, this is a graph indicating the cash flows on annual basis. By moving the mouse on the hand symbol, the calculated cash flow appears as a green or red number. The green color represents revenues (savings), and the red color is the symbol of costs. In the present version (Beta v1.0), the graph is static and only shows the value of the first investment and that of the first revenue. The template of this demonstration has been taken directly from the “Energy Systems” course material.

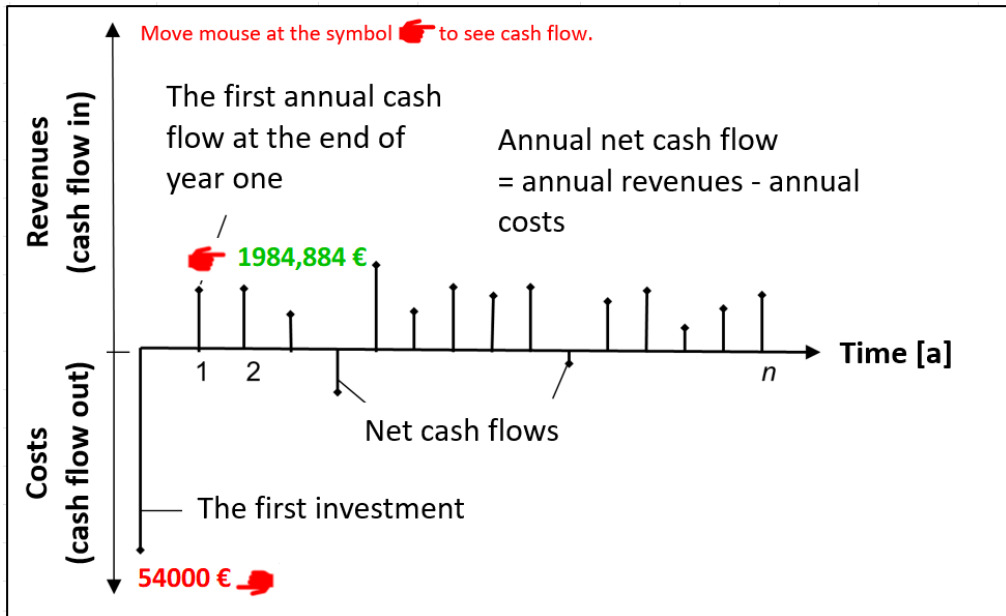


Figure 9. Cash flow visualization in the “Renovation Rush” project.

### 2.9.5 Type 5: Scientific research

Scientific research is considered to represent the top of the project hierarchy, since it requires the ability to combine a large palette of skills and knowledge learned during the study path and boost them with creativity to set appropriate research questions, which enables novel findings.

In the “Quest of Resilience” project of the course “Sustainable Building Energy Systems”, M.Sc. students can conduct simple parametric analyses targeted to three building properties, namely, i) insulation thickness, ii) building mass, and iii) type of glazing. The aim is to find out how these parameters affect the building’s thermal resilience, i.e., its ability to maintain habitable indoor temperatures in the case of a sudden disruption of energy supply. In this two-stage event, a player first creates a two-heat capacity model for a given building. Secondly, he or she conducts energy simulations using this model to find out the number of habitable indoor temperatures within a 24-hour period after the disruption.

The project workspace is presented on Fig. 10. Here, the “Simulation tool” interface is on the top, where the player inserts trial values for each of the three properties. The tool calculates the number of habitable hours (mean values for each hour) for each trial and records the number of simulations. The background color of the result cells indicates on the scale “red...yellow...green”, whether the trial is successful (green) or if there is room for improvement (yellow, red).

Below the simulator cells in the section “My conclusion”, the players are asked to suggest the most impactful building properties for the thermal resilience. To help them visualize their impacts on the habitable indoor temperatures, they can list the data of each trial in the table below the “My conclusion” segment. The table also has a purpose to guide the players to seek the quickest path towards the best outcome by reasoning.

Simulation tool	
Variable	Var No Value
Insulation thickness external wall (insert your input in [m])	1 0.2
Building mass (insert Option No)	2 2
Type of glazing (insert Option No)	3 4
<b>Number of habitable hours</b>	<b>8</b>
<b>Number of simulations done</b>	<b>27</b>
<b>My conclusion:</b>	
The most influential measure to maintain habitable temperature (insert Var No)	1 ✓
The most influential design option (insert Option No)	1 ✓

You can use the table below to record your simulation results. One simulation (No: 1, insulation: 0.2 m, building mass: option 1, and glazing: option 1) has been simulated and listed as an example.

Simulation No	Insulation	Mass	Glazing	No of habitable hours
1	0.2	1	1	1
2	0.2	1	2	3
3	0.2	1	3	8
4	0.2	1	4	5
5	0.2	2	1	1
6	0.2	2	2	3
7	0.2	2	3	9
8	0.2	2	4	8
9	0.2	3	1	1
10	0.2	3	2	4

Figure 10. The user interface of the project “Quest of Resilience”.

## 2.10 Instructions, guidance and counseling

There are two main strategies for instructing players in the “Solar Village”: i) keep the instructions at the touch of a button anywhere in the learning environment and ii) seek means to make guidance and counseling “alive”. This is not just about giving hints or tips for the mechanical calculations but also facilitating the learning process. All in all, a gamified learning environment aims to be much more interactive than conventional teaching platforms commonly are.

For the events to be participated via the MS Excel platform, there is a brief general introduction at the top of each event workspace. This can be seen any time the workspace is activated. The introduction briefly presents the topic, the motivation and the rules of the event. An excerpt of introducing the “Quest of Resilience” project in the version “Beta v1.0” of the “Solar Village” is in Fig. 11.

Solar Village (Beta v1.4): Quest of Resilience	Competency	296	Lvl 5 Scientist engineer ****
© Aalto University / Kari Alanne			
<b>Introduction</b>			
Thermal resilience is one of the major qualities of sustainable buildings.			
A thermally resilient building is capable of maintaining satisfactory room temperatures in the conditions of unexpected distortions such as cold waves or failures in energy supply.			
In this gamified learning assignment, a detached house located in southern Finland confronts an unexpected failure of a thermal supply in the first of January .			
The assignment consists of two stages, which encompass several missions.			
In the first stage (Modelling Stage) your task is to build a simple mathematical model (two heat capacities) to describe the detached house.			
In the second stage (Research Stage) you are to study the capability of various design solutions to maintain room temperatures at a habitable level (i.e., above 15 C) over a 24-hour period.			
<b>Rules</b>			
Perform all the given modelling and research missions in the given order, i.e., from the top to the bottom of this calculation sheet . Read the task statements and instructions carefully. Double-check the units.			
In cells formatted like this, a formula is expected. To implement appropriate equations, rely on the course material.			
In cells formatted like this, a number (parameter) is expected. To assign appropriate parameter values, rely on the course material.			
If the required input is accepted, the green symbol "✓" appears to the right side of the value. If the answer is good, the green text "OK" appears to the right side of the acceptance symbol.			
Your progress will be rewarded by an evolving competence level, which is dictated by competency points earned from each mission. The accumulated competency points allow you to upgrade your title, as well.			
During the work, you can follow your progress at the first row, which is frozen on the top of this calculation sheet.			
You can change the values and equations until you click "Submit". The next stage will be unlocked, and you can't change your input to the first stage any more.			

Figure 11. General instructions for ”Quest of Resilience”.

Given that the “Solar Village” is a comprehensive and all-inclusive learning environment, a direct access to the key learning material has been enabled. In MS Excel, the lecture slides and handouts have been integrated into a separate workspace the player has an access through mission-specific green buttons. The handouts and lecture slides cover the theoretical basics of each mission.

The Stage 2 of the “Flexi Challenge” project focuses on modeling the performance of solar collectors. Here, clicking the green button activating the mission-specific instruction activates a view to the handout presenting the well-known Hottel-Whillier-Bliss (HWB) equation and explaining its use in evaluating solar collector performance. The player’s duty is to apply the equation to the given problem and to show ability to evaluate and interpret the results by way of hourly energy balances.

Virtual assistants are used in “Solar Village” environment primarily for guidance and counseling. The aim is to guide the players to proceed in the game, but also to encourage them to think and to seek information rather than to provide instant facts. On the other hand, virtual assistants are the “workforce” of the player’s startup, which makes the learning environment more interactive. Some virtual assistants are introduced right after the establishment of a new startup, but they can also be recruited later. The virtual assistants’ intelligence and ability to interact may be upgraded during the game, and their position in the startup’s hierarchy may be promoted.

The implementation of virtual assistants in the MS Excel-based “Solar Village” environment is in its infancy, but two AI-generated assistants called “Aino” and “Eino” already have been introduced for the course “Energy Systems” (Solar Village Beta v1.0) to demonstrate the process of guidance and counseling during the gameplay. After a new startup has been established, a pop-up window (Fig. 12) appears and introduces the assistants. The assistants then guide the player through the workspaces explaining general or topic-specific issues, such as how to get an access to the learning material or how to use the resources.

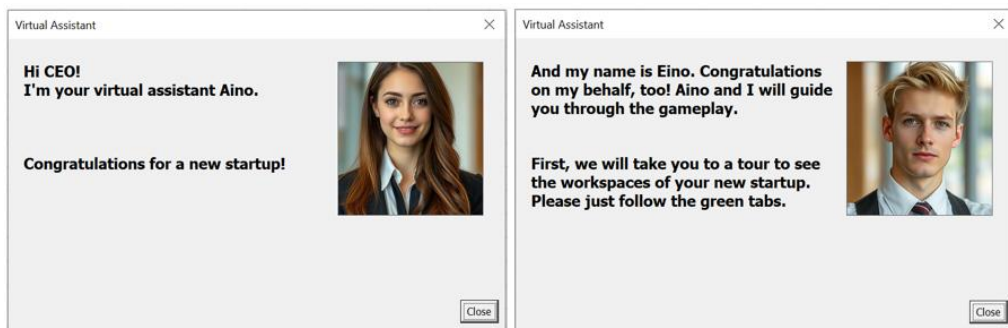


Figure 12. Introduction of the virtual assistants Aino and Eino.

All the achievements, rewards and penalties are announced through message boxes during the gameplay. These announce the project revenues, as well as the increments in the market value and level-ups through upgrades. Each message is equipped with an embedded image symbolizing the achievement. In Fig. 13, a few examples of completion messages from the “Energy Systems” course are shown.

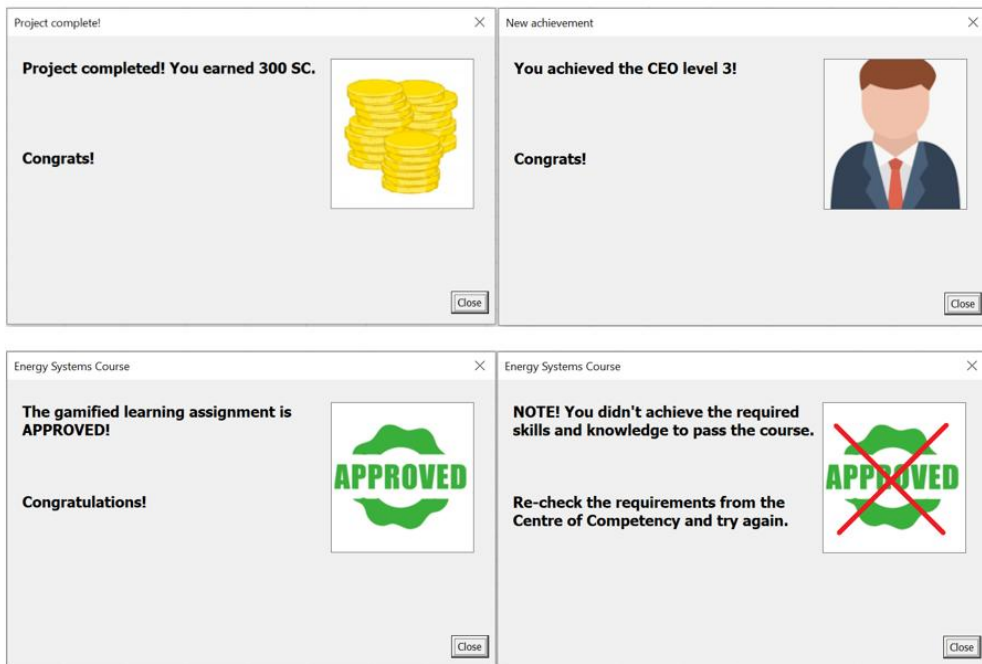


Figure 13. Examples of completion announcements.

## 2.11 Multiplayer activities

The multiplayer mode is an integral part of the gamified learning environment, since it enables group work and simulates the human interaction in working life. The two dimensions of the multiplayer mode, business alliance and competitions, are discussed and demonstrated with examples in the following sections.

### 2.11.1 Business Alliance

Technically, the business alliance is a group of startups that operate within the same domain. Business alliances aim at upgrading their alliance level by collecting awards from student competitions and performing projects that resemble the individual projects. They are just unlocked to all the alliance members and submitted as an alliance.

A player may either create a new alliance or join an existing one. In an alliance, he or she can play various roles at different levels, for example, as a chairperson (Lvl 3), a secretary (Lvl 2), a regular member (Lvl 1) or a recruit (Lvl 0). The higher the player’s level is, the more power he or she has, for example, to decide the events the alliance

participates in. The visibility of events may also be restrained according to the role of an alliance member. When a player creates a new business alliance, he or she is appointed as the chairperson automatically. When joining an alliance, a player automatically becomes a recruit. The chairman can promote an alliance member to a higher level upon agreement or based on the member's achievements.

An alliance can also set initial rules and conditions for new recruits to choose what kind of players they want to join. For example, a certain minimum startup market value, CEO level or combination of skills and knowledge may be set as a condition for joining a business alliance. Case-specific exceptions may be allowed. An alliance membership can be also granted through application or invitation. All these functionalities are to simulate an individual's career development in the working life. Generic conditions and restraints such as the accessibility to events or skill requirements are set by the administrators according to what is required by the curriculum or the study path.

The business alliance mode is not available in the MS Excel implementation of the "Solar Village", but two workspaces have been developed to demonstrate some of its basic functionalities. One of these workspaces contains an introduction to the concept of Business Alliance and two green buttons for registration, where a player can either create a new alliance or join one. The workspace is unlocked and activated, when a pre-defined set of conditions is fulfilled. The other workspace is an alliance information sheet, which is activated after the registration.

When a player decides to create a new business alliance, a pop-up window (Fig. 14) is activated, where the player's user data (name, ID and startup name from the database) is shown and an input field is opened to write the name of the alliance to be created. A three-letter acronym is created for each new alliance automatically. The background color of the button "Create" is changed to green, when the suggested alliance name fulfils the pre-defined conditions (e.g., the name is within a given length, a namesake is not found in the domain the player belongs to).

Given that the conditions are fulfilled, the alliance name is only restrained by the player's imagination, but there are some general principles to create a good alliance name. For example, the name could highlight properties appreciated in the business life, such as innovation and unity. When the new alliance is saved, it is recorded in the database. The databases will be discussed in more detail later in this report.

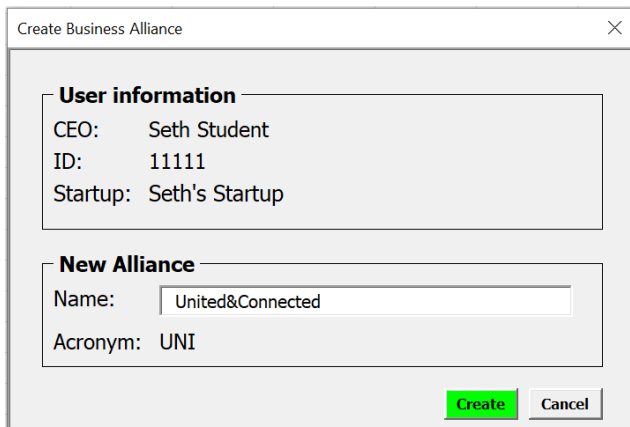


Figure 14. A pop-up window for creating a business alliance.

Creating a business alliance gives the player the status of a chairperson automatically. However, some students may prefer a role other than a team leader. For them, joining an existing business alliance as a recruit may be a more convenient option. On the other hand, joining an alliance also makes it possible to proceed in the “career” step by step through promotions.

When the player chooses to join a business alliance instead of creating it, the pop-up window shown in Fig. 15 appears. The user data is retrieved in the same way as when creating new alliances, but now a list appears below the user information box showing the alliances the player can join, i.e., there is room for new members in those alliances, and the player fulfils their pre-defined conditions and requirements. When the player chooses one of the alliances in the list, the buttons “Visit Alliance” and “Join” become green. The button “Visit Alliance” is for the player to see in advance the information sheet of the business alliance he or she is going to join.

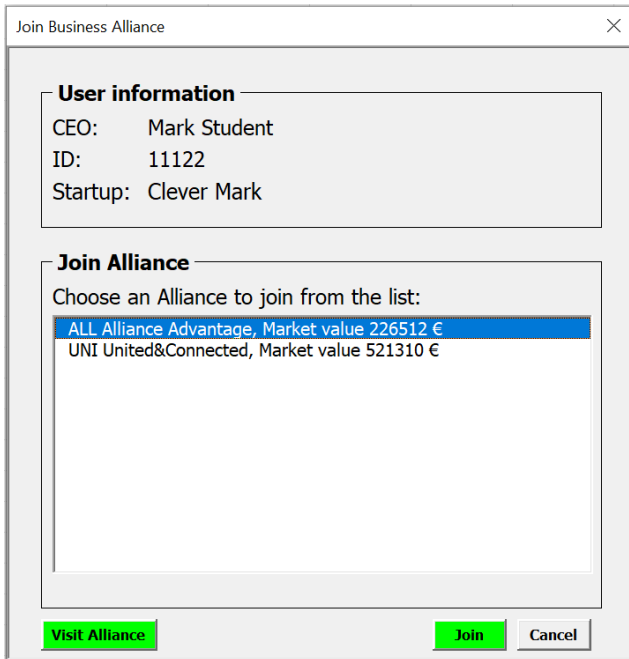



Figure 15. A pop-up window for joining a business alliance.

Both creating and joining a business alliance launches the second workspace, the information sheet, which is the “home” of a business alliance. Here, the basic information is listed, including the name and level of the alliance, its total market value, achievements, members, and their roles. These are visible to all the alliance members, whereas at least the alliance name, market value and achievements should be visible for all the players. The idea behind the extended visibility is to boost competition both among the alliance members and between the alliances. In Fig. 16, the information sheet of “Alliance Advantage” is demonstrated, showing the status after the startup with the name “Clever Mark” having joined the alliance.

Business Alliance		
<b>Alliance name</b>	[ALL] Alliance Advantage	<b>Achievements</b>
<b>Alliance level</b>	1	
<b>Total market value</b>	267 532 €	
<b>Members</b>	5/5	
<b>Members</b>	<b>MV</b>	<b>Role (Level)</b>
Sunny Plan	147 090 €	Chairperson (L3)
Eric's Corner	14 909 €	Secretary (L2)
John's	46 501 €	Member (L1)
JS Consulting	18 012 €	Member (L1)
Clever Mark	41 020 €	Recruit (L0)

[Leave Alliance](#)

Figure 16. An example of business alliance information sheet.

The bluish background color of the information sheet (RGB (221,235,247)) symbolizes the alliance level (Lvl1). The alliance acronym (“ALL”) is shown in brackets before the whole alliance name. The same practice is followed with the startup names after a player has created a business alliance or joined one. For example, the startup owned by Mark Student is shown as “[ALL] Clever Mark” everywhere in the learning environment.

In the example (Fig. 16), the maximum alliance size allows five (5) startups, which means that all the available slots have been used after the startup “Clever Mark” joined the alliance. The role “Recruit (Lo)” has been added to the bottom of the list after the joiner’s startup name and market value. The total market value of the business alliance is the sum of all the members’ market values.

On the right section of the information sheet, space has been dedicated to prizes obtained from student competitions under the title “Achievements”. The example in Fig. 16 demonstrates a scenario, where the alliance “ALL” has participated in three competitions, won one of them and obtained a second and a third place.

Finally, there is a green button in the bottom right corner of the information sheet to be enabled for each player to leave the business alliance. There can be a multitude of reasons to leave the alliance, but a main reason is the essence of the game. A player can only belong to one business alliance at once, and the students of a given domain rarely go through equal study paths.

Besides the two workspaces discussed above, the multiplayer mode may require additional workspaces, for example, to list solo and team events separately and thus clarify the interface. It is also possible to extend the competition from between alliances to that between domains by including multi- or interdisciplinary events, which require a separate workspace for event management simply because otherwise they would be too complicated to manage. The competitions are discussed with some examples in the next section.

### 2.11.2 Competitions

Student competitions are events aimed at encouraging the students to bring out their best effort in creativity and to utilize their skills through the possibility of winning prizes or awards. Thus, participation in different types of student competitions via gamified learning environments is an important part of the learning experience. For the “Solar Village”, this functionality is just a plan at the time when this report is released, but some general ideas and existing examples of student competitions are shared in this section to facilitate the further game development.

The student competitions are suggested to be implemented in the “Solar Village” environment as special events. The following features are different in comparison with the student competitions and projects:

- Players preferably participate in competitions in teams (business alliances) rather than solo players.
- Competitions may be multi- or interdisciplinary.
- The participants may come from several domains and even universities worldwide.
- The workspaces and interfaces may be highly innovative and creative.
- An access to written instructions or communication with virtual assistants maybe restrained or even disabled, whereas other resources (e.g., computational tools claimed by the due date of a competition) are available to full extent.
- The assessment includes comparisons between players’ submissions rather than just a comparison between a submitted solution and a pre-defined reference solution.
- Immediate feedback is not given.

Student competitions may be offered in several formats representing various project types based on the Bloom taxonomy (see Section: Projects).

**Essays** are structured written narratives of a given topic by a solo author. They represent Type 1 projects by challenging the participant’s prevailing knowledge and perspective.

**Ideation** is a solo or team competition, where the participants are simply asked to present an idea to be evaluated and ranked among their peers. The deliverable is a written document, but more informal than an essay. The project type is flexible, and it depends on task statement and the participants’ baseline.

**Business Plan** is a competition to challenge the participants (commonly teams) to describe an existing or a fictional business. The deliverable of business plan is a structured report. The project type is flexible, but the participants get advantage from skills and knowledge required by Type 4 or 5 projects.

**Olympiads** or **Olympics** are solo competitions, where the students participate in examinations testing their knowledge in a way resembling school examinations. The task statements may contain problem solving like in math and science Olympics. Therefore, these competitions can be classified as Type 1 or Type 2 projects.

**Case studies** are extensive Type 4 or Type 5 projects, which challenge the competitors’ ability to investigate real-life systems, problems or phenomena by making use of all the available data on the target entity.

**Design Competitions** aim at designing a new system or equipment by making decisions based on computational and/or experimental studies. These are commonly Type 3 or Type 4 projects and targeted at teams.

**Simulations** challenge the participants (either solo players or team) to create a mathematical model of a given system or phenomenon, assessing its performance using computational analysis methods and draw conclusions based on performance assessment. Hence, this is a Type 4 or Type 5 project.

There are numerous examples of student competitions in various areas of energy engineering. Some of them have been reviewed and listed in Table 5.

Table 5. Selected student competitions in various fields of energy engineering.

Area	Competition	Description	Web reference
Vehicles and mobility	Shell Eco-marathon	The participating teams design and build an ultra-energy-efficient vehicle to achieve the best possible fuel economy.	<a href="https://www.shellecomarathon.com">https://www.shellecomarathon.com</a>
	EcoCAR Mobility Challenge	The students re-engineer a vehicle to reduce its environmental impact while maintaining performance.	<a href="https://avtcsereis.org">https://avtcsereis.org</a>
Buildings and renewable energy	Solar Decathlon	A competition for collegiate teams to design and build and energy-efficient, solar-powered building.	<a href="https://solardecathlon.eu">https://solardecathlon.eu</a>
Power and energy systems	Collegiate Wind Competition (CWC)	Students design, build, and test wind energy systems, preparing them for the renewable energy workforce.	<a href="https://www.energy.gov/eere/collegiatewindcompetition">https://www.energy.gov/eere/collegiatewindcompetition</a>
	International Future Energy Challenge (IFEC)	A competition for undergraduate students to design innovative power electronic systems.	<a href="https://ifec2025.org">https://ifec2025.org</a>
Commercialization and entrepreneurship	EnergyTech University Prize	Student teams develop business plans to commercialize promising energy technologies.	<a href="https://www.energy.gov/technology/commercialization/energytech-university-prize">https://www.energy.gov/technology/commercialization/energytech-university-prize</a>

It can be concluded based on Table 5 that competitions targeted at energy engineering students are usually design competitions for teams. It is also noteworthy that design competitions require a physical prototype of the new equipment or system. One of the reviewed competitions is a business plan with an aim to commercialize promising energy technologies. Two examples of student competitions are discussed with some further details below. Particularly, perspectives for implementing student competitions in the "Solar Village" environment are addressed.

The first example, the “Solar Decathlon”, is an international biennial design competition organized since 2002 by the Department of Energy (DoE) of the USA. The event was adapted to Europe as “Solar Decathlon Europe” (SDE) and organized first time in Madrid in 2010. The competition aimed at designing small (60-80 m<sup>2</sup>) solar-powered houses.

Aalto University participated in the 2010 competition with a 71.2 m<sup>2</sup> wooden zero-energy house “Luukku” (Weckman, 2010). This multi-disciplinary project lasted for two years (2008-10) activating a working team (“Team Finland”) of up to 100 students, researchers and other staff from various research units (architecture, engineering, design and business). The project also involved industrial partners and received external funding (Sitra). The “Team Finland” was successful in the competition, obtaining the top rank in the architecture. The house fulfilled the plus-energy target in Spain and zero-energy target in Finland. The stages and key activities of the project are summarized in Table 6. For further details, the reader is referred to the work of Weckman (2010).

Table 6. Summary of the “Team Finland” activities for the Solar Decathlon Europe 2010.

<b>Time</b>	<b>Stage</b>	<b>Key activities</b>
Autumn 2008 – Summer 2009	Preparation stage	Approval of Aalto application to the SDE Architectural concepts Material, structural & technical concepts Energy simulations to support decision-making Decision on the best concept
Autumn 2009 – Spring 2010	Design stage	Detailed design (architecture, structures, HVAC) Logistical plans Energy simulations to validate the design solutions
Spring 2010	Construction stage	Construction at the Espoo Campus
Spring 2010	Testing stage	Energy measurements & monitoring (Espoo)
Summer 2010	Final stage	Disintegration of the building for transport (modules) Transportation to the venue (Madrid) Reassembling the building at the venue (Madrid) Tests at the venue (10 areas, including architecture, energy, habitability etc.) Final assessment

As seen in Table 6, the Solar Decathlon event is characterized by multiple stages, multiple disciplines and an extremely large and multi-layered, and – to some extent – hierarchical working team including external partners.

The suggested baseline playground in the “Solar Village” learning environment is a domain combining students of one discipline and one class, whereas the unit participating in student competitions is to be a business alliance. Assuming energy technology students at Aalto ENG would shape a domain, the size of the entire domain is dozens rather than hundreds of players. Based on everyday experience, the appropriate size of a working team (here: business alliance) is rather five than, for example, ten students.

Due to the reasons listed above, a participation in competitions akin to the “Solar Decathlon” requires the development of a global, multi-stage special event that enables a step-by-step process during a long period and global collaboration for different domains. To that end, inspiration can be acquired, for example, from the “Desert survival” or “M.I.G.O” events included in the “State of Survival” strategy game (<https://stateofsurvival.game/en>).

The realization of this large a competition requires the division of the project into well-defined missions, scheduling the missions appropriately and allocating them between domains down to the level of individual business alliances. Therefore, it is crucial that the participants are selected via an application procedure before the preparation stage.

The stage-by-stage process of implementing the special event “Solar Decathlon” in the “Solar Village” environment is described in Table 7. Here, the process is assumed to involve the following actors: 1) administrators (ADM, competition organizer, university personnel), 2) one (1) business alliance from architecture (A), 3) two (2) business alliances from energy technology (E1, E2), and 4) one (1) applicant from structural engineering (S). Moreover, it is assumed that the participation of only one applicant (E1) from energy technology is approved by the administrators.

A commonly accepted communication platform (Telegram, WhatsApp, Discord etc.) is useful to enable collaboration between the actors within the virtual environment. Because the “Solar Village” is completely virtual whereas the event as such requires contributions in the physical environment (such as accepting and validating measurements from certain equipment), the development a “Solar Village” mobile application is recommended.

In fact, the competitors’ contribution is complete by the final stage. The logistics may be taken care of by external partners, supervised by the administrators. The decisive tests at the venue are completed by the administrators, as well as the judgements. The assessment criteria related to the “Solar Decathlon” are discussed in more detail later in the report.

Table 7. A procedure of implementing a “Solar Decathlon” special event.

Stage	Activity	Actors				
		ADM	A	E1	E2	S
Application stage	Application by universities / domains	x				
	Application by business alliances		x	x	x	x
	Approval of universities / domains	x				
	Confirmation of participation by business alliances as a response to approval (by chairpersons L3)		x	x		x
Preparation stage	Defining and scheduling the subtasks	x				
	Networking with external partners	x	x	x		x
	Publishing and enabling the subtasks	x				
	Mission: Architectural concepts		x			
	Mission: Material & structural concepts					x
	Mission: Technical concepts			x		
	Mission: Preliminary energy simulations			x		
Design stage	Mission: Selection of the best concept	x				
	Mission: Detailed architecture		x			
	Mission: Detailed structures					x
Construction stage	Mission: Validation by energy simulations			x		
	Mission: Supervision of the construction	x	x	x		x
Testing stage	Mission: Energy measurements & monitoring			x		
Final stage	Mission: Logistics	x				
	Mission: Tests	x				
	Mission: Assessment	x				

Besides large, multi-disciplinary student competitions like the Solar Decathlon, there are numerous smaller events with short duration and limited cohort of participants. An example of this kind of a student competition is the annual HVAC student competition (In Finnish: LVI-alan opiskelijakilpailu), which has been organized since 2008 by Finnish HVAC companies. This competition is primarily targeted to HVAC students from Finnish universities of applied sciences, but Aalto University has participated actively in the competition in the 2000s in the same competition series with the universities of applied sciences. The most recent Aalto participations were between 2008 – 2012.

The conventional way to organize the HVAC competition has been to invite teams of 3-4 students to a given venue for a one-day event to perform assignments related to ventilation, refrigeration, water and sewage systems, and the carbon footprint of buildings and construction. The assignments include theoretical and design missions plus practical implementation and team exercises. The teams are equipped with tools necessary to perform the tasks.

In the HVAC competition 2009, for example, one of the tasks included the theoretical analysis of a ventilation heat recovery. Equipped with given system data, an Excel tool and the duration curve of external temperatures, the students asked to find out the temperature limits for activating the frost prevention, the impacts of heat recovery in the target building's annual energy consumption, and annual energy efficiencies. In the 2012 competition, there was a practical implementation, where the teams conducted air flow measurements for terminal devices using given instruments and educational facilities.

The recommended way to implement an HVAC student competition in the “Solar Village” environment is a multi-stage special event containing an application stage and the final stage (duration: one day). In the application stage, the chairpersons (L3) of business alliances within a given domain apply for the participation and the participating alliance is chosen and registered to the competition by deadline by the administrator (teacher). The students can complete the final stage missions in the “Solar Village” environment, where the required workspaces are unlocked according to the pre-determined schedules. An interface (e.g., Application Programming Interface, API) for the communication between the learning environment and devices such as thermometers or flow meters is needed for the physical implementation. The submissions are assessed after the deadline by a jury, possibly assisted by AI. The results are published, and leaderboards are updated automatically.

## 2.12 Leaderboards

Leaderboard is a separate workspace, technically a list or table, where the names and current scores of the leading players are published. The players may be ranked according to their scores with respect to various attributes.

Leaderboard is one of the most attractive game-like elements in the “Solar Village”, since it enables the public (albeit nickname-based) comparison between solo players (and between business alliances), and thus competition with an opportunity to pursue an improved ranking position. Since there is both single- and multi-player mode in the “Solar Village”, separate leaderboards are needed for both. To encourage competition between domains, universities (multiple domains), and even countries (multiple universities worldwide), the domain-level and game-level (covering all the accounts registered in the gamified environment) leaderboards should be implemented.

Given these premises, the realization of the leaderboard requires a networked “Solar Village” environment with an access to an up-to-date database, where the players and their achievements are recorded every time when a change takes place. This feature has not been implemented so far, since in the MS Excel environment, the leaderboard requires a separate workbook, and the scores must be recorded manually and ranked automatically.

The appearance of the Solar Village Beta v1.0 leaderboard is illustrated by Fig. 17. Here, the names and startups of some fictional solo players have been created for demonstration and ranked according to their market values. The other ranking options include HQ level and CEO level. Again, the listed startups belong to a fictional domain and business alliance. The alliance acronym (UNI, ALL) is presented before the startup name, if the startup belongs to one. The cell background colors manifest the overall quality level of each startup using the color codes explained in Table 1.

Startup	ID	Market value [€]	HQ level	CEO level
[UNI] Dr. Clayton's	11119	1 300 705 €	10	5
[UNI] Seth's Startup	11111	501 020 €	8	4
[UNI] Bright Brian	11114	297 065 €	6	3
[UNI] Henry's Shop	11112	205 015 €	6	3
[ALL] Sunny Plan	11113	147 090 €	5	3
[ALL] John's	11117	46 501 €	3	2
[ALL] Clever Mark	11122	41 020 €	2	2
Candy Queen	11120	39 804 €	4	2
Jane47	11121	34 018 €	2	1
Leader's House	11116	33 392 €	2	2
Ed's House	11125	23 114 €	1	1
MS Innovations	11123	19 230 €	1	1
[ALL] JS Consulting	11124	18 012 €	1	1
[ALL] Eric's Corner	11118	14 909 €	1	1
Will the Tiger	11115	11 126 €	1	1

Figure 17. An example of “Solar Village” leaderboard visualization.

### 3 Hidden elements of the gamified learning environment

This section is to present those areas of the “Solar Village” learning environment that are not visible to the players but are essential for game administration and scoring.

#### 3.1 Protection

The term protection consists of the following two dimensions: 1) protecting the player’s actual identity and privacy from unauthorized access, and 2) precluding the player’s access to such game elements that would provide him/her with an opportunity to cheat.

Regarding the first dimension, the design and implementation of the gamified learning environment is guided by the European Data Protection Regulation (GDPR), national data protection legislation and other legislation associated with processing personal data. The details may slightly vary depending on the country and the university, and the appropriate practices must be implemented by the game developers and administrators. In the Aalto University, for example, the university-specific guideline is the Aalto University Data Protection Policy.

The proposed approach for the “Solar Village” environment is that the personal data is processed by the university. The startup established by a university student is switched to his/her university account. This means the Aalto students, for example, would play the “Solar Village” via their Aalto accounts. The game administrators are then obliged to observe the fulfilment of the Aalto Data Protection Policy regardless of where the data is being stored and who owns the equipment used in processing activities.

Switching a startup established via the MS Excel environment to an Aalto account is not yet possible. In the piloting phase, the procedure is to share an identical Excel workbook in advance to each student as an “assignment” via the MyCourses learning platform, where they have an access via their Aalto accounts. Having completed the game (by a given deadline), the students submit the modified workbook via the same platform. The personal information including the student’s name, ID and startup name is known by the teacher only. The students’ identity as whole (name + ID) is not shown on the leaderboard, either, but the student ID only is visible (pseudonymized data).

The second dimension of protection, i.e., precluding the player’s access to selected game elements in the MS Excel environment requires measures in two levels, namely, at the level of a workbook and at the level of single worksheets. A public constant “PASSWORD” has been defined for the macros of the “Solar Village” environment to be asked every time the user tries to protect/unprotect objects.

The protection of the entire workbook is needed

- to control the users' access to the macros/developer tools
- to control the users' rights to add or delete workspaces or to change their visibility or order in the tab list

The command to protect the entire workbook is "Workbooks(1).Protect PASSWORD". Correspondingly, the command ".Unprotect" is used to unprotect the workbook. It is also noteworthy that if the procedure repeats the command ".Protect" sequentially in the order of execution, the workbook is in fact unprotected.

The protection of a single worksheet is needed

- to control changing the visibility of that worksheet
- to control editing the appearance of the worksheet (e.g., color codes)
- to control content change in target cells

The command to protect a single worksheet is "Worksheets("SheetName").Protect PASSWORD". The worksheet-specific property "EnableSelection" should be set as "xlUnlockedCells". If so, given target cells (e.g., A1, A2, B1, and B2) can be locked using the command "Worksheets("SheetName").Range("A1:B2").Locked = True".

### 3.2 Variables and databases

The data storage strategy of the "Solar Village" environment is presented in this section. The descriptions are applicable in MS Excel, but the general principles can be extended to other environments, too.

Variables are used to store data during the period when the game is played. When the player quits game, the variables will be reset. The variables are classified into local and global (public) ones. The global variables are visible and usable everywhere in the workbook, whereas the local variables only store data for procedures functioning within one workspace (sheet). The variables are declared using the Dim, Private, Public, ReDim, or Static statements of Visual Basic Applications (VBA) and located in a separate module, when applicable. The "Option Explicit" statement is recommended to necessitate the variable declarations.

Databases are used for long-term data storage. The data are recorded in databases when the player saves the game and retrieved when the game is opened. The storing process is slower than when using variables. In the present Excel version of the "Solar Village Beta", databases have been realized both as separate hidden worksheets and hidden/locked (white) cells/tables in worksheets visible to the players. The latter approach is not fully transparent, wherefore it will be replaced by separate sheets in the non-beta versions of the "Solar Village". A summary of the data storage requirements of the "Solar Village" environment is shown in Table 8.

Table 8. Key data storage requirements for the “Solar Village” environment.

<b>Name</b>	<b>Contents</b>	<b>Type</b>
Player database (worksheet)	CEO name (first name, family name) CEO ID CEO profile CEO level Startup name Startup profile Market value HQ level	String String String Integer String String Currency Integer
Skill & knowledge database (worksheet)	Skill /knowledge name Skill 1 Skill 2 ..... Skill n Level Skill 1 Skill 2 ..... Skill n Completed Skill 1 Skill 2 ..... Skill n	Vector (n- dimensional, string)  Vector (n- dimensional, integer)  Vector (n- dimensional, Boolean)
Alliance database (worksheet)	Alliance name Alliance acronym Number of alliance members Member name Startup 1 Startup 2 ..... Startup n Role of member in alliance Startup 1 Startup 2 ..... Startup n Alliance market value Alliance level	String String Integer Vector (n- dimensional, string)  Vector (n- dimensional, string)  Currency Integer



In addition to the contents listed in Table 8, some data items are recorded either in visible or hidden cells in the workspaces visible to the players. The accumulated profits and costs plus the cash are recorded visibly on the “Balance sheet” workspace. In the current “Solar Village Beta” implementation (MS Excel), the component-specific levels of the HQ have been recorded visibly and the overall HQ level, i.e., the lowest of the component-specific levels, hidden on the “Headquarters” workspace. The number of accepted inputs (“OK”) is calculated and recorded in a hidden cell on each project worksheet. This number is used to determine the player’s achievement level with respect to a certain skill and to convert the achievement to the startup’s added market value and the incoming cash flow in Solar Credits. The assessment and conversion mechanisms are discussed with more details and examples in Section 3.3.2.

All the data listed in Table 8 and discussed in the body text above also have been defined as variables. This is to avoid updating the values in worksheets every time they are needed, and thus to make the playing experience smoother. Instead, the databases are read into variables each time the game is activated, whereas the overall update of databases is triggered only when the game is saved.

Workspace-specific data ranges are defined using public (global) variables (Type: Range). The purpose of these variables is to compact cell references in the VBA code. Local (string) variables have been used in the “Solar Village Beta” to store the text contents of communication windows and to record the player’s confirmation for a yes/no-question presented in a message box (“vbYesNo”).

### 3.3 Assessment

The concept “assessment” refers to a process needed to score up the startup market values, CEO levels, profits and finally the course grading. This is fully automated in the “Solar Village” learning environment. The elements of the assessment process include reference solutions, scoring criteria and AI-assisted evaluation, which are discussed in this section.

#### 3.3.1 Reference solutions

In the currently available “Solar Village Beta”, all the players’ outputs are simply assessed by comparing them against a reference solution implemented in a separate, hidden workspace including the input data and calculation cells identical with the project workspace. If the match between the reference solution and the player’s solution is acceptable, the green “OK” appears at the right side of the input cell.

The rules of acceptance depend on the essence of the mission. In the case of multiple choices, there is only one correct answer, which requires an exact match between the suggested solution and the reference solution. In most of the computational missions, some variation is allowed due to slightly varying assumptions the players must make during a mission.

A practical example is the fluid properties. The player may need to fix the density of water or air in the conditions of incomplete source information. In situations like this, an acceptable range for the calculated result is given in the reference solution with absolute bounds (upper/lower). Instead, relative tolerance may be more useful when the calculation does not need assumptions on the player's behalf, but deviations are a result of computational discrepancies.

An example of an acceptance rule, where the answer is to be inserted as a *number* in the cell "B120" of the project workspace in MS Excel and assessed based on *absolute bounds* can be written as:

```
"=IF(AND(ISNUMBER(B120)=TRUE;AND(B120>='Ref!F18;B120<='Ref!G18));"OK";"")"
```

The rule tests that the input is numerical ("ISNUMBER" function) AND checks whether the answer is between the given lower (cell "F18" in the reference solutions worksheet "Ref") and upper bounds (cell "G18").

An example of an acceptance rule, where the answer is to be inserted as a *formula* in the cell "B77" of the project workspace in MS Excel and assessed based on *relative tolerance* can be written as:

```
"=IF(AND(ISFORMULA(B77)=TRUE;ABS(B77-'Ref!B48)<=Settings!B106*'Ref!B48);"OK";"")"
```

The rule checks that the input is numerical ("ISFORMULA" function) AND calculates the absolute value of the difference between the player's answer (cell "B77") and the reference answer (cell "B48" in the reference solutions worksheet "Ref") plus verifies that the absolute value of the difference remains less than the absolute tolerance, i.e., the reference answer multiplied by a relative tolerance. Here, the relative tolerance has been defined as a percentage on the separate hidden workspace "Settings".

In both the above cases, when the acceptance rule gets the value "TRUE", the text "OK" appears in the target cell (otherwise, the cell remains empty). The font color has been pre-set as green.

### 3.3.2 Scoring criteria

In "Solar Village", the term "scoring" primarily refers to the rules to convert the accepted answers ("OKs") into rewards such as startup market value increments. It also refers to conditions to be fulfilled to upgrade the skill and knowledge levels, and CEO level, as well as condition rules to penalize surpassing pre-defined constraints, e.g., project budget overruns.

The scoring should reflect the project's level of difficulty and the players' computational effort. The more difficult and laborious a mission, the better the reward. On the other hand, scoring makes visible the evolution of a startup's market value and simulates the CEO's career development in real life. To that end, the game developers and administrators are in charge to determine the validity of scoring

criteria and extending it down to the level of single missions or even to the level of single outputs.

In “Solar Village Beta”, scoring is based on the players’ achievements in upgrading skill levels. The outputs required to achieve a level-up for each skill/knowledge are pre-defined by the administrators by appropriate cell/range references and settings.

For example, reaching the Lvl 1/1 of the skill “Heat loss and heating demand of a building” has been set to require 22 accepted outputs in total, including the selection of correct degree hours and design temperature and calculation of heat transfer coefficients for various structural parts, design heat losses and energy demands. The number of accepted outputs (22, verified using the “COUNT” function of Excel) is multiplied by the weight factor six (6) to obtain a normalized score considering the level of difficulty of the achievement in comparison with other projects of the entire project pool. Again, the scale factor ten (10) is used to convert the normalized score ( $6 \times 22 = 132$ ) into a market value increment ( $132 \times 10 = (+) 1320 \text{ €}$ ) to value the increase in the startup’s competence capital by a credible amount of money. There are no restraints for the scale factors in the “Solar Village”, but they have been chosen between 0 and 10.

In the “Energy Systems” course, the conditions required to upgrading the CEO level and passing the course are also based on the number of skill upgrades. Here, the approval threshold has been set to 50% of the maximum number of skill upgrades (6/12), whereas the CEO Lvl 1, 2 and 3 require 6/12, 9/12 and 12/12 level-ups, respectively.

For projects such as the “SolAthon” (See: Fig. 8), where there is a pre-defined project budget, the proportional budget overrun (i.e., the ratio of the overrun and the original budget) is penalized so that 5%-overrun results in a score reduction by 25%, whereas the overrun of 40% zeroes the score. In the same project, the number of simulations is counted, too, and an ineffective approach is penalized. The maximum number of simulations without penalty is 20, whereas the number of trials of 50 or more results in the score reduction of 30%.

The scoring example presented above is just one possible option to assess the student output, and it is not necessarily applicable as such to whatever type of events. In student competitions, for example, scoring based on counting the “OK” markings in the event workspace might not be useful. The student competitions typically require a comprehensive assessment in several areas, and the output to be evaluated is not a single number or even a formula.

In the “Solar Decathlon” student competition, for example, the competitors’ performance is assessed and scored in eleven (11) different areas (also known as “contests”). These key assessment areas are summarized in Table 9.

Table 9. The breakdown of the key assessment areas in the “Solar Decathlon”.

<b>Assessment area</b>	<b>Content</b>
Architecture	Evaluates the creativity and integration of the design, balancing aesthetics with functionality.
Engineering	Assesses the effectiveness of engineering systems for energy efficiency and renewable energy production.
Energy performance	Focuses on the building's energy consumption and generation capabilities, often aiming for net-zero or energy-positive performance.
Market analysis	Judges the building's appeal, affordability, and likelihood of adoption by its target market, including financial analysis and life-cycle costs.
Durability/resilience	Measures the building's capacity to endure environmental conditions and respond to disruptions.
Embodied environmental impact	Assesses the total environmental impact of the building over its entire life cycle, from resource extraction to disposal.
Integrated performance	Evaluates how different design elements work together to optimize overall building performance.
Occupant experience	Focuses on how the design supports a safe, convenient, comfortable, and enjoyable living or working environment for occupants.
Comfort & environmental quality	Evaluates the indoor comfort and air quality for the building's occupants.
Presentation	Assesses the quality and clarity of the deliverables and how effectively teams communicate their designs.
Innovation	Recognizes and rewards innovative ideas and solutions in the design.

There are three (3) ways the teams may earn points related to the assessment areas listed in Table 9. First, the teams just need to *complete* given tasks that simulate modern living, such as cooking, doing laundry, or charging an electric vehicle with energy from the house's solar electric system. Second, the performance of houses and appliances is *monitored* against specified criteria, such as maintaining indoor temperature and humidity, ensuring refrigerators maintain appropriate temperatures, and controlling the flow of electricity between the house and the utility. Thirdly, *jurors* who are experts in various fields, such as architecture, engineering, homebuilding, and communications, award points for features that cannot be measured, such as aesthetics, design inspiration, and innovation. Each assessment area is worth a maximum of 100 points.

In the “Solar Village”, monitored contests, i.e., completing missions and monitoring variables (e.g., energy consumption, duration of temperatures) may be reverted to a trivial procedure. Quantifiable variables can be verified, for example, by performing simulations and normalizing the results to a given commensurate scale (e.g., from 0

to 100). For juried contests, where subjective elements such as “creativity” or “enjoyable living” are to be assessed, an automated and built-in scoring of the players’ outcome poses a further challenge. Here, a potential approach might be AI-assisted evaluation, which is discussed in more detail in the following section.

### 3.3.3 AI-assisted evaluation

AI-assisted evaluation provides a tool to automate the assessment of students’ working reports or essays in a consistent and effective way. The most useful tools to that end (in October 2025) are so called Natural Language Processing (NLP) tools, i.e., such software and platforms that allow computers to process and generate human language by using AI and machine learning to extract meaning from text data.

These features have not yet been implemented in the “Solar Village” (Beta), but the principle is simple: a player’s output is uploaded to the AI tool via an online interface together with pre-defined evaluation criteria (by administrator), whereas the AI tool generates complete feedback and, upon request, a score assessment.

Creating accurate and quantifiable assessment criteria to control the AI tool is necessary for the AI-assisted evaluation. Because the language models have a limited capability to process numerical data, the principle of quantifiable assessment must be explained in words. The evaluator’s outcome (statement) is based on statistical incidence of certain characteristic attributes. To that end, an assessment matrix is a good administrator’s tool. The rows represent given assessment areas, whereas a short description of requirements to achieve a certain score (e.g., 1 to 5) against each assessment area is presented in the columns.

In Table 10, an example of assessment matrix created with the assistance of the Grok AI is shown. This is a generic matrix with an aim to assist the automatic evaluation of student essays on a five-level scale (1 to 5). The AI tool was not equipped with instructions related to the assessment areas, but it produced the matrix based on its training material, making use of standard key areas for academic essays.

Table 10. A generic evaluation matrix for student essays by Grok AI.

Assessment area	Requirements for score 1	Requirements for score 2	Requirements for score 3	Requirements for score 4	Requirements for score 5
Content and Development (Depth, Accuracy, Relevance)	Superficial treatment with major inaccuracies and irrelevant material that fails to address the topic.	Limited depth, some inaccuracies, and partial relevance with underdeveloped ideas.	Adequate depth, mostly accurate information, and relevant content that covers the basics.	Strong depth, accurate details, and high relevance with well-developed ideas.	Exceptional depth, complete accuracy, and perfect relevance with insightful analysis.
Organization and Structure	Completely disorganized with no logical flow or structure, making it difficult to follow.	Weak organization with unclear progression and poor transitions between ideas.	Basic structure with logical flow and adequate transitions.	Well-organized with clear progression, smooth transitions, and effective structure.	Outstanding organization with seamless flow, sophisticated transitions, and cohesive structure.
Language Use and Style (Clarity, Vocabulary, Sentence Variety)	Unclear expressions, limited vocabulary, and repetitive sentence structures that hinder comprehension.	Somewhat clear but with basic vocabulary and minimal sentence variety, leading to monotony.	Generally clear with appropriate vocabulary and some sentence variety.	Very clear with rich vocabulary and good sentence variety enhancing engagement.	Exceptionally clear with sophisticated vocabulary and excellent sentence variety for stylistic flair.
Mechanics (Grammar, Spelling, Punctuation)	Numerous errors in grammar, spelling, and punctuation that severely impede readability.	Frequent errors in grammar, spelling, and punctuation distract from the content.	Some errors in grammar, spelling, and punctuation, but overall understandable.	Few minor errors in grammar, spelling, and punctuation, with a polished appearance.	Virtually error-free grammar, spelling, and punctuation, demonstrating impeccable control.
Research and Citation (Quality of Sources, Integration, Formatting)	No evidence of research, missing or improper citations, and no adherence to formatting standards.	Poor quality sources, weak integration, and multiple formatting errors in citations.	Adequate sources, basic integration, and mostly correct formatting with some inconsistencies.	Good quality sources, effective integration, and correct formatting throughout.	Excellent sources, seamless integration, and flawless formatting in citations.

The Grok AI ([www.grok.com](http://www.grok.com)) is an example of a useful and effective AI tool. Aalto University has its own AI tool (<https://ai.aalto.fi/>), which is based on the OpenAI GPT5 language model. Regarding the generic evaluation matrix, the Aalto AI creates a proposal almost identical to that of the Grok AI.

The generic matrix presented in Table 10 is useful for the administrators as a template for developing more specified evaluation matrices. For example, a more specified criterion under the assessment area “content and development” may require that at least three (3) justified arguments is found in the student essay.

In practice, mission-specific assessment criteria are needed. The criteria must be aligned with the domain-specific requirements (e.g., assessment templates provided by Aalto University). To that end, for example, the evaluation tool should be able to check and ensure an authenticity of the essay under the assessment area “Research and Citation”.

The authenticity is commonly verified by comparing the similarity of the essay to the literature. The similarity is expressed as percentage, for example, less than 10%. The capabilities of language models to deal with this kind of information are limited. Hence, a separate tool (e.g., Turnitin) may be necessary in guiding the AI to provide reliable similarity assessments for the authenticity check.

Making the AI assisted assessment automatic is also challenged by the stiffness of the current AI tools. A separate session is required for each student report, which slows the assessment process. In practice, the evaluation matrix is first inserted in the tool’s rubric field. Then, the student report is attached as a text document, and the tool is guided to evaluate the report using the evaluation matrix and further specifications, such as plagiarism check reports.

The following example is to illustrate the implementation of AI-assisted evaluation in the assessment of a student essay. This is a learning assignment in the course “Sustainable Building Energy Systems” in Autumn 2022. The task statement is below.

Write an essay (case style, maximum length: one (1) A4 text page, excluding the list of references) with the topic “***Improving the energy performance of buildings using phase change materials***”. Specifically, seek an answer to the following questions and outline your essay accordingly:

1. What phase change materials (PCM) are in use?
2. How are phase change materials typically integrated in buildings and why?
3. For which kind of an application you would recommend a hybrid PCM solution?

Any literature is allowed as source material. The enclosed review article “*Phase change materials and energy efficiency of buildings: A review of knowledge*” is to help you to familiarize yourself with the concept and to give ideas/further references.

The following paragraphs address the assessment of an actual student essay, which is not published in this report, however, for privacy reasons. In the original teacher’s assessment, the essay was evaluated using the five-level scale. The assessment was based on the contents, including pre-defined content items related to the students’ responses to the three questions presented in the task statement. Moreover, a teacher’s subjective estimate was given on the essay’s quality and style of academic writing.

The essay was assessed by the course teacher against based on the assessment matrix containing ten (10) separate assessment areas as summarized in Table 11. Each area was assessed on a five-level scale (1 to 5).

Table 11. Assessment matrix based on the teacher’s evaluation.

Assessment area	Requirements for score 1	Requirements for score 2	Requirements for score 3	Requirements for score 4	Requirements for score 5
Motivation statement	Missing	Generic	Number of arguments > 0  No of facts >0	Number of arguments > 1  No of facts > 1	Number of arguments > 1  No of facts > 2
PCM types	Missing	Number of types > 0	Number of types > 1	Number of types > 2	Number of types = 3 + explanations
Chemical compounds	Missing	Number of examples > 0	Number of examples > 1	Number of examples > 2	Number of examples > 3
Integration in buildings	Number of examples > 0	Number of examples > 1	Number of examples > 2	Number of examples > 5	Number of examples > 7
SWOT analysis	-	-	-	Number of SWOT points > 0	Number of SWOT points = 4
Case studies	-	-	Number of examples > 0	Number of examples > 1	Number of examples > 2
Energy performance improvement potential	-	-	Number of facts > 0	Number of facts > 1	Number of facts > 2
Presentation	Academic style  Structure  Length < 200 words	Academic style  Structure  Length > 200 words < 250 words	Academic style  Structure  Length > 250 words < 300 words	Academic style  Structure  Length > 300 words < 350 words	Academic style  Structure  Length > 350 words
References	Missing	Quantity Tot > 1	Quantity Tot > 3  Quantity Sci > 1	Quantity Tot > 5  Quantity Sci > 3	Quantity Tot > 7  Quantity Sci > 5
Authenticity	Similarity < 25%	Similarity < 20 %	Similarity < 15%	Similarity < 10%	Similarity < 5%

The student essay had a logical structure entailing four paragraphs organized according to the task statement: i) Motivation, ii) Generic description of the PCM based on Wikipedia (Question 1), iii) Explanation of how PCM is incorporated in buildings (Question 2), and iv) Recommendations for hybrid-PCM (Question 3).

The areas “SWOT analysis”, “Case studies”, and “Energy performance improvement potential” were not visible. Since these areas were considered an added value rather than a requirement, they were not included in the assessment after all. A similarity check using the Turnitin tool was added in the evaluation.

The teacher's evaluation concerning the student essay resulted in the following statements:

- Motivation: The motivation is presented in Paragraph 1 (energy efficiency, environment), but the argumentation remains at a generic level and no facts based on the literature are referred to. The score is two (2).
- PCM types: Any of the three PCM types (organic, inorganic, eutectic) is not mentioned. The score is one (1).
- Chemical compounds: Examples of chemical compounds are not given. The score is one (1).
- Integration in buildings: The incorporation in buildings has been explained by four methods (direct incorporation, immersion, encapsulation and stabilization). The building parts (walls, panels, bricks) are not mentioned, nor are examples given to explain the practices. The score is three (3).
- Presentation: The language and structure fulfil the minimum requirements. The essay is brief, yet the length is >250 words. Thus, the score is three (3).
- Authenticity: According to the Turnitin report, the similarity is 22%. The score is one (1).

The average value of the scores by assessment area is 1.83, which results in the rounded final score of 2/5.

Besides the teacher's evaluation, the student essay was evaluated using the Aalto AI tool (GPT5) and the generic evaluation matrix (Table 10). The statements and scoring by the five assessment areas are shown in Table 12.

Table 12. An evaluation statement generated by the Aalto AI for the sample essay.

Assessment area	Statement	Score
Content and Development	<p>Strengths: Clearly identifies PCMs as a means to improve building energy performance and correctly states the principle of latent heat storage (“releasing/absorbing energy”). Lists common incorporation methods (direct incorporation, immersion, encapsulation, stabilization) and notes hybrid PCMs for broader temperature spans.</p> <p>Gaps: Lacks classification of PCM types (organic, inorganic, eutectic), quantitative detail (melting ranges, latent heat values), trade-offs (subcooling, leakage), and any case studies. Some statements are vague or awkward (e.g., “ease of use of microencapsulation and microencapsulation”).</p>	3
Organization and Structure	There is a general flow from problem statement to PCM concept to methods to hybrids, but the introduction is repetitive, transitions are abrupt, and the reference section ends abruptly with “References 1.” within the essay text. The thesis is implicit rather than clearly stated.	2
Language Use and Style	Meaning is generally recoverable but marred by awkward phrasing, imprecise vocabulary, and some confusing sentences (e.g., “waste of an affective energy,” “exceeds times its consumption”). Duplication (“microencapsulation and microencapsulation”) suggests editing issues.	2
Mechanics	Numerous grammatical errors, agreement issues, and punctuation problems that at times hinder readability (e.g., run-ons, missing articles).	2
Research and Citation	Sources: Wikipedia and a relevant journal review are listed. While the review article is an appropriate scholarly source, the essay does not integrate specific findings or use in-text citations consistently. Reference formatting is inconsistent, and the in-text “References 1.” in the body appears incomplete.	2
Overall rating	<p>Notes and next steps tied to the rubric</p> <p>To reach 4–5 in Content and Research, add a section that explicitly compares organic, inorganic, and eutectic PCMs; include at least two case studies with quantitative results; and integrate findings from the review article with proper in-text citations.</p> <p>Improve structure by stating a clear thesis in the opening, using focused subsections (e.g., Principles, Types, Integration Methods, Case Studies, Challenges), and concluding with synthesized implications.</p> <p>Edit for clarity and mechanics: simplify sentences, fix grammar, and remove duplicated phrases.</p>	2.2 (rounded to 2)

Even though the teacher's evaluation and the AI evaluation are based on different assessment matrices, the conclusions are quite similar, and it is easy to agree. The first assessment area (content and development) summarizes several issues that are treated separately in the teacher's evaluation. Here, for example, the AI tool has meritoriously identified the lacking PCM types by comparing the essay with its training data.

The AI tool has evaluated presentation and language issues meticulously. It has perceived duplication ("microencapsulation and microencapsulation"), which was not included in the teacher's evaluation. On the other hand, the AI tool ends up with weird conclusions in some respects. For example, the conclusion "the reference section ends abruptly with 'References 1'" looks like a misinterpretation of the body text and the list of references.

The overall rating section is provided by the AI tool with a statement to suggest ideas to improve the presentation. The suggestions are agreeable as such. The teacher's scoring is slightly more stringent than the AI's scoring, but the score rounded the closest integer is equal (2).

In conclusion, the evaluation example shows the potential of AI-assisted evaluation in scoring events in the gamified learning environment, when the output is a written document. However, some areas of the assessment (such as the similarity check) need such techniques of content analysis that are not realizable by way of language models only. Therefore, multiple supporting tools or methods may be needed, which increases the level of complexity.

The use of external AI tools needs a separate interface with the "Solar Village" learning environment. In principle, this is also possible using MS Excel. The premises to implement interaction between AI tools and the "Solar Village" environment are discussed with more detail in Section 4.2.

### 3.4 Settings

In "Solar Village Beta", a separate workspace is used to set and adjust the game parameters. The workspace is intended to be visible for game administrators and developers. Although most of the game parameters are event-specific, there is still a need for interaction between the teachers regarding general principles such as the weight of single events or skills in the startups' total market value.

By the game parameters we refer to such constants that are valid for given events. First, event/skill names (string) and availability windows can be edited in the "Settings" workspace. In "Solar Village Beta", the availability of events is determined simply by assigning the date and time (in the future) when each event is unlocked and locked. The present format is "DD.MM.YYYY hh:mm".

Second, the workspace "Settings" is used to define the scoring, rewarding and approval mechanisms. The market value increment is the main rewarding mechanism, and it is skill specific, calculated as the weighted sum of accepted student inputs. The

procedures of approval and rewarding were described and exemplified in Sections 3.3.1 and 3.3.2. The weight factors, i.e., the scaling factors and the absolute and relative tolerances for the acceptance are determined in the workspace “Settings”.

Because rewarding is skill specific, no general recommendations can be provided. In “Solar Village Beta”, for example, the scaling factor of the skill “Energy consumption of building” (10) has been set twice as high as that for the skill “Saving potential of energy renovations” (5). This means that the number of approved student inputs is multiplied by a scaling factor (10 or 5) to convert it into the market value increment.

No general recommendations can be provided for the numerical values of the absolute tolerance either, since they are case-specific, too. The absolute tolerance is applied, for example, to the task to estimate the use of domestic hot water consumption per person or the temperature difference between cold and hot water. The relative tolerance is more applicable to output calculated based on a formula, where outright miscalculations are penalized, whereas the inaccuracies in rounding etc. are tolerated. Based on experience, it can be suggested that the relative tolerance less than 0.5% of the reference solution is applicable to most situations.

The skill specific approval thresholds are defined as a percentage of the total number of student inputs. In the case of the skill “Energy storage modeling”, for example, the total number of inputs is 96 and the threshold is 50%, which means that the student must obtain at least 48 “OKs” to have this skill achieved.

## 4 Future development of the Solar Village

The current state-of-the-art of the “Solar Village” environment has been discussed in previous sections with the notion that all the key building blocks are in place. In fact, this is just the starting point of the game development. Further steps must be taken in all areas. Some of the most crucial needs for the further development are discussed in this chapter.

### 4.1 Platform

To ensure the students’ legal and data protection, the gamified learning environment needs to be integrated with universities’ administrative systems. The “Solar Village” is not meant to be built as an overlapping platform to existing solutions, but either it replaces an existing teaching platform or is used as a supplementary component that has a direct and protected access from the official teaching platform.

The current version of the “Solar Village Beta” is merely a protected and macro-enabled Excel workbook with the size of 15 MB. The workbook is shared in its entirety to the course participants via the Aalto University’s teaching platform “MyCourses”. Aalto’s official student information system “SISU” is manually updated with approved accomplishments by the teacher. In the future, a mechanism will be needed to automatically convert and transfer the accomplishments into the student information system.

The “Solar Village Beta” has worked reasonably well in MS Excel, being capable of piloting the basic concepts of the gamified learning environment. The students have been guided to download it onto their own computer and to enable macros. The following issues have been detected:

- Some virus protection applications require that the downloaded file is individually marked as trusted.
- When the “Solar Village” workbook is opened for use, other Excel workbooks, if open, must be closed. Otherwise, the macros do not work properly.
- Macros do not work in the devices by Apple.
- Macros are disabled in a cloud-drive (e.g., Sharepoint).

For the reasons above and given that all the functionalities suggested in this report are to be included in the future versions of the “Solar Village”, Excel is apparently not the preferred gaming platform in the long term. Specifically, because the use of macros in the cloud is limited, Excel would not support the multiplayer mode and collaboration between multiple administrators and developers. Hence, there are no decent means to enable full interaction between a plethora of accounts (worldwide), protected visibility and data transfer between workspaces, and a shared access to large, collective databases. In the final analysis, Excel is simply too narrow and clumsy an application to work as a game engine.

To get the “Solar Village” out of Excel, a preferred option is to develop the game on one of the existing game engines to avoid building everything from scratch. There is a multitude of game engines available for 2D or 3D-based gaming. In most of them, expertise in the C/C++ or Java programming languages is required. The survival game “State of Survival”, for example, has been built on the game engine *Unity*, which is based on C++. In fact, the development of the “Solar Village” was also launched using the *Unity* engine. The implementation did not progress, however, since Excel was found to be a more agile option to quickly embrace all the game’s key functionalities. The earliest version (only in Finnish) was stored (and is still available, November 2025) at:

<https://tatuheinamaki.com/solarvillage/phaseone/>.

Because the “Solar Village” environment requires computational input akin to Excel, the preferred choice is a Python-based framework (e.g., *Pygame*). Here, the possibility to use specialized libraries (e.g., *Pycel* or *xlcalculator*) that directly handle and execute Excel formulas means the core mechanic of the game can be maintained. Moreover, Python can be considered a low-threshold programming language that allows excellent data management. The drawback is that the Python-based framework is rather data-focused than visual-focused, which means that more coding is needed to build visual game features, i.e., the User Interface (UI) and animations, in comparison with visual-focused game engines.

For game developers, *GitHub* (<https://github.com/>) is recommended as a platform to create, store, manage and share the code. It enables several useful services like distributed version control, bug tracking, feature requests and repositories for file storage. There are also platforms with the purpose of practicing programming skills online, such as <https://www.w3schools.com/>.

## 4.2 User interface

The user interface of the “Solar Village” environment is one of the areas needing a plenty of future development. The major areas to be developed are visualizations, leaderboard, multi-player mode and the use of AI agents via the interface.

Above all, the appearance of the game is to be developed from ordinary sheet calculations towards increased interaction and game-like elements. For example, the power plant process depicted in Fig. 7 can be enhanced by allowing the player to draw system boundaries to identify relevant sub-systems and by equipping the boundary lines with automatically changing colors (green, red) according to their applicability of the student’s suggestion to solve the given problem. A more advanced approach is to allow the students to build their own power plant configurations and to test the impact of different variables and operational parameters on the plants’ performance, including mechanisms for immediate rewards and penalties. These upgrades are relatively easy to implement, even in MS Excel environment, using graphical objects.

An access to AI assisted tools via the user interface is another major avenue of further development, which is also possible in MS Excel. In the “Solar Village”, the most urgent first step is to increase the intelligence of the virtual assistants and those evaluating student essays. To that end, ChatGPT can be installed as an Excel Add-In, which is available via the Office Store.

In Excel, ChatGPT is called using the function “GPT()”, where the prompt (e.g., “Hello”) is given as an argument. There are also several other functions for a variety of tasks, such as “GPT\_TRANSLATE()” for translation and “GPT\_CLASSIFY()” for text content classification. After a while, ChatGPT writes its response in the target cell including the GPT function (e.g., “A1”), and the response can be retrieved.

To call the ChatGPT Add-In using a macro, the GPT function needs to be written as a text (string) in the target cell. To avoid error notifications when retrieving the response, the macro needs to ensure that the response is complete. The following script exemplifies entering the word “Hello” as a prompt in the target cell “A1” of “Sheet1”. The contents of the target cell are checked every five (5) seconds, and, when complete, the response (string variable “Response”) is displayed in a message box.

```
' Write the GPT function and the prompt "Hello" in "A1":  
Sheets("Sheet1").Cells(1, 1).FormulaLocal = "=GPT(" & """"Hello"""" & ")"  
  
' Give five (5) seconds before the first content check:  
Application.OnTime Now + TimeValue("00:00:05")  
  
' Retrieve and display the response, when complete:  
Response = Sheets("Sheet1").Range("A1").Value  
If IsError(Response) Or Response = "" Then  
    Application.OnTime Now + TimeValue("00:00:05")  
Else  
    MsgBox Response  
End If
```

For the implementations of “Solar Village” in platforms other than MS Excel, there are several avenues for further development. The first step is potentially the development of such leaderboard, where the players’ achievements are automatically registered in the database and listed in a separate workspace visible to all the students. Besides the market values, the leaderboard should be sortable by the players according to diverse variables such as HQ level and CEO level. The leaderboard should be cross-domain to allow competition between disciplines and universities.

The next steps include other multi-player aspects, i.e., multi-player registration and administration of business alliances and collaborative events as outlined earlier in this report. An integral part of the multi-player mode is a real-time chat, where the players can discuss with each other when they are on-line. This method of communication is handy for various uses, for example, applying the membership of a business alliance or planning successful business strategies during student competitions.

A visually prestige and interesting addition to the user interface contains a workspace showing a 3D world map, where all the registered HQs are located at actual coordinates by country, by university and by domain. When zoomed to maximum, the HQ appearances aka skins and their levels will be shown. The HQ skin manifests its power on the map, and it can be upgraded by a purchase in a “skin store” workspace by Solar Credits. Clicking the skin opens the startup and interaction icons. This is an easy and illustrative way for the players to interact with their business partners or opponents during the events. The map view is illustrated in Fig. 18.



Figure 18. An example of a 3D view of two HQs on the “Solar Village” map.

Finally, the 3D map view is to be assigned as the main view of the “Solar Village” interface. The key workspaces and a zooming tool are to be shown using icons and menus at the edges of the map view. When played first time, the “Solar Village” introduction workspace (See: Section 2.2) will be replaced by a wizard that guides the player from to the welcoming to the establishment of a startup (game account). Later, the platform always opens to the map view, the player’s HQ placed in the center of the map.

### 4.3 Events

Regarding the event development for “Solar Village”, the earlier sections have mainly focused on regular and recurrent projects, where the students develop basic skills and knowledge associated with their degree. On the other hand, the possibility to enable a participation to special events like student competitions via the “Solar Village” has been discussed as one of the future trends of development. This section is to briefly present a few further ideas for the future.

First, a new type of competition, the challenge, is to be developed to increase the gamified momentum of the “Solar Village”, to nourish the competitive drive and to teach supplementary skills like leadership or management. In real life, a company may confront distortions that threaten its market value, balance, and even existence. For example, the distortion may take the shape of a lawsuit or declining market due to various reasons (e.g., recession, trade war, a strong competitor entering the market etc.). Situations like this challenge the CEO’s ability to lead the company and make solid but wise decisions. In “Solar Village”, these scenarios can be simulated, for example, by way of events organized as follows:

1. A startup (or a business alliance) is challenged with a selected type of challenge (lawsuit, market entry etc.) by one of the peers (typically an individual startup or business alliance with higher market value and/or HQ/CEO). They can be also raised automatically by AI. The challenge may be triggered anytime or in terms of events tailored to that end (e.g., “Economic Forum”, “Slush fair”).
2. Both the incumbent (defender) and the challenger are asked to perform a task measuring the level of strategic leadership within a given time.
3. The victory (rise of market value/cash) or defeat (drop of market value/cash) is determined based on a weighted score, which considers bonuses due to high HQ/CEO level. A delayed response automatically results in defeat.

In challenges, the player’s ability to make proper decisions within a limited time and under pressure is crucial, since the tasks must be solved in minutes or even seconds. There will be no time to use AI assistants or other resources. Therefore, the tasks differ drastically from the projects described in Section 2.9. Basically, the challenges should contain questions measuring the players’ instant knowledge, intuition, or logical reasoning. They may follow the structure of traditional IQ tests that require an ability to figure out mechanisms or verbal tests including facts to predict the most probable outcome. The format of these tasks can be (for example):

- Choice (multiple, yes/no, correct/incorrect etc.)
- Re-organizing a list of words or sentences
- Combining (word couples, identifying relationship between concepts etc.)
- Written response (if applicable)

The following example is to demonstrate a challenge including re-organizing a list of contents and to provide a guideline for the development of challenge-type events. Let us assume that the challenger is the Lvl 10 startup “Dr. Clayton’s” who decides to challenge the Lvl 2 startup “My Startup” that has appeared as a newcomer to the market territory of “Dr. Clayton’s” (see: Fig. 18). By clicking the skin of “My Startup” HQ on the map view, a menu opens around the HQ skin showing the challenger the icon of the “MyStartup” business card and two command icons, where “My Startup” can be challenged either by a solo player or a business alliance (Fig. 19).

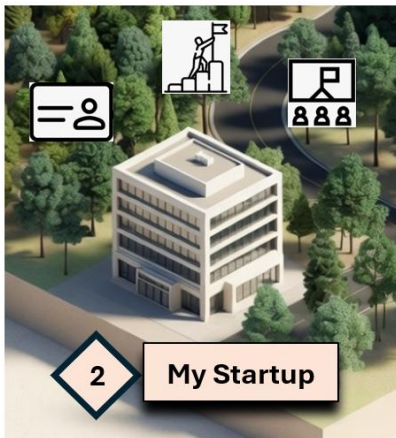


Figure 19. An example of the “Solar Village” map view menu.

By clicking the solo challenge icon (in the middle), the challenger is asked to confirm the challenge and select the type of challenge. If the response is “yes”, the challenge is sent to “My Startup” with an option to either accept or reject it. If “MyStartup” rejects the challenge it will expire. However, a recommendation is that the number of rejections given by a startup would be limited. If “MyStartup” accepts the challenge, the instructions will be sent with a deadline to perform the task. Correspondingly, the challenger will get the same message with a note about the accepted challenge.

The challenge deadline (e.g., one week from accepting the challenge) is to prevent the players from postponing the task indefinitely. If the company fails to perform the accepted task by the deadline, a defeat is declared. The task statement itself opens to the player not earlier than when he or she begins to perform the task. The task-specific timer starts immediately and runs until the given time is over. The time to perform the task may be, for example, ten (10) minutes plus a cooldown period of four (4) minutes, during which the total score is fined by 25% per minute.

Assume that in this example, the challenger has chosen a task where regulatory hurdles and sudden policy changes pose a threat to the young energy startup’s mission and budget. When performing the task begins, a detailed task statement is opened to the players. The task includes a mixed list of measures for the CEO (player) to choose five and set them in an order to build an appropriate procedure to manage the situation. The exemplified list is shown in Table 13.

Table 13. Exemplified list of measures for a challenge event.

No	Measure
1	Invest in inventory and forecasting: Build strategic stockpiles of critical materials and implement AI-driven demand forecasting to anticipate shortages.
2	Explore alternative financing options: Pursue government grants, crowdfunding campaigns, or strategic partnerships with suppliers to reduce upfront capital needs.
3	Diversify market entry strategies: Explore alternative regions with more stable or supportive regulations, such as shifting focus to emerging markets with incentives for renewables.
4	Conduct a comprehensive regulatory audit: Engage legal experts to review current and upcoming policies in key markets, identifying potential impacts on operations and creating a compliance roadmap.
5	Refine the pitch and business model: Update the investor deck to emphasize unique value propositions, market potential, and early traction metrics, backed by data from pilot tests.
6	Map and assess the supply chain: Identify all suppliers and vulnerabilities through a detailed audit, using tools to track dependencies and potential risks.
7	Innovate for resilience: R&D efforts to substitute scarce materials with sustainable alternatives, while hedging costs through futures contracts or insurance against disruptions.
8	Optimize internal cash management: Conduct a cost audit to cut non-essential expenses, negotiate better terms with vendors, and implement lean operations to extend runway until funding is secured.
9	Secure contingency funding: Allocate a reserve budget or seek grants specifically for regulatory compliance, ensuring the company can absorb unexpected costs without derailing core activities.
10	Network aggressively in the ecosystem: Attend energy-focused investor conferences, leverage accelerators, and connect with angel investors or corporate venture arms from established energy firms.
11	Diversify supplier networks: Source materials from multiple regions and vendors, including domestic alternatives, to reduce reliance on any single source.
12	Build relationships with policymakers: Attend industry forums, join advocacy groups, and schedule meetings with regulators to influence favorable policies and stay informed about changes.
13	Form strategic alliances: Partner with larger energy companies or consortia for shared procurement, gaining access to more stable supply channels and bulk pricing.
14	Implement agile compliance systems: Invest in software tools and training for the team to monitor regulatory updates in real-time and adapt processes quickly without halting progress.
15	Demonstrate milestones transparently: Set and achieve short-term goals, like completing a minimum viable product, and share progress reports to build credibility and attract follow-on investments.

A success in this challenge requires a careful familiarization with the optional measures and identifying the key concepts related to regulations and policies. Then, the player must re-organize the chosen measures to a workable procedure. The time is limited to ten minutes. The recommended way to realize this in the “Solar Village” platform includes two lists: one for all the options (Table 13) and another list, to which the player can move the chosen options using a drag and drop method. Again, the final order of measures can be adjusted easily using the same method.

In this example, the options 3, 4, 9, 12, and 14 can be recognized as potential measures to tackle the given challenge. The winning final order is 4 – 12 – 3 – 14 – 9. Assume that the incumbent finds the correct measures but organizes them in the increasing order (3 – 4 – 9 – 12 – 14). Instead, the challenger suggests the procedure 4 – 9 – 3 – 14 – 15, where 15 is not a desired option. Both participants need eleven (11) minutes to nail the task, which means that one (1) minute of the cooldown period was used.

The scoring criteria are as follows:

- A correct measure chosen from the raw list yields 10 points (max. 50 p).
- Each correct relationship between the measures yields 5 points (max. 50 p).
- Each overtime minute reduces the total score by 20%.
- The HQ level yields +5% bonus / each level.
- The CEO level yields +10% bonus / each level.
- The difference in the final score determines the winner. The difference is converted to an increase/drop in the market value using both general and specific scaling factors.
- The specific scaling factor is the unity + the sum of the players' HQ & CEO bonuses.
- The general scaling factor for score-to-market value conversion is 100.

In the example, the incumbent (HQ Lvl 2, CEO Lvl 2) manages to pick up all the five correct measures from the raw list, which results in the score of 50 p. In comparison with the reference, it can be noted that the relationships 3–9, 3–14, 4–9, 4–12, 4–14, and 12–14 are correct (six correct relationships from max.10), which yields 30p in total. The total score ( $50 + 30 = 80$ p) is weighted through multiplication by the sum of unity (1), the HQ bonus (5%), and the CEO bonus (10%), which results in the weighted score  $1.15 \times 80 = 92$ p. Due to one overtime minute, the weighted sum is reduced by 20%, which results in the final score of 73.6p. The identical procedure gives 79.2p to the challenger.

With the conditions above, the outcome is the challenger's victory. The difference in final scores ( $79.2 - 73.6 = 5.6$ ) is converted to market value using the winner's (HQ 10, CEO 3) specific scaling factor ( $1 + 0.45 + 0.2 = 1.65$ ) and the general scaling factor 100, i.e.,  $1.65 \times 100 \times 5.6 = 924$  €. This is added to the challenger's market value and subtracted from that of the incumbent.

The above assessment criteria were designed to favor high HQ and CEO level by being forgiving towards mistakes and by boosting the market value rise in the score-to-market value conversion. Here, the players' earlier achievements within the game are rewarded retrospectively. This is done by setting the specific scaling factor according to whether the winner has higher or lower bonuses. For example, assuming the incumbent won the competition, the specific scaling factor would have been 1.15 instead of 1.65.

The example above represented a solo challenge, where an individual startup challenged another one. The realization of an alliance challenge is no more than an idea at the publication of this report, but the main principle is to remain the same as in solo challenges. The key difference is that in alliance challenges, the benefits of teamwork and the strength of the community are brought to use. In principle, any alliance member can trigger an alliance challenge, and the other members either join the challenge or abstain as per their discretion. The challenge is to be targeted at either another business alliance or an individual startup. Development efforts are needed to design suitable tasks for short teamwork and to build workspaces and team organization tools for them.

The development of challenges can be considered a top-notch priority for the future, but another worthy idea for the further work is developing the “Solar Village” towards a service platform, which provides external parties such as companies or authorities with an opportunity to have their practical problems solved by university students and student teams (business alliances) free of charge. In the pedagogic sense, this approach is called project-based learning (PBL). The service platform would work in the other direction, too, i.e., the students’ startups offer services for external customers according to the startup’s profile and expertise, following the example of companies such as Wolt or Uber. That would help individuals to stand out and polish their skills towards the top.

The use of AI tools needs to be extended to automatic ideation and designing events and even to autonomous game evolution. The most promising first-step approaches are personalized events based on the players’ startup profiles, their achievements in earlier events, and potential gaps in the curriculum. Workable models can be collected from early adopters within this area, such as Washington State University

(<https://reelmind.ai/blog/washington-state-university-online-ai-for-higher-education>).

A “Solar Village” mobile application was already stated useful for student competitions, but an access to geospatial data would also increase the flexibility of the learning environment and open possibilities to location specific events such as surveying sites for wind power or getting to know a certain power plant or a geothermal borehole field.

Detailed analyses for each event, including the key performance metrics (e.g., ratio of correct/total inputs), should be communicated and recorded for the players’ own use. To that end, an internal email system within the platform needs to be developed. The statistics can be recorded, for example, in a private tab in the startup’s business card.

## 4.4 Resources

Regarding the resources of the “Solar Village”, accessing tools besides Excel Solver Add-In, steam tables etc. is a necessity. Thus, the interplay between the learning environment and numerous computational tools needs to be developed using the application programming interface (API) and required licensing issues must be resolved. Developing the “Solar Village” towards a platform to offer services to external customers might result in the need to develop specialized in-built facilities in case commercial tools do not match the demand. Here, a potential field of application could be specialized data-driven industry. To that end, new tools and workspaces for purposes such as automated data analysis or research centers are to be created.

The future evolution of “Solar Village” is marked by the great potential of artificial intelligence. The trend is from specific tasks towards general, human-like intelligence, which can learn, remember, adapt and reason. Thus, tasks are to be developed for the players to model and simulate the complicated interactions a CEO probably will confront in real life, including interplay with both humans and AI. This opens extensive possibilities, such as designing virtual “workforce” to meet the demand of the players’ startups. AI agents can also act as virtual customers for the startup. Some of the external “attacks” to test the readiness and resilience of the startup towards cyber threats or other unpredictable events can be AI-induced (See also: Challenges).

So far, the “virtual workforce” has been only demonstrated in “Solar Village” by the virtual assistants “Aino” and “Eino” and modeled through their static, pre-scripted comments. First, animated characters and ability to speak will be added to enhance the interaction between the CEO and AI. Second, their work description will be expanded. A possible trend is that the startups actively seek and recruit virtual workers (AI bots) from the platform’s internal “labor market” and assign them to appropriate positions within the startup. This needs a separate workspace to be developed. Potential job descriptions with required skills and knowledge are listed in Table 14.

When it comes to the skills of the AI workers, they are to be equipped with individual skills that can be upgraded during the gameplay by investing Solar Credits in “education”. The workers can be also promoted, or their job description can be adjusted (for example, from ordinary staff positions to leadership positions). Promoting the workers and upgrading their skills are not only to enhance the workers’ usefulness for the startup but also to raise the market value and HQ/CEO bonuses needed to win competitive events.

The intelligence of the virtual workforce is to grow in tandem with the general AI evolution. Hence, more advanced workers will enter the “labor market” in generations. Assuming “Aino” and “Eino” represent Generation 0 (G0), the Generation 1 (G1) workers are based on large language models (LLM), whereas Generation 2 (G2) workers add multi-agent AI capable of performing multiple tasks. The evolution is envisioned to continue generation by generation towards workers representing artificial general intelligence (AGI) and even artificial super intelligence (ASI).

Table 14. Possible job descriptions, skills and knowledge required by an energy startup.

<b>Job</b>	<b>Skills</b>	<b>Knowledge</b>
Chief Technology Officer (CTO)	Leadership Strategic Planning Prototyping Innovation Management	Energy Systems Emerging Technologies Intellectual Property Industry standards
Research and Development (R&D) Engineer	Design and Testing of Prototypes Data Analysis Simulation Modeling Problem Solving	Specific Energy Tech Materials Science Software Safety Regulations
Project Manager	Timeline/Budget Management Risk Assessment Stakeholder Coordination	Project Lifecycles Grant/Funding processes.
Regulatory Affairs Specialist	Legal Drafting Negotiation Compliance Auditing Policy Advocacy	Energy Regulations International Trade Laws Permit Processes Intellectual Property
Sales and Marketing Specialist	Market Research Pitch Development Customer Relationship Digital Marketing	Energy Market Competitor Analysis B2B Sales Strategies Sustainability Certifications
Financial Analyst	Financial Modeling Forecasting Fundraising Cost Optimization	Startup Financing Energy Economics Tax Incentives Risk Management
Supply Chain Manager	Vendor Negotiation Inventory Management, Logistics Optimization Crisis Response	Global Supply Chains Sustainability Sourcing Trade Tariffs
Data Scientist	Machine Learning Data Visualization Predictive Analytics Programming	Energy Data Sets AI-based Forecasting Cybersecurity Ethical Data Use

To make the experience realistic for the CEO, the whole life cycle of virtual workforce needs to be modeled and simulated. One of the intentions is that the players develop an emotional relationship with their AI workers. This would revolutionize the players' experience in practicing real-life situations such as recruiting new workers, solving problems related to a work community's atmosphere, and finally, the termination of job contracts (e.g., firing workers representing old generations).

## 4.5 Other

This section is dedicated to briefly addressing the prospects of the “Solar village” in such areas that have not been discussed earlier in this report.

In Section 2.2, a playful suitability test was demonstrated in terms of establishing a startup company. To enhance the credibility of the test, psychometrically robust methods and protocols for assessing personality traits and job suitability are to be implemented in the future versions of the “Solar Village”. The methods need to measure traits like conscientiousness, openness, analytical thinking, and problem-solving, which predict the player’s performance in technical, innovative, and detail-oriented tasks. They should be applicable without face-to-face proctoring. Again, the results should be interpretable by AI and convertible to appropriate startup profiles in a way akin to the example in Section 2.2. The test ought to be repeatable throughout the study path. However, the testing protocol must not appear to the players too serious, but the playfulness needs to be maintained. A list of on-line-ready testing protocols suitable for psycho-social assessment (particularly in the field of engineering) with characterization and references is shown in Table 15.

Table 15. Robust methods for computer-assisted suitability testing.

<b>Test</b>	<b>Characterization</b>	<b>Reference</b>
Big Five Inventory-2 (BFI-2)	Five-Factor Model (Openness, Conscientiousness, Extraversion, Agreeableness, Neuroticism) Duration: 10-15 min	Soto & John (2017)
NEO Personality Inventory-Revised (NEO-PI-R) Short Form (NEO-FFI)	Big Five domains with facets (e.g., ideas for openness in innovative engineering) Duration: 15 min	Costa & McCrae (1992)
Hogan Personality Inventory (HPI)	206 items assessing normal personality for occupational fit (e.g., Adjustment, Ambition, Inquisitive scales) Duration: 20-30 min	Hogan & Hogan (2007)
Wonderlic Personnel Test (WPT-R)	50-item cognitive ability test (verbal, numerical, spatial reasoning) Duration: 12 min	Wonderlic (2002)
Raven's Advanced Progressive Matrices (APM)	Non-verbal reasoning test (36 items) measuring fluid intelligence (engineering problem solving) Duration: 40 min	Raven et al. (2003)
Occupational Personality Questionnaire (OPQ32)	104-230 items measuring 32 traits (e.g., data rational, innovative) Duration: 30...45 min	SHL Group (2013)
16 Personality Factor Questionnaire (16pf)	185 items yielding 16 primary factors (e.g., reasoning, rule-consciousness) Duration: 35...50 min	Cattell & Mead (2008)

The better the virtual “Solar Village” environment mimics the real world, the more beneficial it can be expected to be for the learning. Sometimes the easiest methods are the best, and the fidelity of the “Solar Village” as a digital twin of the business world can be enhanced by small details. For example, the virtual currency “Solar Credits” could be exposed to interest rates, or the resource prices could follow the market fluctuations.

As suggested in Alanne (2016), the gamified comprehensive educational model could – in principle – result in an individual salary recommendation for each graduated student. Several practical issues need to be solved, however, including the search for harmony between the achieved level of skills and knowledge and the salary recommendation, legal, data exchange and protection issues etc. In Finland, the salary recommendations are provided by “TEK”, a Finnish trade union for academic engineers, architects, computer scientists (<https://www.tek.fi/en>). Yet no collaboration has been started by the publication of this report to that end.

So far, the “Solar Village” environment has been piloted in the field of energy engineering only. Basically, there is no reason not to upscale its use into other disciplines, as well. The closest next steps would be the expansions to areas such as business and architecture, which both are taught at the Aalto University. The base paradigm – the startup company and the player’s role as its CEO – would remain the same. Yet there is no reason not to change the base according to the discipline, either. The essentiality is the *community* and the player’s role as one of the key people within that community.

## 5 Discussion

### 5.1 Opportunities and challenges

The gamified learning environment “Solar Village” includes several strategy elements (establishing an own startup, development in the market value, HQ & CEO levels, leaderboards and competitions), which make the students addicted to pursue continuous development. The competition is expanded from peer-to-peer level to other domains, universities and even countries. Thus, there is a remarkable motivation factor compared to traditional learning platforms, lectures, exercises and assignments.

In “Solar Village”, the skill development is visualized at a holistic level by way of the learning center workspace and implemented through extended approaches such as project-based learning, student competitions, and challenges. These characteristics are most suitable for building critical thinking, collaboration, and problem-solving skills in solo/team modes. The progress in various skills and knowledge is easy to follow.

Personalized and freely chosen study paths guided by the virtual AI assistants will be helpful in adapting difficulty, providing real-time feedback, and supporting diverse learning styles. Again, integrated AI analytics can be harnessed to track the student’s progress, enabling early intervention for at-risk students and offering customized career pathways.

In “Solar Village”, a good deal of learning takes place in the virtual environment. This poses a risk of over-reliance on screens leading to digital fatigue, isolation, or reduced social skills. Moreover, the virtual learning approach may disadvantage students preferring hands-on labs or lectures. Many of these challenges can be tackled, however, by including events like student competitions (Solar Decathlon), a mobile application with “field events”, real-time chat, and integration with advanced technology to enhance experiential learning and global peer networks (such as VR/AR for immersive strategy challenges or networking in virtual meeting rooms or labs). Some of the challenges, such as cheating in virtual environments, may be more difficult to deal with. Algorithmic biases in AI assessment may result in unfair grading or stereotyping student abilities, causing frustration or dropout. On the other hand, peer competitions as such may foster toxic rivalry.

The gamification of entire study paths is a radical proposal. This is why it is appropriate to briefly address the societal change and “Solar Village” as a part of it. The three key ingredients are digitalization, artificial intelligence and the change in human roles in the work life. In brief, artificial intelligence will replace jobs and the interaction not just between humans but also with AI will become crucial. The digital platform economy and telepresence will extend and evolve, unchaining humans from locations.

The “Solar Village” learning environment is a gamified attempt to facilitate the adaptation of university students and societal actors to the ongoing transition. The intention is to drill skilled workforce for both AI collaboration and human interaction. The idea of project-based learning (PBL) and utilizing the “Solar Village” as a service platform for companies supports fostering innovations by simulating real-world scenarios and opening unique collaboration between universities and industries to align education with the needs of the job market. Hence, the threshold to recruit graduates may become lower, which would reduce youth unemployment.

“Solar Village” represents a ubiquitous, scalable education model, which promotes equity for remote/rural students and lifelong learning plus paves a way to reduced physical campus infrastructure. Again, the platform can be considered an effective approach for content sharing and reuse and harmonizing curricula between universities. Presuming that the platform is embraced widely and it reaches millions of users, there is a potential to narrow down the global skill gaps and promote digital literacy.

The three main societal challenges are technology, legislation, and money. First, a virtual platform requires reliable network and terminal equipment. Access to them may not be possible everywhere, which exacerbates the inequality and widens educational gaps. AI-assisted learning is sensitive to misinterpretations and may provide biased feedback. The situation may change, however, with the next generations of AI agents.

Second, there is a concern about privacy and security. Collecting a significant amount of user data makes the platform prone to leaks, which, in turn, would erode the trust in virtual educational systems. Data privacy laws (GDPR in EU) and accreditation mechanisms are to protect the users from breaches, but on the other hand they complicate the technical challenges and may limit the adoption of the gamified degrees or even result in lawsuits.

Third, developing the platform to commercial products and maintaining it over time requires remarkable financial contributions. High initial capital investments and maintenance costs without proven long-term efficacy prevent universities from using their budgets to a sufficient extent. On the other hand, economic downturns reduce funding for educational technology, whereas there is also a societal pushback against "gambling-like" education, because it could be easily seen as academic inflation.

## 5.2 On the university teachers' role in the future

The ultimate topic to be addressed in this report is the university teachers' role in the AI-assisted and gamified university education. The central questions are how the AI agents evolve and how quickly.

In short term (by 2030), an incremental AI adoption is expected, where the teacher remains the central authority and the curator of skills and knowledge. AI agents serve as virtual assistants, as was described earlier in this report. The teachers' workload is eased by AI assistants that handle administrative and routine tasks such as scoring, objective assessments, and tracking students' progress. The teachers, in turn, will have more time to direct student interaction, to maintain the control of the course curriculum, and to design events for the virtual platform. They are needed to keep track of the latest research findings and to harmonize the education with it. They will teach the students to ask apt questions, to evaluate information critically, to understand biases, and to create intuitive connections. They keep their role of a "moral compass" that guides students on the ethical use of AI tools.

In medium term (by 2040), more decisive changes can be expected. The virtual assistants become adaptive and personalized tutors for students. They will provide foundational knowledge and are capable of criticism. The teacher's focus shifts towards human-centric skills, complex guidance, and socio-emotional development. In brief, when AI focuses on developing the students' skills and knowledge, the teacher focuses on wisdom and creativity. Again, the teachers are needed to design project-based events that represent real-world edge cases and to lead multi-disciplinary student competitions that require human judgment and collaboration. They may be needed to establish industry networks, which AI agents cannot replicate. The medium-term AI evolution may enable personalized learning paths, but the teachers are still needed to provide the students with guidance and counseling.

In long term (2045 –), advanced AI systems can deliver high-quality, customized education with minimal human input. The event synthesis is automated. The AI can innovate and autonomously conduct end-to-end scientific research and integrate the lessons learned in education. Here, both the teachers' and the students' roles need to be reimaged. Although the future is virtually impossible to predict in the long term, the vision is that the human roles would shift towards the highest-level orchestration, ethical oversight, and a unique human touch. Their position as the critical "moral compass" will be highlighted, the attention being paid to complex ethical dilemmas and ensuring the responsible use of technology and knowledge. In such a scenario, the core curriculum itself should be redesigned to focus on uniquely human skills like empathy, resilience, and creative application of knowledge – in collaboration with the AI. Moreover, the entire economic system will probably require a transition to a project-based employment model and universal basic income.

## 6 Conclusions

In this report, the novel gamified learning environment “Solar Village” was described. The report presented the fundamentals of the gameplay, platform, the user interface, and workspaces through commentaries and examples. The key building blocks of the “Solar Village” were addressed. The next steps of the “Solar Village” evolution, as well as the opportunities and challenges of gamified learning platforms were discussed. The teacher’s role in the digitalized and AI-assisted higher education was elaborated. This report is targeted at university teachers and software developers to stimulate the implementation of the proposed approach in new courses, programmes, and disciplines.

“Solar Village” is essentially a large, open-ended and event-based strategy game. The gameplay begins with the player (university student) establishing a startup company. The player develops the startup as a chief executive officer in a virtual business world by participating regular, recurrent and special events (projects and student competitions & challenges). An intuitive user interface guides the player during the gameplay, providing an access to various workspaces and several tools and resources.

The events may replace traditional learning assignments, but the approach may be extended to replace entire courses or even degree programmes. “Solar Village” is not to overlap traditional teaching platforms, but either to supplement them or replace them completely. In the future, it may act as a service platform for external customer projects and offer project-based learning for students. The next major steps focus on developing the game engine, the implementation of AI agents, the interface between “Solar Village” and diverse tools and platforms, and the development of events and workspaces.

“Solar Village” is expected to boost student learning due to its competitive nature and immediate feedback. It enables personalized study paths and releases teachers from administrative and routine tasks and opens opportunities to simulate the future work life, where human and AI agents collaborate. From the societal viewpoint, the education can be aligned with the needs of the job market, which potentially reduces the threshold to recruit graduates. As a ubiquitous, scalable learning environment, “Solar Village” is to promote regional equity and lifelong learning. On the other hand, the virtual environment poses a risk of digital fatigue, reduced social skills and toxic rivalry. The main societal challenges arise from technical reliability and cybersecurity, legislation, and substantial economic contributions the development and maintaining the system require.

The university teachers’ role in the AI-assisted and gamified future depends on how the AI agents evolve. The main conclusion is that in the next few years, the teacher will keep the position as the central authority and AI agents will serve as virtual assistants that deal with administrative and routine tasks. In the future, however, the teacher’s role can be expected to shift from knowledge-centric towards human-centric skills.

## References

Alanne, K. (2016). An overview of game-based learning in building services engineering education. *European Journal of Engineering Education*, 41(2), pp. 204–219.

Alanne K., Pakkanen, K., Heinämäki, T. Suunnitteluharjoituksen toteutus digitaalisena oppimispelinä energiatekniikan yliopisto-opetuksessa. (Only in Finnish Yliopistopedagogiikka. (2023) 1.

Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., Krathwohl, D. R. (1956). *Taxonomy of educational objectives: The classification of educational goals*. Vol. Handbook I: Cognitive domain. New York: David McKay Company.

Cattell, H. E. P., Mead, A. D. (2008). The sixteen personality factor questionnaire (16pf). In G. J. Boyle, G. Matthews, & D. H. Saklofske (Eds.), *The SAGE handbook of personality theory and assessment: Vol. 2. Personality measurement and testing\** (pp. 135–159). SAGE Publications.

Cetin, A. (2012). A 3D game based learning application in engineering education: Powering a recreational boat with renewable energy sources. 15th International Conference on Interactive Collaborative Learning (ICL), Villach, Austria, 2012, pp. 1–4.

Costa, P. T., Jr., McCrae, R. R. (2008). The Revised NEO Personality Inventory (NEO-PI-R). In G. J. Boyle, G. Matthews, & D. H. Saklofske (Eds.), *The SAGE handbook of personality theory and assessment*, Vol. 2. Personality measurement and testing (pp. 179–198). Sage Publications, Inc.

Hogan, R., Hogan, J. (2007). *Hogan Personality Inventory manual* (3rd ed.). Tulsa, OK: Hogan Assessment Systems.

Juan, Y.-K., Chao, T.-W. (2015). Game-based learning for green building education. *Sustainability*, 7(5), pp. 5592–5608.

Raven, J., Raven, J. C., Court, J. H. (2003). *Manual for Raven's Progressive Matrices and Vocabulary Scales*. Section 1: General overview. San Antonio, TX: Harcourt Assessment.

Romanov, D., Holler, S. (2021). District heating systems modeling: A gamification approach. *Energy Reports*, 7(4), pp. 491–498.

SHL Group. (2013). *OPQ32 Technical Manual*. SHL Group Ltd., Thames Ditton, Surrey.

Soto, C. J., John, O. P. (2017). The next Big Five Inventory (BFI-2): Developing and assessing a hierarchical model with 15 facets to enhance bandwidth, fidelity, and predictive power. *Journal of Personality and Social Psychology*, 113(1), pp. 117–143.

Suzuki, K., Shibuya, T., Kanagawa, T. (2021). Effectiveness of a game-based class for interdisciplinary energy systems education in engineering courses. *Sustainability Science*, 16(2), pp. 523–539.

Toba, A.-L., Seck, M., Ngatang, I. (2018). Gaming and simulation for energy system infrastructure: A case of the power grid system. *SpringSim 2018*, April 15-18, Baltimore. Society for Modeling and Simulation (SCS) International.

Torres, M., Macedo, J. (2000). Learning sustainable development with a new simulation game. *Simulation Gaming*, 31(1), pp. 119–126.

Varano, M., Patel, M., Asnani, D., TsyKalyuk, A., Idowu, P. (2006). Basics of energy systems through games. *38th North American Power Symposium*, 2006, pp. 371–374.

Weckman, U.I. (2010). *Luukku-talon suunnittelu ja rakentaminen 2009–2010, Solar Decathlon Europe 2010*. Master's thesis. Aalto University Dept. of Architecture.

Wonderlic, E. F. (2002). *Wonderlic Personnel Test & Scholastic Level Exam User's Manual*. Wonderlic Personnel Test, Inc.



Business, Economy

Art, Design, Architecture

**Science, Technology**

Crossover

Doctoral Theses

**Aalto ST 7/2025**

ISBN 978-952-64-2915-1

ISBN 978-952-64-2914-4 (pdf)

**Aalto University**  
School of Engineering  
Department of Mechanical  
Engineering  
**aalto.fi**