Next-Lab

Next Generation Stakeholders and Next Level Ecosystem

for Collaborative Science Education with Online Labs

Innovation Action in European Union's 2020 research and innovation programme

Grant Agreement no. 731685

Deliverable 3.6

Final releases of the 21st century apps, self- and peer assessment apps, and modelling app

Editors	Ton de Jong (UT) and
	Henny Leemkuil (UT)
Date	30 June 2019 (M30)
Dissemination Level	Public
Status	Final

The Next-Lab Consortium

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11	Turun Yliopisto	UTU	Finland
12	University of Leicester	ULEIC	United Kingdom

Contributors

Name	Institution
Denis Gillet, André Lemos Nogueira, Juan Carlos Farah, Yves Piguet, Ezequiel Gonzalez Debada	EPFL
Jakob Sikken, Hagop Jamkojian, Anjo Anjewierden, Casper de Jong, Natasha Dmoshinskaia, Judith ter Vrugte, Karel Kroeze, Ton de Jong, Henny Leemkuil	UT
Tasos Hovardas	UCY
Leo Siiman, Meeli Rannastu, Margus Pedaste, Äli Leijen	UTE
Internal Reviewers	
Matthias Heintz	ULEIC
Enrique Martin	EUN

Legal Notices

Executive Summary

The title of this deliverable includes the final release of the modelling app. However, also D3.7 (M36) will include the final release of the modelling app and this is the deliverable where we will present this final release.

The current deliverable has many overlaps with D3.3 in which a first version of the apps has been presented. Since this deliverable, many smaller changes to the apps have been applied, for example to ensure their stability, speed, and user friendliness. The main changes or additions in the current deliverable compared to D3.3 are:

A collaboration app was developed that enables groups of students to work together on an app (and labs in the future). The teacher can create groups of students by using this app. When the collaboration app is added to an ILS, other apps that have the collaboration feature implemented will get a new section in their configuration, through which the teacher can enable collaboration for that specific app. Enabling collaboration means that students who are in the same group can work together on the same product. This includes viewing the actions and mouse movements of the other students in real time. A chat facility was also added to support the collaboration activities.

To promote collaboration between students two new asymmetric collaboration labs were developed: the Collaborative Rabbit Genetics Lab and Collaborative Dollhouse Electricity Lab. In asymmetric collaboration students have different versions (variations) of the same lab that offer different types of functionalities and/or information to the users. Therefore, they need to collaborate and exchange information to successfully solve the task at hand.

Besides enabling collaboration, we also developed an app that helps students to acquire good collaboration skills: the *RIDE app*, named after the collaboration rules which it includes. It supports students in assessing their own and their peers' collaboration skills, visualizes these skills and helps students to plan improvements for collaboration.

A new introduction and organization of the section about the apps that facilitate reflection has been written. And a new Time summary app is added to golabz.eu.

At the end of the deliverable there is a new chapter about "Automatic feedback" and one about a new app called Quiz overview. An automated feedback tool has been developed for hypotheses and is being developed for concept maps. The Quiz overview is an app that provides a summary of all the quiz tools in the ILS.

To support the reading process a glossary has been created that can be found here: http://bit.ly/nextlab-glossary

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1. Introduction

One of the goals of Next-Lab is to extend and update the apps (learning tools) that were available after the Go-Lab project. A major effort has been put into a full restructuring of the internal architecture of all apps to simplify and streamline them. The common app code has been rewritten to make it easier to use in different apps. In more detail: the whole code base has been converted from untyped CoffeeScript and JavaScript to fully typed TypeScript. This results in a uniform collection of apps, which are faster to create and easier to maintain. In addition, we designed and created a set of new and revised apps to support the acquisition and application of 21st century skills by students. The skills concern: collaboration, reflection, and peer assessment. The initial specifications of these apps and their initial implementations were already described in Deliverables D3.1 and D3.3. The current deliverable concerns the apps themselves in their final form, as they have been made available at www.golabz.eu. The app for creating models by students (Gomodel), as it was specified in D3.1, has been released, but it will still be undergoing improvements and its final version will be described in D3.7.

To facilitate *collaboration* as a 21st century skill, a *collaboration ap*p was developed that enables running apps in a collaborative fashion. Teachers can set up which students form a collaborating group. Teachers can simply enable this facility by adding the collaboration app to their Graasp space and indicate which apps should be used collaboratively. Besides apps, all labs that are under our control will gradually be made collaborative, for labs from third parties to be made collaborative we will start talking to lab providers, most probably starting with the PhET labs first. A chat facility was also added to support the collaboration. For more advanced communication between students, *SpeakUp* was created, an app that is fully integrated in the Go-Lab ecosystem. SpeakUp enables communication between students, not only through a browser on their PC or laptop, but also using mobile devices. Through using SpeakUp as communication channel, a new type of collaboration, *asymmetric collaboration*, has been introduced to the Go-Lab ecosystem. In this form of collaboration, students have different versions (variations) of the same lab and therefore need to exchange information to successfully solve the task at hand. Four labs (each with two variations) have been developed now for this kind of asymmetric collaboration: Collaborative Rabbit Genetics Labs, Collaborative Rate Of Photosynthesis Lab, Collaborative Dollhouse Electricity Lab and Collaborative Seesaw Lab. Besides enabling collaboration, we also developed an app that helps students to acquire good collaboration skills. This app, the *RIDE app*, named after the collaboration rules[1] it includes, supports students in assessing their own and their fellow-students' collaboration skills, visualizes these skills and helps students to plan improvements for collaboration.

The apps for *reflection* are based on presenting students a view of their own processes or products and asking them to compare these with some kind of norm (e.g., a baseline set by the teacher, a baseline set by themselves, or the processes/products of their fellow students). The apps developed for reflection, therefore, concern student processes (e.g., time spent in phases, transition of phases, activities in apps) or products (e.g., individual concept maps compared to aggregated concept maps). Several of the 21st century reflection apps have a teacher and student version. The teacher version (for the teacher dashboard)

[1] The RIDE rules refer to: respect, intelligent collaboration, deciding together, and encouraging, see Saab, N., van Joolingen, W. R., & van Hout-Wolters, B. H. A. M. (2007). Supporting communication in a collaborative discovery learning environment: The effect of instruction. *Instructional Science, 35*(1), 73-98. doi:10.1007/s11251-006-9003-4

provides the teacher with an overview of ILS usage (Learning Analytics) by students, including their names. The student view basically has the same interface, but here a student can only see his/her own name in full, the names of the other students are not shown. In the student view the learning analytics data is accompanied by a set of, teacher configurable, reflection questions. These apps are a combination of the work done in Task 2.2 (learning analytics) and Task 3.1 (21st century skills).

For *peer assessment,* an app has been developed that enables students to ask for feedback on a product they created with an app in an ILS (e.g., a hypothesis created with the hypothesis scratchpad) and also to give feedback to other students on these products. The teacher can configure which apps will offer these peer assessment facility in an ILS, select from different options the way feedback can be given (textual, smileys, both), and can assign students to each other for giving and receiving feedback. The latter can also be done automatically. In the peer assessment app in the authoring platform, the teacher can see an overview of all feedback given and received together with the respective learning products.

In addition to peer assessment, students may also reflect on the basis of *automated feedbac*k to their products. As a proof of concept, an automated feedback tool has been developed for hypotheses and is being developed for concept maps.

Finally, we developed a new app (the *Quiz overview*) that helps the teacher to grade students' answers to the quiz questions created using the Quiz tool and to have an overview of their class so that they can give feedback to the students and that the students can use this feedback for reflection. At the moment we see this app as a premium app that will play a role in the sustainability strategy of Go-Lab.

The apps as presented in this deliverable and available at Golabz were based on extensive co-creation and input from teachers (see Deliverables D4.1 and D4.3 for details).

2. 21st century apps

2.1 Collaboration

For the 21st century skill of collaboration we have developed a collaboration tool which enables synchronous collaboration on the same product (e.g. a hypothesis), three asymmetric collaboration labs and an app called SpeakUp that enables students to communicate with each other. Teachers can use this app to examine the communication process and to pose questions to their students. This section describes the functionalities and application of these tools.

2.1.1 Collaboration tool

To enable collaboration within apps for students, the teacher has to first configure the collaboration groups. This can be done using the Collaboration tool (Figure 1). The tool lists all students that have already logged in to the ILS and can also add students before they log in by adding their names to the “Not in a group” list.

Figure 1: Collaboration tool

When the Collaboration tool is added to an ILS, other apps that have the collaboration feature will get a new section in their configuration, through which the teacher can enable collaboration for that specific app (Figure 2). Enabling collaboration means that students who are in the same group can work together on the same product. This includes viewing the actions and mouse movements of the other students in real time.

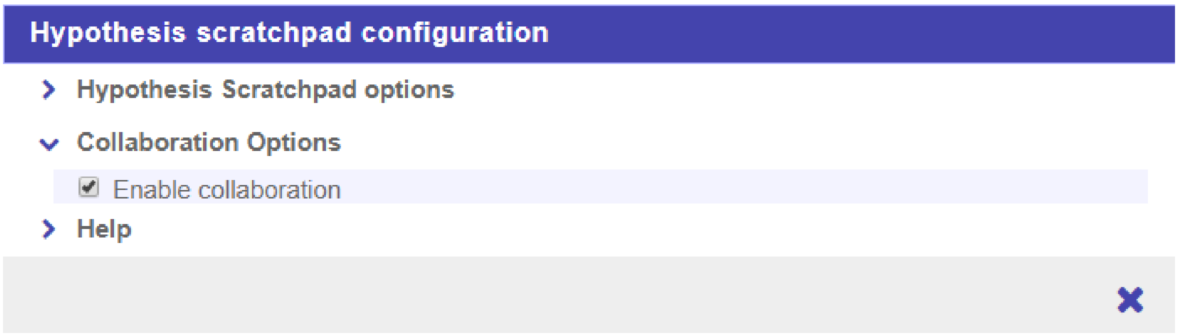


Figure 2: Enabling collaboration in an app

2.1.2 The student chat

To further enhance the collaboration process and allow discussions among students of the same collaboration group, the teacher can also add the chat app to the learning space (Figure 3). The best location to add this app is the top-level of the ILS. By doing so, the chat app will appear in the toolbar and the student can access it from any phase.

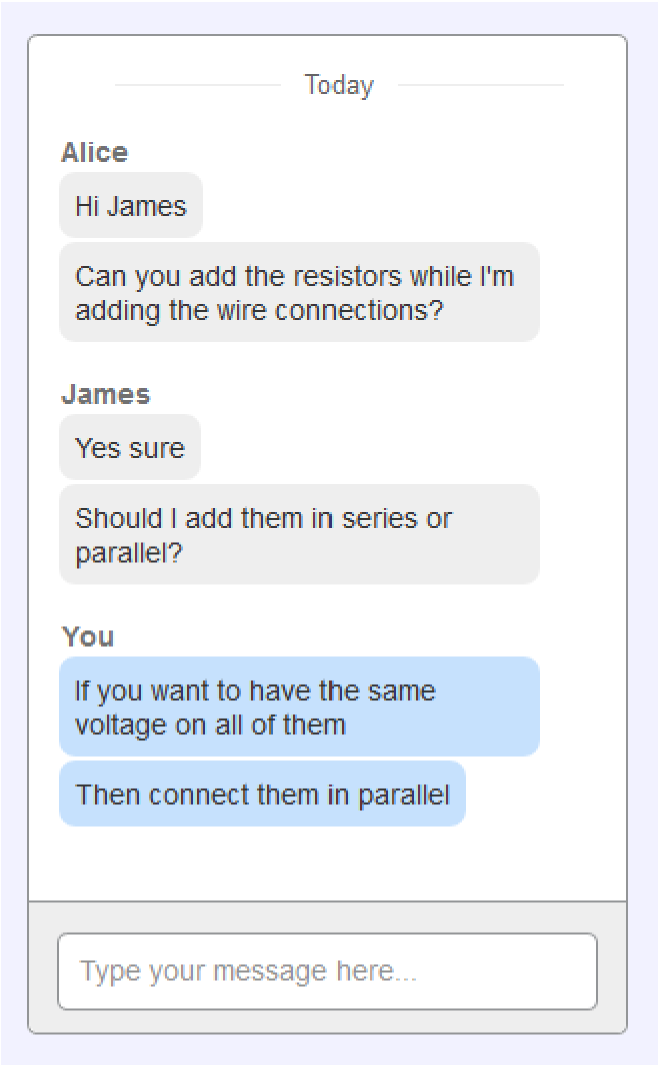


Figure 3: Chat app

2.1.3 Collaborative chat: SpeakUp

If a teacher wishes to offer a collaborative chat application to enable discussions between all students of a class, the SpeakUp app should be added to the relevant inquiry learning phase (Figure 4).

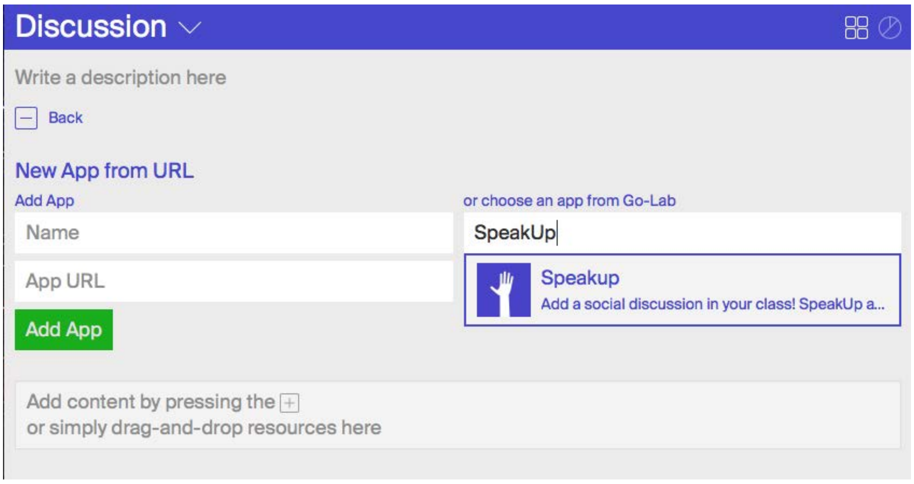


Figure 4: Adding SpeakUp to the Discussion phase of a learning space

An alternative location for the SpeakUp app is in the Toolbar of the standalone (student) view, where it is accessible from all the inquiry learning phases (at the right of the ILS screen).

Besides included in an ILS, SpeakUp can also be accessed from a mobile app. Note that students or teachers using the mobile app version can communicate with users using the version embedded in a learning space providing they are connected to the same virtual SpeakUp room (using its name, location, or ID). This is helpful to support the BYOD (bring your own device) scheme. As an example, we can imagine a biology class scenario with students going in the field to observe plants and make comments on their observations using SpeakUp on their mobile devices. Once back in the classroom, they can validate their hypotheses and draw conclusions in the ILS hosting their field observations. Another usage of SpeakUp on a mobile device could be for a teacher to keep an eye on discussions while moving in the classroom to support students.

After opening SpeakUp in the authoring environment, a room can be created (Figure 5). The anonymous mode can be activated or not. If active, all messages will be completely anonymous. If inactive, the nicknames of the students will be displayed with their contributions.

In SpeakUp, students can post messages, vote on messages of others (using the up or down thumb), or add comments to them (Figure 6). The messages can be sorted either according to the number of positive votes (Best) or reverse chronological (Recent).

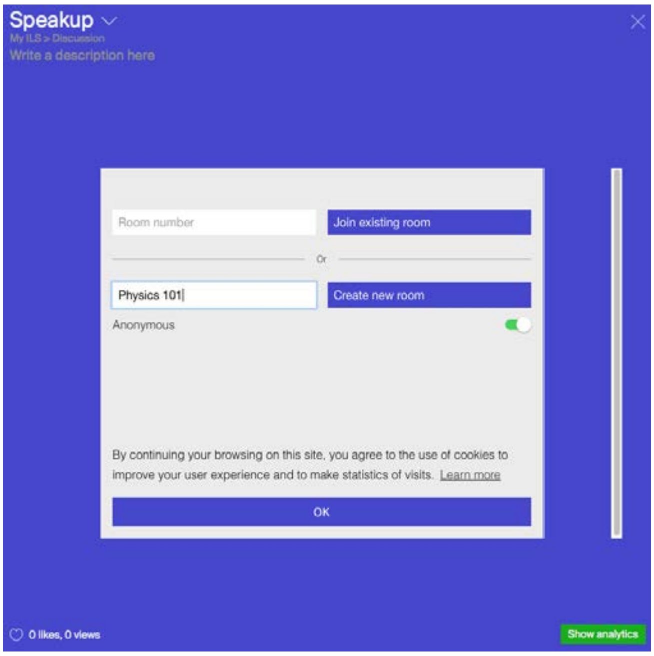


Figure 5: Creation of a room in SpeakUp

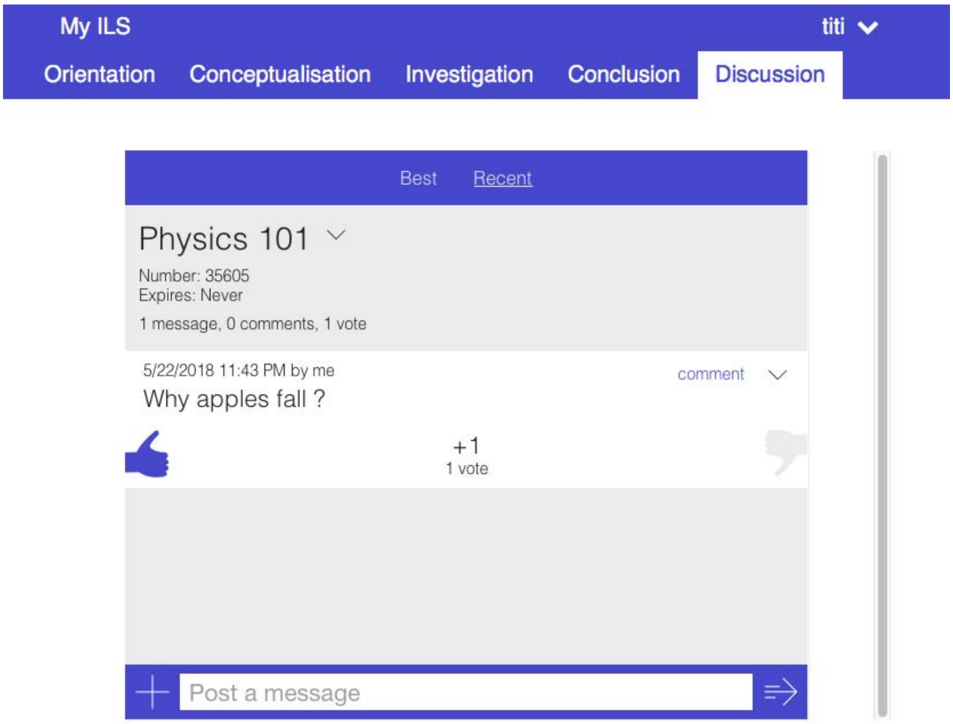


Figure 6: The view of a SpeakUp room in the standalone student view

Clicking on the downward arrow next to the name of the room opens a menu from which the teachers or students can access additional features, like displaying the room analytics (Figure 7). The creator of the room, typically a teacher, can delete it or share an admin key with a colleague or a teaching assistant to grant him or her the right to delete inappropriate posts or to add multiple choice questions.

Figure 7: Display options as a popup menu for the teachers and students

The teachers can create multiple choice questions using the "+" button at the left-hand side of the message input field (Figure 8) with a few options (allowing multiple answers, revealing the right solution(s) or not, and displaying immediately the results to students who already answered, while others are still answering).

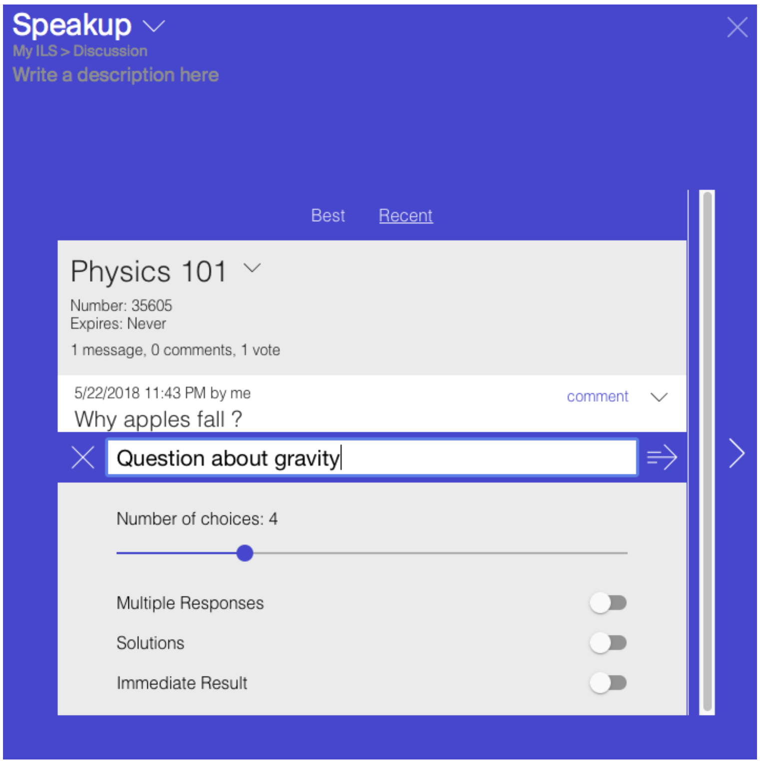


Figure 8: Creating a multiple choice question in SpeakUp

The question is displayed until the teacher closes the poll with the green switch button and clicks on the grey eye to show the votes of the class to the students (Figure 9).

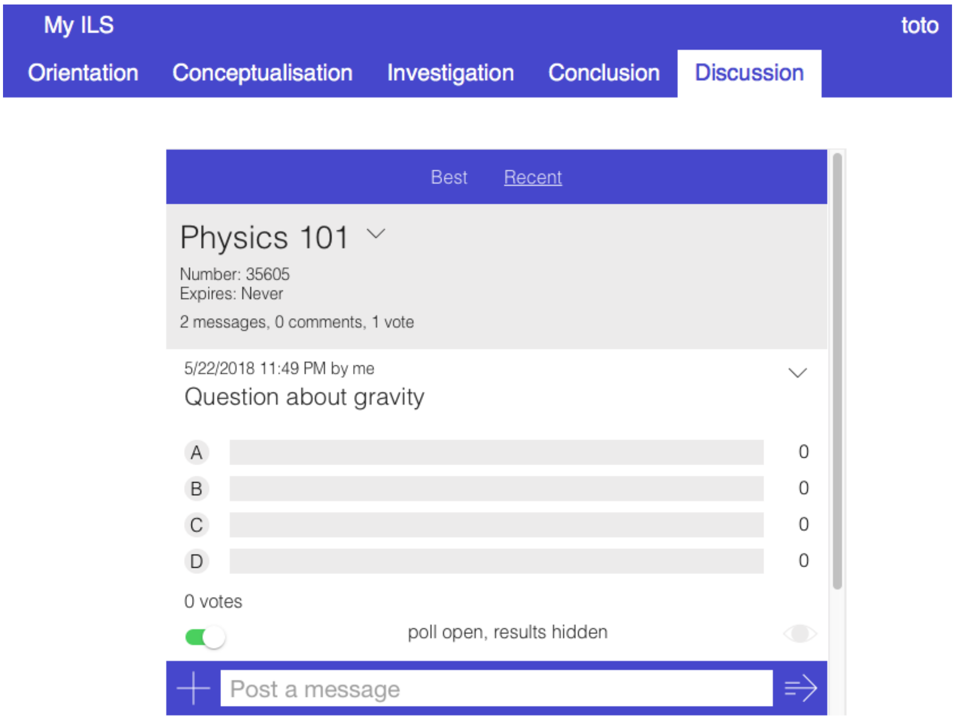


Figure 9: A multiple choice question in SpeakUp

2.1.3.1 Advanced use case of SpeakUp for asymmetric collaboration

In Deliverable D3.1 an innovative type of lab for collaboration, now called asymmetric collaboration, was introduced (see also Section 2.1.4). This type of lab is designed to have at least two variations that offer different functionalities to students working in the different variants. For example, the Collaborative Seesaw Lab allows a student in one variation (version) to place masses on only the left side of a seesaw. Thus, this student cannot balance the seesaw by him- or herself because he or she lacks the functionality to place masses on the right side of the seesaw. A second student working with the second version of the lab is allowed to place masses on the right side, but not on the left side. In this way the two students are dependent upon one another to solve the task of balancing the seesaw with masses.

One way for a pair of students (or two groups of students) to communicate when using a lab for asymmetric collaboration is by text-based messaging. To support this use case, the SpeakUp app can be configured for pairwise communication, rather than class wide discussion between a teacher and students. Applying this pair-wise collaboration in your ILS requires the creation of multiple rooms (one for each pair) and distribution of the unique room numbers to pairs of students. The design of accessing the asymmetric collaborative labs discussed above was based on the SpeakUp app design, in that before a student sees the simulation, he or she has to “Enter a chat room number” and click on a “Join” button. A pair of students who enters the same number in their respective variations of the lab are then able to control variables and see the effects in the same lab.

Assigning chat room numbers to pairs of students can be practically done in several ways. One way is to print a table where instructions are given to each student about their assigned room number and how to access their variation of the asymmetric collaborative lab (see Figure 10). After printing the table, the instructions for each individual student can be cut out and the slips of paper distributed to different students. For students using tablet computers, it is often convenient to add a QR code, so that they can quickly open the web link without having to type the URL. An alternative way to assign chat room numbers is to use a cloud-based document where students enter their name (or find their name already listed their) and click on a link which leads them to instructions similar to the ones shown in Figure 10.

VERSION A INSTRUCTIONS	**VERSION B INSTRUCTIONS**
You have been assigned the number 81052. Open the link lingid.ee/versionA and enter 81052 when asked to enter a nickname for login.	You have been assigned the number 81052. Open the link lingid.ee/versionB and enter 81052 when asked to enter a nickname for login.

Figure 10: A table to be printed out and used for assigning chat room numbers to pairs of students who will work in different versions of an asymmetric collaborative lab

To set up the different variations of an asymmetric collaborative lab in Graasp it is important to realize that both variations of the lab are added to the ILS when such a lab is added using the ‘Add Lab’ button. A teacher can proceed to create their ILS with both labs present, keeping in mind that ultimately one version will have to be deleted. However, working with both labs present during ILS creation is convenient because when the ILS is finalized, the teacher can make a copy of it, retitle the name of the ILS copy (e.g., version 2) and delete the respective lab that it was not meant for. After this, the teacher goes back to the original ILS and deletes version 2 of the lab, keeping only version 1. In the end, there will be two ILSs with two different versions of an asymmetric collaborative lab.

2.1.3.2 Example use case of the SpeakUp app for asymmetric collaboration

A new asymmetric collaborative lab, called the Collaborative Rabbit Genetics Lab was recently developed. In one version it allows a student to select only black rabbits as parents and subsequently breed offspring. In the second version, a student can only breed white rabbits. However, working together, students can breed combinations of black and white rabbits. Only through collaboration can students discover that it is possible for two black rabbits to breed a white offspring. This is possible because the recessive gene for white fur colour can be masked in a black rabbit. Using the Collaborative Rabbit Genetics Lab a pair of students can investigate exactly what combination of genotypes leads to the condition where two black rabbits breed a white rabbit offspring.

At the Go-Lab Tallinn Spring School 2019, participants were divided into groups to work with the Collaborative Rabbit Genetics Lab. The participants also had to use the SpeakUp app to communicate via text messaging and answer the question whether two black/white rabbits can breed a white/black rabbit offspring. Feedback from the participants showed that this type of collaborative task is challenging because they are not used to having different information that needs to be pooled together. The Spring School organizers anticipated this challenge and prepared a series of hints, which they revealed every 5 minutes to ensure that all groups were making progress with the collaboration activity. For example, the organizers would tell participants that they controlled different parts of the lab and provided background information about genetics relevant to answering the given questions. With this support the participants were better equipped to solve their tasks. The response by participants was positive towards this kind of collaborative activity and they were impressed by the level of challenge it offers to improve collaboration skills.

2.1.3.3 Using SpeakUp as a standalone solution (mobile app)

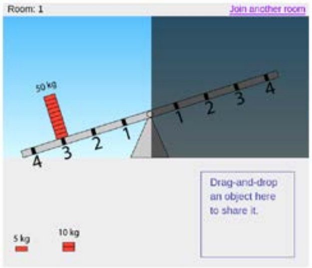
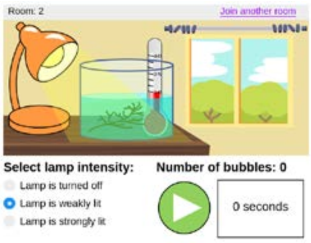
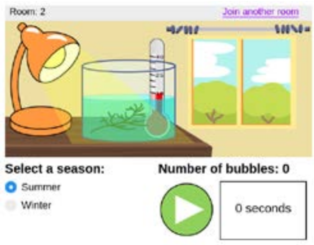
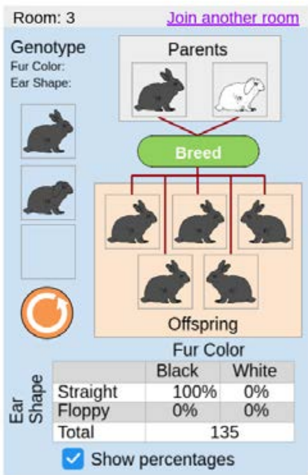
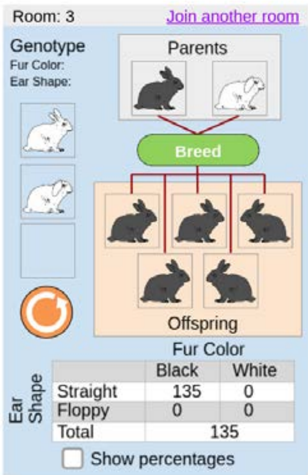
The SpeakUp app can also be used outside the Go-Lab context. SpeakUp can be downloaded from the Apple Store or Google Play. See the online tutorial available for more details and best implementation practices: http://speakup.info/bib/speakup-tutorial.pdf

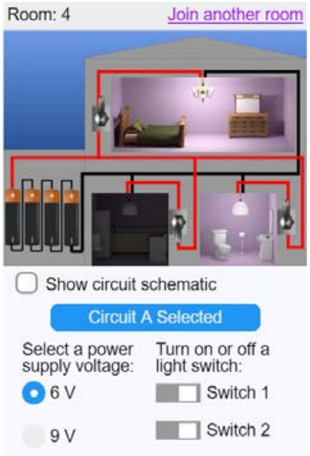
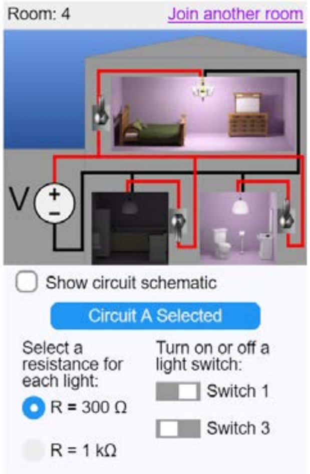
2.1.4 Asymmetric Collaborative Labs

As described above, the Next-Lab project has enabled us to develop a new type of collaborative science lab, the so-called asymmetric collaborative lab. The initial idea for creating a computer simulation with asymmetry to prompt collaboration was introduced in the context of the Assessment and Teaching of 21st Century Skills (ATC21S) project (http://www.atc21s.org). The partners in that project aimed to define 21st century skills and developed ways of measuring them. They eventually decided to focus on two skills: collaborative problem solving and ICT literacy. In the context of developing assessment tasks to measure those two skills, the ATC21S research team developed computer simulations in which there is an asymmetry in the way two people can interact with the simulation. This asymmetry is achieved by dividing information/functionality between two versions of the simulation. For example, one version of an asymmetric collaborative lab about photosynthesis could allow making changes only to the variable *temperature*, whereas the other version would only allow changes to the variable *light intensity*. Students in both versions would be able to synchronously see the effects of both variables on a plant growing in a pot, but would need to effectively communicate about which variables they can change and how they have manipulated them in order to successfully solve various inquiry tasks. The ATC21S researchers emphasized that the asymmetry condition was crucial for them to create valid assessment tasks of collaborative problem-solving which reflected the characteristics of problems where collaboration is both desirable and essential. However, aside from a few preliminary pilot studies, the ACT21S team reports little about student results when learning or working with asymmetric simulations. Moreover, since the researchers were concerned with collaborative problem-solving as the main construct, issues related to inquiry and science learning were not addressed.

Table 1 provides a summary of the four asymmetric collaborative labs currently available in Go-Lab. To the best of our knowledge, asymmetric collaborative labs are not publicly available elsewhere for science teachers to freely access. Therefore, Go-Lab is exclusive in terms of offering such resources to science educators worldwide and has taken a leading role in developing innovative learning materials that integrate 21st century skills such as collaboration and communication with inquiry-based science learning.

Table 1. Summary of currently available asymmetric collaborative labs in Go-Lab

<table>
<tr><th>Lab</th><th>Description</th><th>Version A Screenshot</th><th>Version B Screenshot</th></tr>
<tr><td>Collaborative Seesaw Lab</td><td>Students share a common seesaw but can only place masses on one side. They can exchange masses using a “sharing” box located in the lower right-hand corner. An example task could be to find out whether it is possible to balance the seesaw using a total of 2, 3 or 4 masses on the seesaw.</td><td>
</td><td>
</td></tr>
<tr><td>Collaborative Rate of Photosynthesis Lab</td><td>Students share a view of an indoor aquatic plant. When the play button is pressed, bubbles are emitted, representing the release of oxygen gas which is related to the rate of photosynthesis. The students control different variables (lamp intensity or season) that may or may not affect the rate of photosynthesis in this situation.</td><td>
</td><td>
</td></tr>
<tr><td>Collaborative Rabbit Genetics Lab</td><td>Students share a rabbit breeding simulation. Initially, student A can only select homozygous black rabbits as parents, whereas student B can only select homozygous white rabbits. However, if they collaborate, then it is possible to create a second generation of rabbits with heterozygous traits and save them for another round of breeding. In this way, it is possible in this lab to demonstrate that two black rabbits can breed a white rabbit offspring.</td><td>
</td><td>
</td></tr>
</table>

Lab	Description	Version A Screenshot	Version B Screenshot
[Collaborative Dollhouse Electricity Lab]()	Students share a view of a dollhouse which has been wired with LED lamps and switches to permit lighting in various rooms. Both students can explore three possible electrical circuit configurations. Student A can control the power supply voltage to the circuit, whereas student B can control the LED lamp resistances. They must explore different combinations of voltage and resistance to determine which of the three electrical circuits is optimal (i.e. rooms are not lit too dimly nor too brightly, and turning switches on or off only affects the room the switch was intended for).		

Some preliminary results of testing asymmetric collaborative labs with students in grades 5 and 6 show that collaborative inquiry is challenging[2]. Students may report that they perceive their collaborative experience to be positive and that their collaboration skills are above average, but their results on inquiry tasks involving asymmetric collaborative labs are rather poor. This suggests that students require more practice or support with collaborative activities involving communicating information from different perspectives and pooling it together to successfully solve inquiry problems.

The uniqueness of the Go-Lab asymmetric collaborative labs has attracted attention from science researchers globally. In one case, researchers from Taiwan translated these labs into Chinese and integrated them into the CloudClassRoom (CCR) learning environment (https://ccr.tw/) that their teachers were using (see Figure 11). This demonstrates that some components of Go-Lab are interoperable with other learning environments and promotes a more open use of educational digital learning resources.

[2] Rannastu, M., Siiman, L. A., Mäeots, M., Pedaste, M., & Leijen, Ä. (2019). Does group size affect students' inquiry and collaboration in using computer-based asymmetric collaborative simulations? Manuscript submitted for publication.

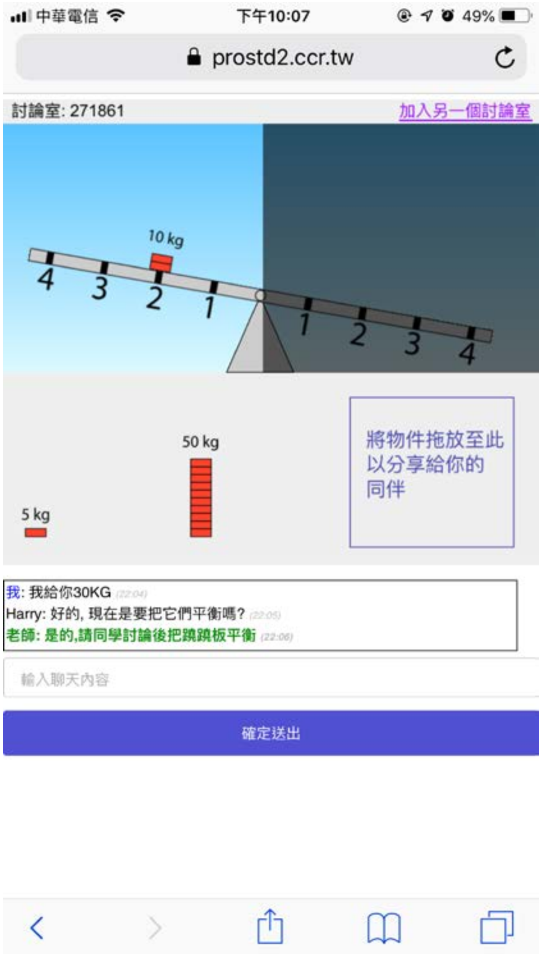


Figure 11: A Go-Lab asymmetric collaborative lab translated into Chinese and embedded into another learning environment, i.e., the CloudClassRoom (CCR) environment

2.1.5 Assessing the collaboration process, the RIDE app[3]

Besides enabling collaboration, we also developed an app that helps students to acquire good collaboration skills. This app, the RIDE app, named after the collaboration rules it includes, supports students in assessing their own and their fellow-students collaboration skills, visualizes these skills and helps students to plan improvements for collaboration.

RIDE stands for: Respect, Intelligent collaboration, Deciding together and Encouraging, which summarizes essential characteristics of good collaboration (see Table 2).

[3] The initial version of the RIDE app and its associated research was sponsored by the Dutch NWO.

Table 2. The RIDE characteristics with examples

RIDE characteristic	**Examples**
Respect	• Give everyone a chance to talk • Consider other students' input • Don't judge students personality after they make a mistake
Intelligent collaboration	• Share all relevant information and ideas • Clarify the information/answers given • Ask for explanations if they have not been given or when something is unclear • Give constructive criticism of other students' ideas (not of person himself or herself)
Deciding together	• Check if everyone agrees before taking actions or giving answers • Contribute to the decision making process if others want to make a decision
Encouraging	• Encourage others to participate actively • Give compliments when others make a useful contribution

In the RIDE app students are guided through a collaborative reflection process that combines principles of self- and peer-evaluation and goal setting. The app can simply be added to an ILS at a point where the teacher wishes students to reflect on the quality of their collaboration. The goal of the app is to optimize future collaboration and improve collaboration skills through awareness and reflection.

The app uses data from the collaboration tool to assess which students were grouped together by the teacher. For each collaboration group the app requires students to individually assess their own and each other's performance regarding the four RIDE rules (see Figure 12).

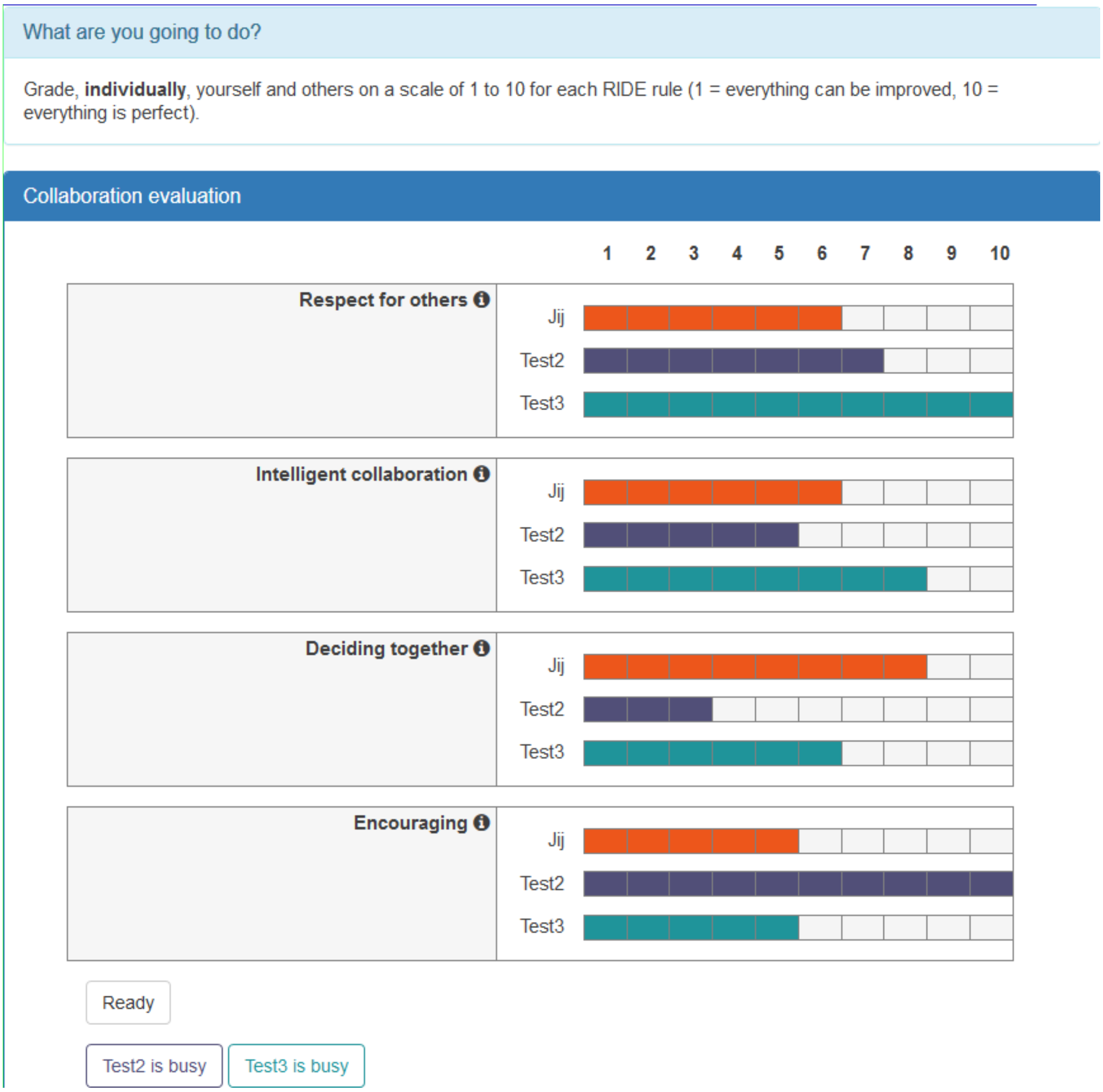


Figure 12: Phase 1 of the RIDE app: Assessment

After assessing each other each student indicates that they are done and only when all students are done they can proceed to the next phase. Here they can evaluate how they performed. They can see self-assessments in comparison to the average of the assessments of others in the group and in comparison to the group's average.

Figure 13: Phase 2 of the RIDE app: Feedback/evaluation

When students feel they are done evaluating this data they can indicate so via a button and only when all students are done they proceed to the next phase. In this phase the students are directed to discuss the outcomes, identify strong and weak points, and set goals to further optimize their future collaboration (see Figure 14).

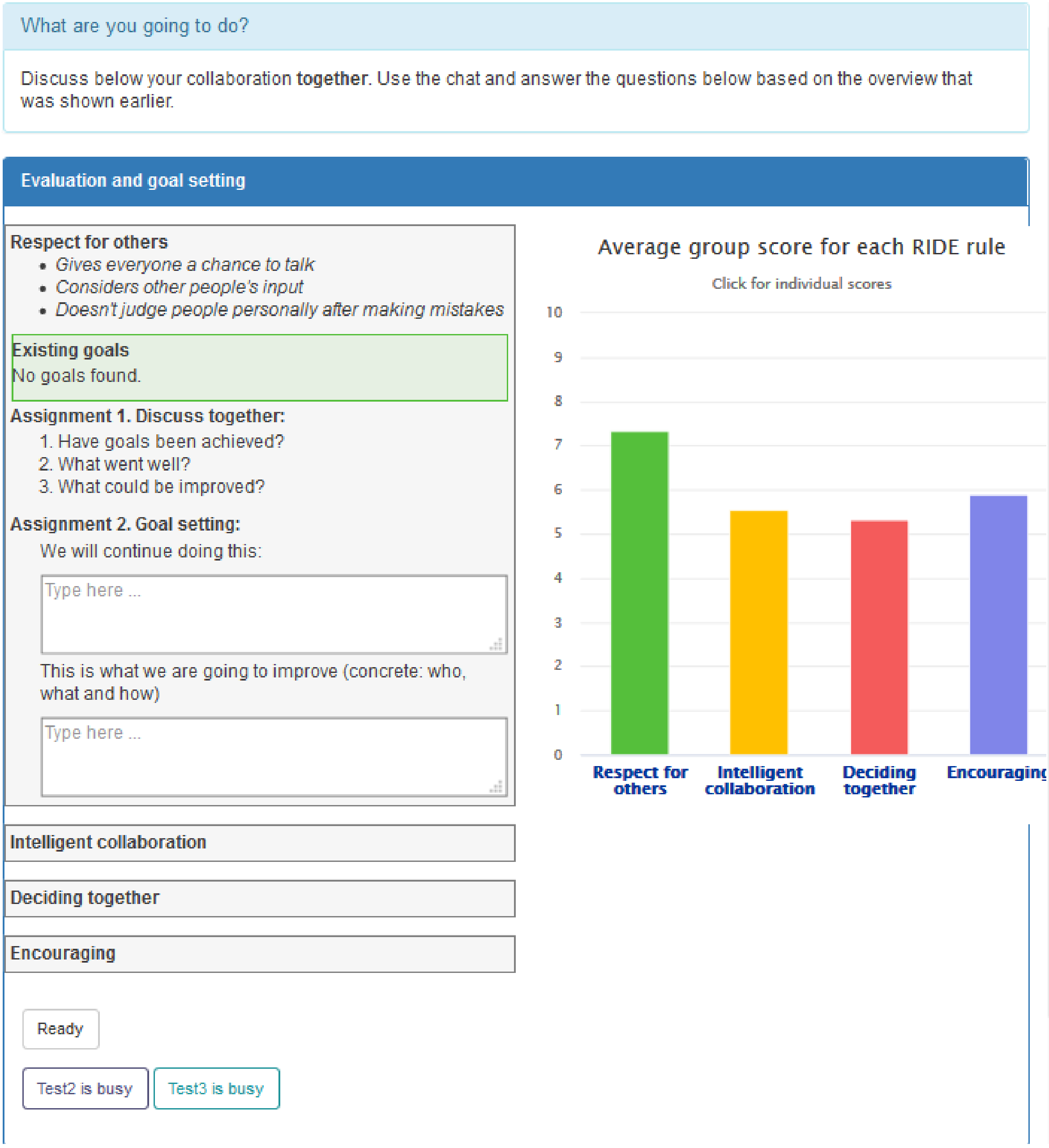


Figure 14: Phase 3 of the RIDE app: Discussion/goal setting

Teachers can indicate whether the RIDE app is the first iteration (the first time students fill it out) or whether it is a follow up. In the case that it is a follow up the RIDE app will load students' goals from the previous iteration in the 'existing goals' textbox that is presented to students in phase three.

The performance visualizations (i.e., bar charts) in phase 2 and 3 contain two levels; students can see the group's score per RIDE characteristic in comparison to the group's average score and when they click on a specific RIDE characteristic they can 'zoom in' and see the self-assessments in comparison to the average peer assessment (see Figure 15).

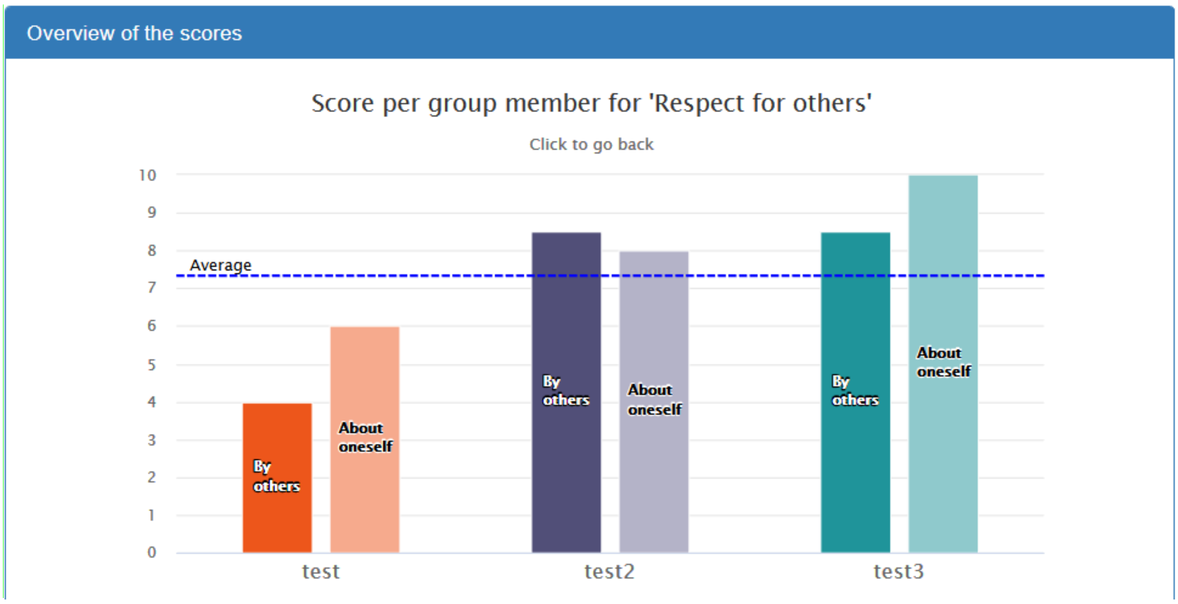


Figure 15: Performance visualizations in the RIDE app

The RIDE app has been thoroughly tested and experimental research demonstrates its positive effects on the quality of students' collaboration (as assessed by their communication content and patterns). The experimental study[4] utilized a pre-test - intervention - post-test design. During the intervention students worked collaboratively in heterogeneous triads in an ILS. Groups were created using the collaboration tool and heterogeneity was based on scores of a paper-and-pen-based pre-test. ILSs consisted of a multitude of tools, apps, and labs among others: the electrical circuit lab, the transportation lab, input boxes and concept mappers. Collaboration in these labs, apps and tools was enabled; meaning that students could interact in real time with the environment and with each other.

First-year technical vocational students (N = 198, M_{age} = 17.7 years) worked in the ILSs for about 270 minutes spread across three sessions. The ILSs focussed on topics concerning electricity. Collaboration groups were divided across three conditions, the difference between the conditions being that they received either 1) conventional instruction about collaboration and the RIDE app (which they filled out four times), 2) conventional collaboration instruction only, or 3) no collaboration instruction and no RIDE app. Analysis of chat data (n = 92) and knowledge tests (n = 87) showed that students from the instruction with app condition outperformed the other students on their domain knowledge gains (see Figure 16).

[4] Eshuis, E. H., ter Vrugte, J., Anjewierden, A., Bollen, L., Sikken, J., & de Jong, T. (2019). Improving the quality of vocational students' collaboration and knowledge acquisition through instruction and joint reflection. *International Journal of Computer-Supported Collaborative Learning*, 1-24.

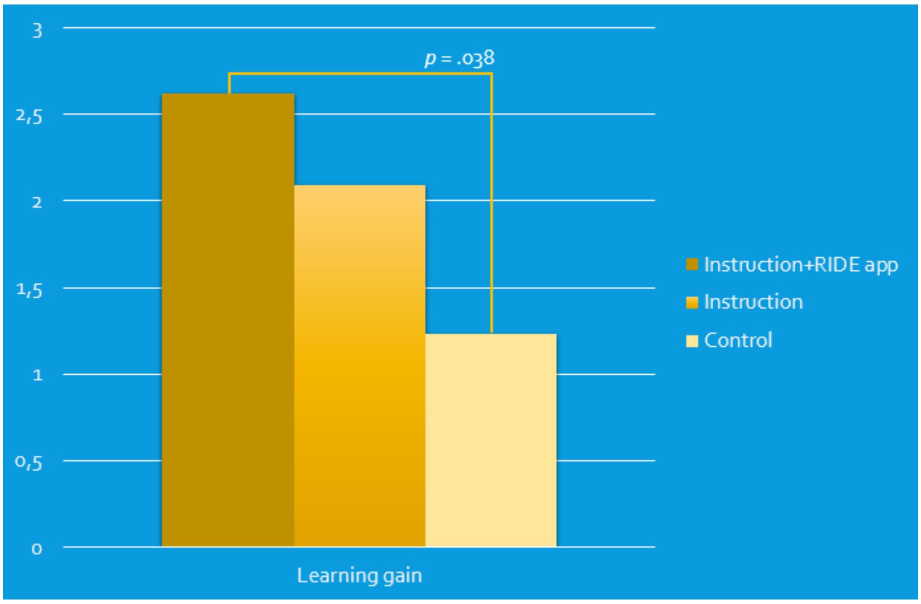


Figure 16: Learning gain scores for the three groups

In addition, among others, students who worked with the RIDE app spent more of their chats to domain related topics and were more responsive to their peers' utterances (see Figure 17).

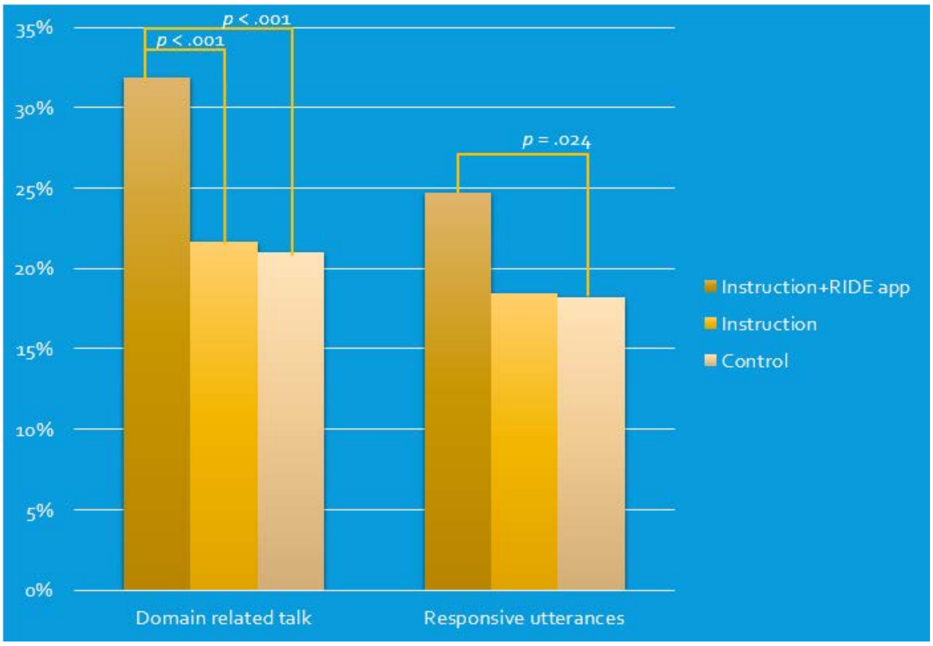


Figure 17: Comparison of domain related talk and responsive utterances for the three groups

Of all domain related talk students who worked with the RIDE app spent a larger percentage on talk that indicates intelligent collaboration; they were more critical towards statements of their peers, they enquired about their peers' opinions more, and they voiced their opinion during collaborative decision making (see Figure 18).

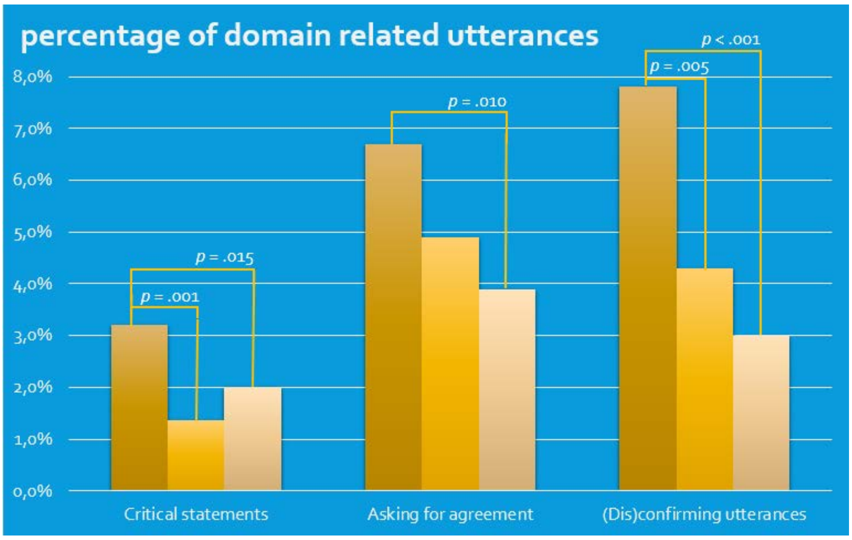


Figure 18: Comparison of domain related utterances for the three groups

2.2 Reflection

Reflection on own learning processes or learning products is an important aspect of a successful learning experience. In Go-Lab we make a distinction between reflection on content/product and reflection on processes. One of the apps refers to a reflection on a product (the aggregated concept map), but most of the apps in this section refer to process reflection (time spent, activities performed, sequences followed). To support students in the reflection process the apps described in this section have three additional features: a) they visualize a product or process, b) they present students with a norm to which they can compare their own products (content) or process. This norm can be set by a teacher or can be the individual products or aggregated product or process(es) of their fellow students and c) they can contain a set of (teacher configurable) guiding questions for reflection.

Three of the apps presented allow students to make a comparison of *their own activities* to *activities of other students*.

- The *Timeline app* shows for all students graphically in a timeline which phases they have been in over time and within each phase when and how long students have been active in the apps that were present in that phase.
- The *Time spent summary* app, shows, in table form, how much time in total each student spent in each phase of an ILS and also the total time spent in the ILS for each individual student
- The *Activity plot* app displays, as a bar graph, for each student and as an average how many activities have been performed in each app of the ILS. The number displayed is a relative number compared to the maximum number of activities performed for a specific app.

These three apps visualize the inquiry process, as activities or time spent, in different ways. Each app shows the data of an individual student and of his or her fellow students, so that a student can compare his or her own process with that of other students. In the ILS, a specific student will only see his or her own name for the ILS displayed; the other students are indicated by an anonymized label (student 1 etc.). When these apps are added to the ILS in Graasp (e.g., in the teacher dashboard) the teacher can see the names of all students.

Two apps allow students to make a comparison of their time spent in the ILS and in the ILS phases to a norm:

- The *Time spent* app lets students compare their own time spent in the ILS overall and in the individual phases to the expectations of their teachers. This app is usually added somewhere towards the end of an ILS and in Graasp the teacher has to indicate his/her expectations on time spending in the ILS. For each of the phases of the ILS the teacher can fill in how many minutes he or she expects his or her students to spend in this phase, or he or she can indicate the percentage of the total time he or she expects each phase will take the students. When a student opens the app in the ILS he or she will see, in a bar graph, his or her actual time spending in comparison to the expectations of the teacher.
- Another comparison students can make with respect to time spent, is a comparison of their actual time spent with their own expectations. To realise this type of reflection, two apps are available, the *Time planner* (usually included at the start of an ILS), in which students can indicate the time they expect to spend in the phases of this ILS and the *Time checker* (usually included towards the end of an ILS) that shows, in a bar graph, the actual time a student spent in comparison to his or her expectations.

In an ILS students make several products with the available apps, such as concept maps, hypotheses, reports, observations etc. Currently, for one of these products it is possible to let the students reflect on their own concept map in comparison to the (aggregated) concept map of other students:

- In the *Aggregated concept map* app, students can see their own concept map (in a different colour) as part of a concept map that aggregates the concept maps of all students. They can see how often a concept has been included in all concept maps and how often relations between two concepts have been made.
- The *Concept mapper dashboard* is the version of this app for teachers. In this app, the teacher can see per student how his or her individual concept map relates to the aggregated concept map of all students.

The final reflection app that is now available in Golabz has no comparison to other students or a norm:

- The *Phase transitions* app shows a student, in a graphical way, how he or she transited through the phases of an ILS over time, also showing returning to earlier phases or skipping of phases (if applicable). This information is basically also present in the Timeline app, but the phase transition app uses a different (and individual) representation.

The next sections present a more detailed description of each of these LA-based reflection apps. After that, a section is devoted to the reflection questions that can be added to each of these apps.

2.2.1 Comparing own ILS activities with other student activities

2.2.1.1 Timeline

The Timeline app displays a timeline of the student activities in a linear time scale (Figure 19). It shows the times during which the students were active in the different phases and apps of the ILS. The visualization indicates at the same time how many times and in which order the students accessed the different phases and apps. This way the timeline also gives the students an insight on how the other students performed in the ILS.

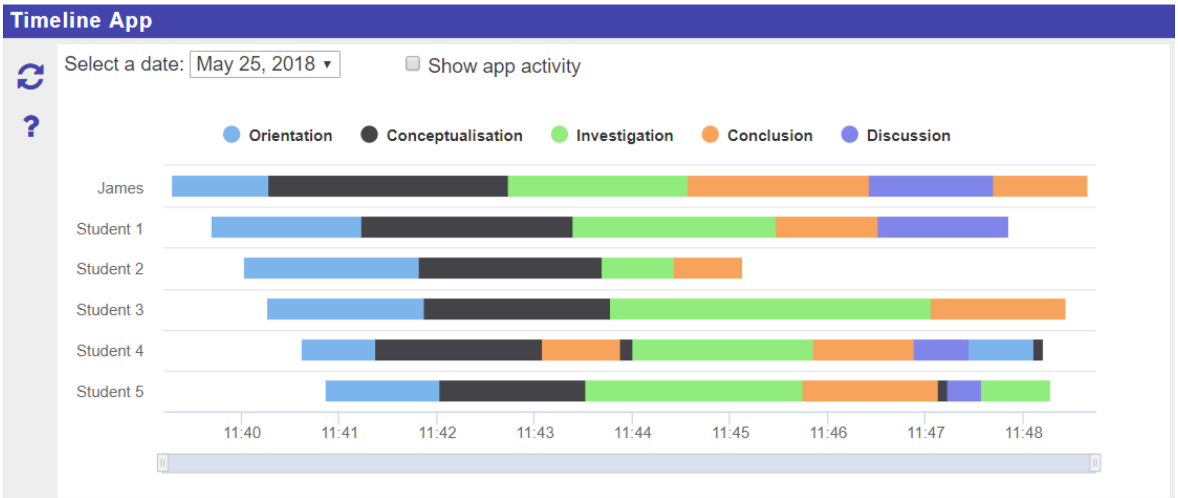


Figure 19: Timeline app

The timeline shows the list of students on the y-axis and the time intervals on the x-axis. In the student view, the activities of all the students are shown but the names of the other students are anonymous.

Initially, only the phase activities are displayed in the timeline. Each phase is represented by a unique colour throughout the timeline. The student can then choose to also display the app activities by toggling the “Show app activity” checkbox. The app activities are shown as thinner bars within the corresponding phase activity (Figure 20). Hovering on any bar in the timeline displays more information about that activity, such as phase/app name, start and end times, and duration.

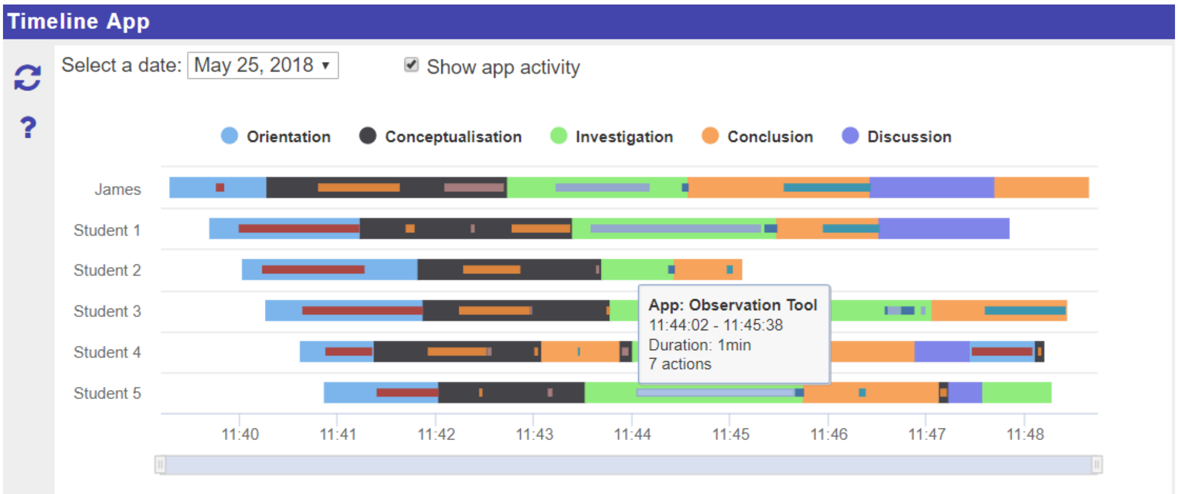


Figure 20: Timeline with app activities

The legend (above the timeline) gives an indication of which colour is used for which phase. Clicking on any of the phases in the legend will show/hide the corresponding phase from the timeline. This feature allows the students to better extract activity information by visually focusing on a subset of the phases. The students can also use the navigator at the bottom of the timeline to zoom in on a certain time interval so that they can have a better view of the activities during that period.

The Timeline app also has a teacher view that is very similar to the student view, the only difference being that the teacher view shows the names of all the students in the list (Figure 21).

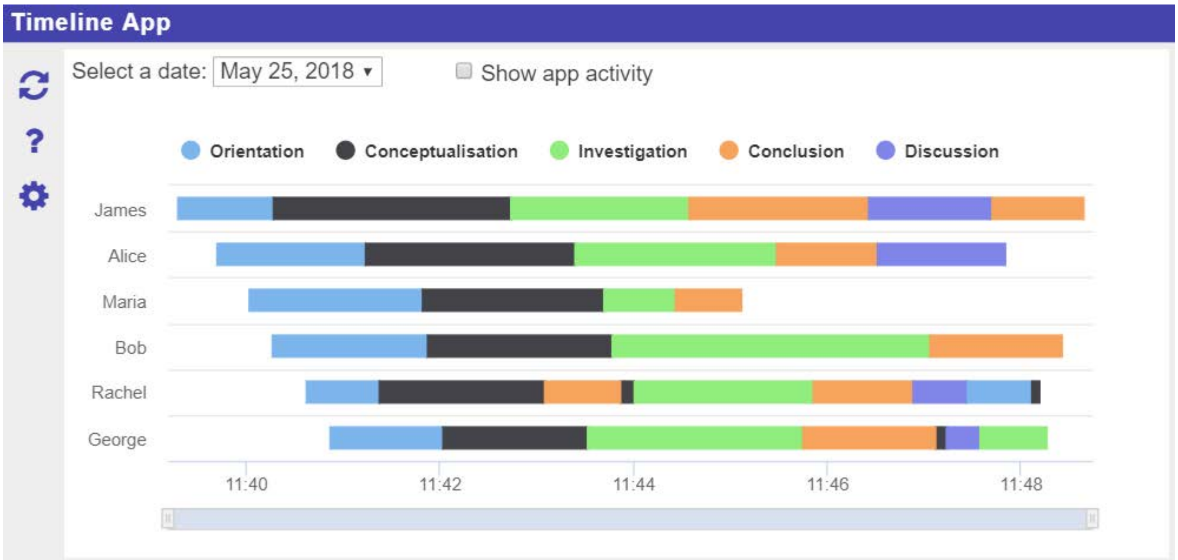


Figure 21: Timeline teacher view

2.2.1.2 Time spent summary

This app presents a summary of the time spent by the students in each phase of the ILS (Figure 22). It has a teacher view and a student view. The difference between the two is that, in the student view, the names of other students are anonymous.

The table shows how much time each student spent in each phase and in the ILS in total. It also computes an average for each column. The times are updated in real time.

Time Spent Summary

	Orientation	Conceptualisation	Investigation	Conclusion	Discussion	Total
Average	4:21	4:21	2:48	2:49	0:56	15:17
Alice	3:40	4:45	3:53	4:26	0:00	16:46
Bob	2:20	4:07	0:00	5:16	1:43	13:27
Carla	7:18	7:52	4:34	2:25	0:51	23:02
Edward	2:13	2:47	3:23	3:56	1:38	13:59
Fiona	2:03	3:09	3:53	1:04	2:36	12:47
Frida	1:56	6:41	1:03	0:36	0:20	10:39
George	7:37	5:53	5:14	4:33	0:11	23:31
James	6:10	4:07	1:53	0:00	1:09	13:19
Mark	9:16	4:49	4:50	3:37	1:54	24:27
Rachel	1:56	2:22	0:00	2:33	0:00	6:52
Tom	3:25	1:16	2:06	2:30	0:00	9:18

Figure 22: Time spent summary

2.2.1.3 Activity plot

The Activity plot app presents a summary of the number of actions performed by the students in the different apps found in the ILS (Figure 23). Students can use it to compare their app activities with those of the other students and the average. In the student view, the names of the other students are hidden.

Figure 23: Activity plot

The summary of app activities is represented as a column chart, where each column represents the actions performed by a student in a specific app. The columns have percentage values. The number of actions by each student in each app is converted to a percentage relative to the maximum number of actions performed by all students in that particular app. Since some apps generally require more actions than others, the number of actions to percentage conversion is necessary to normalize between all the apps and allow the students to easily compare actions done in each app separately. Hovering on any column will display more information about it, such as the name of the app, the phase in which the app is found, number of actions, and percentage relative to the maximum number of actions performed.

Students can also switch between regular mode and stacked mode by toggling the “Stacked” checkbox (Figure 24). In the stacked mode, the columns are added up to one cumulative column for each student.

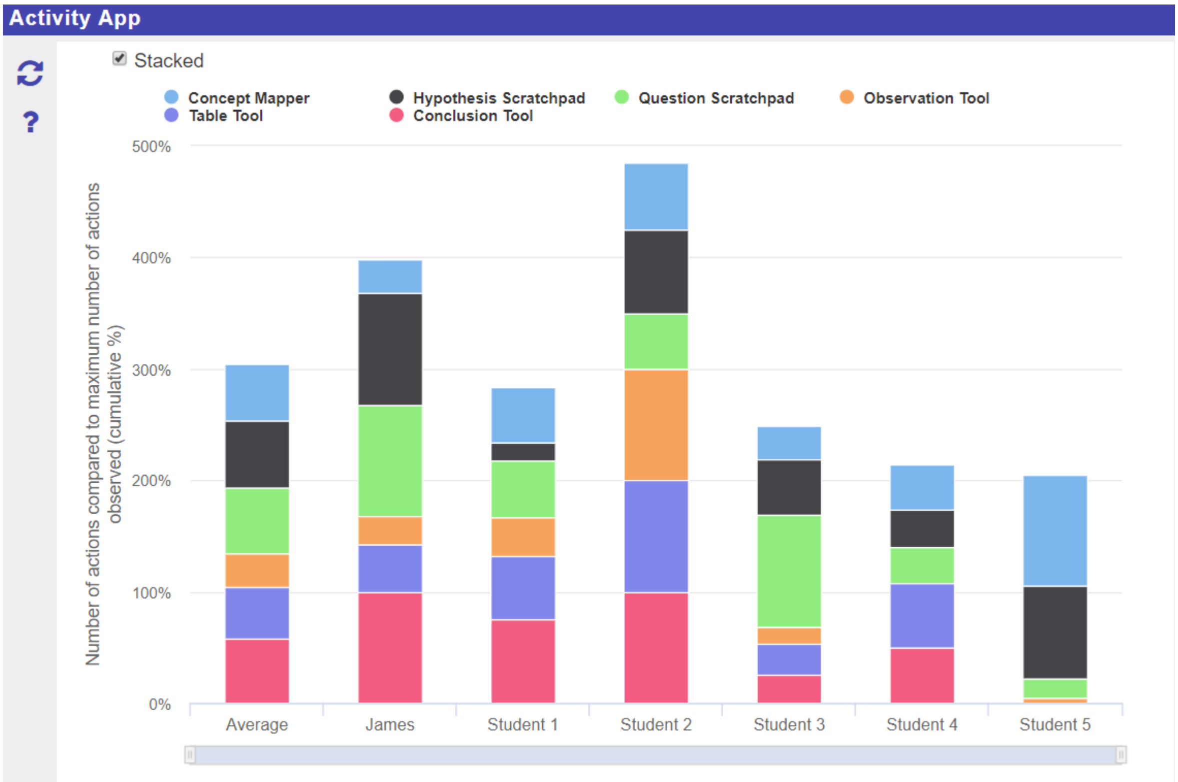


Figure 24: Activity Plot in stacked mode

The legend at the top indicates which colour is used for each app and clicking on an app in the legend will show/hide it from the chart. The students can also use the navigator at the bottom of the chart to zoom in and out.

The Activity Plot app also has a teacher view that functions similarly to the student view, but instead shows the names of all the students (Figure 25).

Figure 25: Activity Plot teacher view

2.2.2 Comparing own time spent to a norm

The Time spending apps show the total time spent in an ILS, and the time spent in the individual phases as a bar chart with the total amount per phase on the x-axis and the phases on the y-axis. For reflection purposes the actual time spent can be compared to a norm (either a percentage per phase, or total time per phase). Further, the norm can be specified by either the teacher for all students (this is the Time spent app, see next section) or by the student. In the latter case, the student has to plan his or her time in advance and this is done with the time planner tool (see Section 2.2.2.2).

2.2.2.1 Time spent

Figure 26 shows how the teacher can set the norm for the time spent in phases, as either a percentage or the total (absolute) time norm. When a phase is assigned a value of 0, it is ignored by the app. Usually, this is done for the phase in which the time spent tool itself resides.

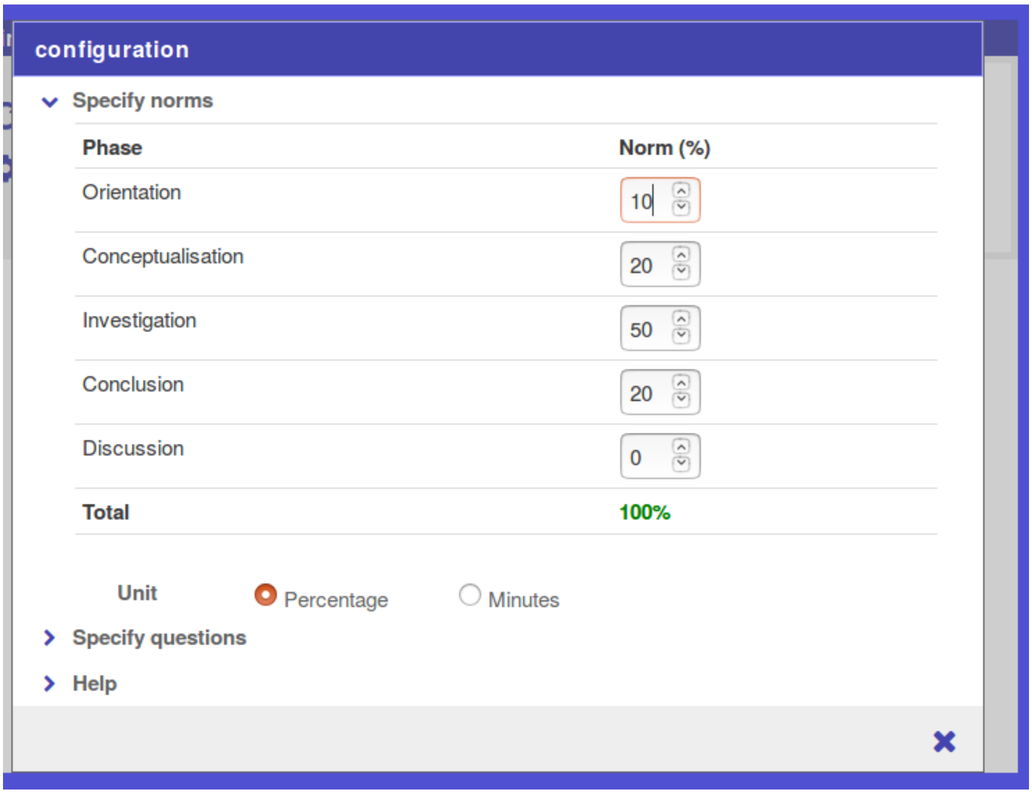


Figure 26: Teacher configuration screen of the Time spent app

The student view of the time spent tool is given below (Figure 27). The tool allows the student to compare the norm time set by the teacher (Suggested) and the actual time (Yours).

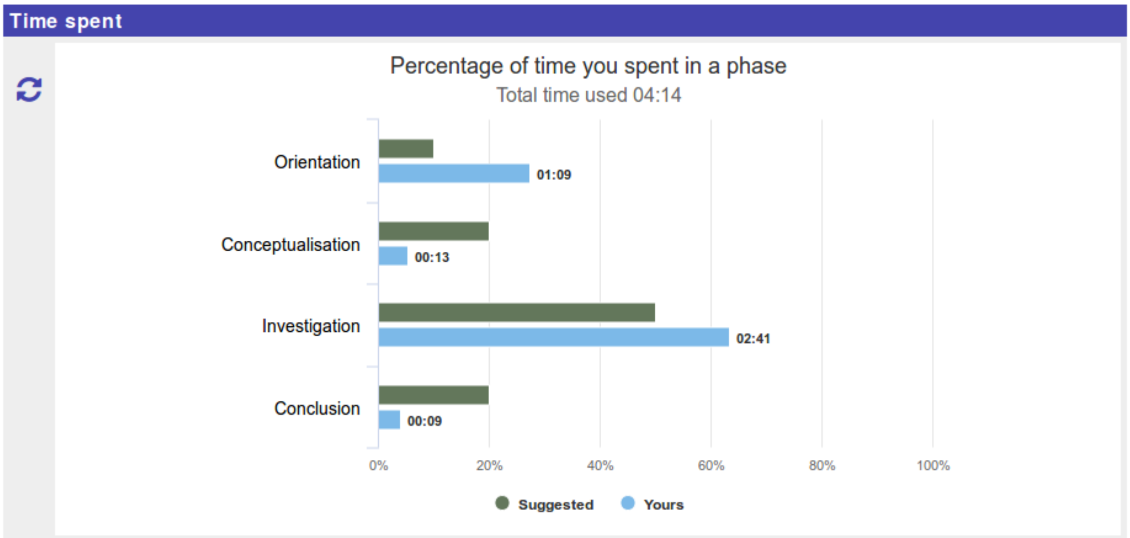


Figure 27: Time spent app (student view)

2.2.2.2 Time planner/checker

The time planner is an app in which the student plans how much time she or he will spend in each of the phases. This contrasts with the time spent in phases tool described in the previous section, which only displays the amount of time they actually spent. Because the time planner only makes sense when used by students the following "splash" screen is shown to the teacher (Figure 28).

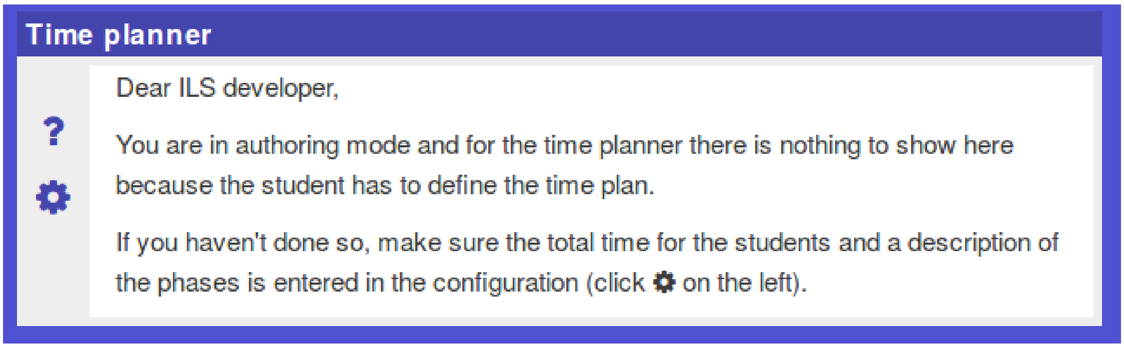


Figure 28: Teacher message in the Time planner app

In the configuration, the teacher specifies the total amount of time recommended/planned/... for working through the ILS. Additionally, a description is entered for each phase of the ILS. The latter is necessary for the student to be able to make a plan at all (given that he or she never used the ILS before). Figure 29 gives an example of a complete configuration. When a phase description is empty, Discussion in the example, the student is not expected to spend time there.

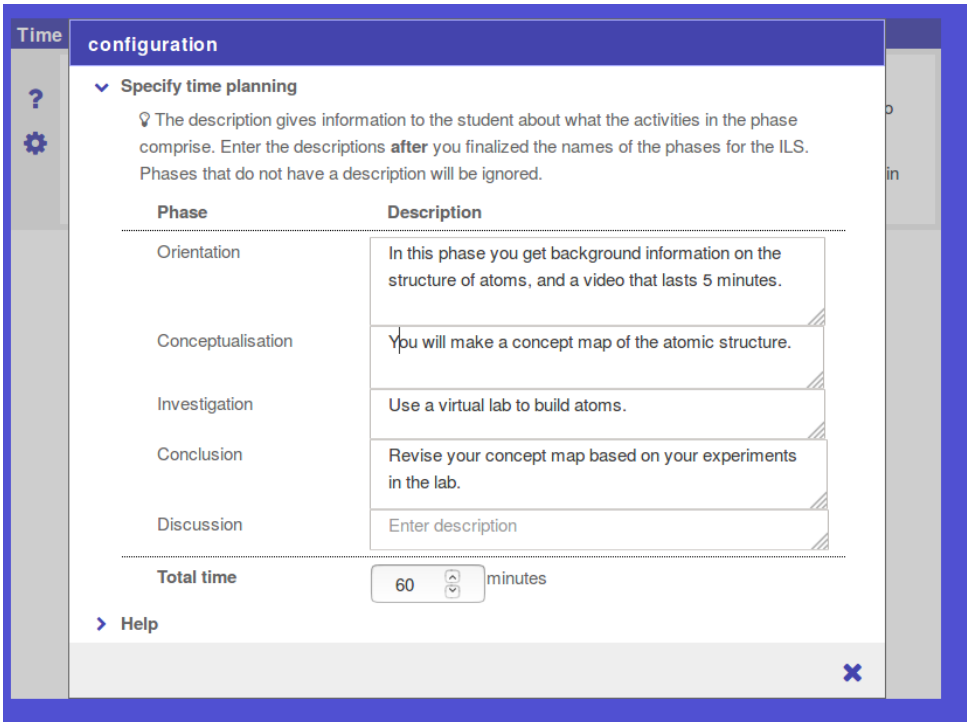


Figure 29: Teacher configuration of the time plan/checker app

The student view of the time planner tool is shown in Figure 30. For each of the phases he or she sees the description and can indicate the amount of time he or she expects to spend in this phase. The total amount turns green when it is equal to the total time specified by the teacher (60 minutes in this example).

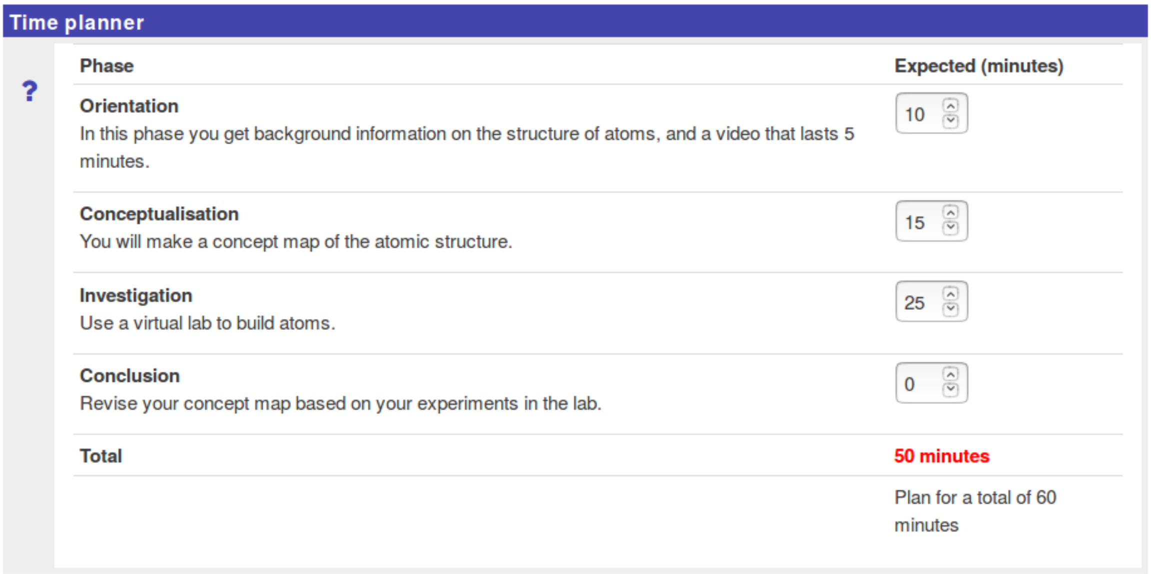


Figure 30: Time planner app (student view)

In one of the final phases of the ILS, here the Discussion phase, the time checker tool can be used to show the actual time spent and time planned by the student. See Figure 31 for an example. The students can then use this visualization to reflect on their planning.

Figure 31: Time checker

2.2.3 Comparing own product with other students' products

2.2.3.1 Aggregated concept map

In this section we describe the application of the aggregated concept map (ACM) for reflection on content. The aggregated concept map makes it possible for students to switch between an individual concept map and the aggregated view as illustrated in the figures below (Figures 32 and 33).

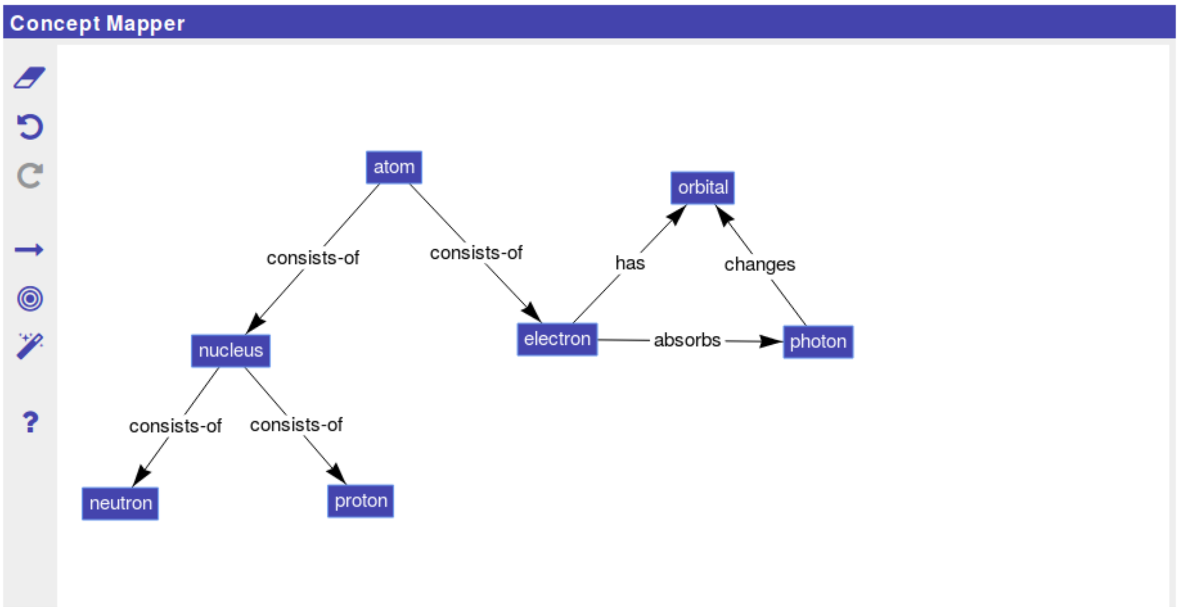


Figure 32: The concept mapper

Figure 33 shows a concept map created by a student on the topic of the atomic structure. Concepts are shown as blue boxes and links are shown as labelled arrows between the concepts.

The same student who created the concept map shown in Figure 32, has opened the ACM and gets a view as in Figure 33. This student now sees the concepts and links in his or her own concept map (blue) as well as the concepts and links other students in the same ILS have used. In this example, another student has created two additional concepts called **wave** and **particle**. The student can now reflect on whether these two concepts he or she did not include, should also be in his or her own concept map. A possible approach to stimulate reflection on the difference between a student's map and the aggregated map are questions in which the student is asked which concepts he or she did not use and why (see Section 2.2.5).

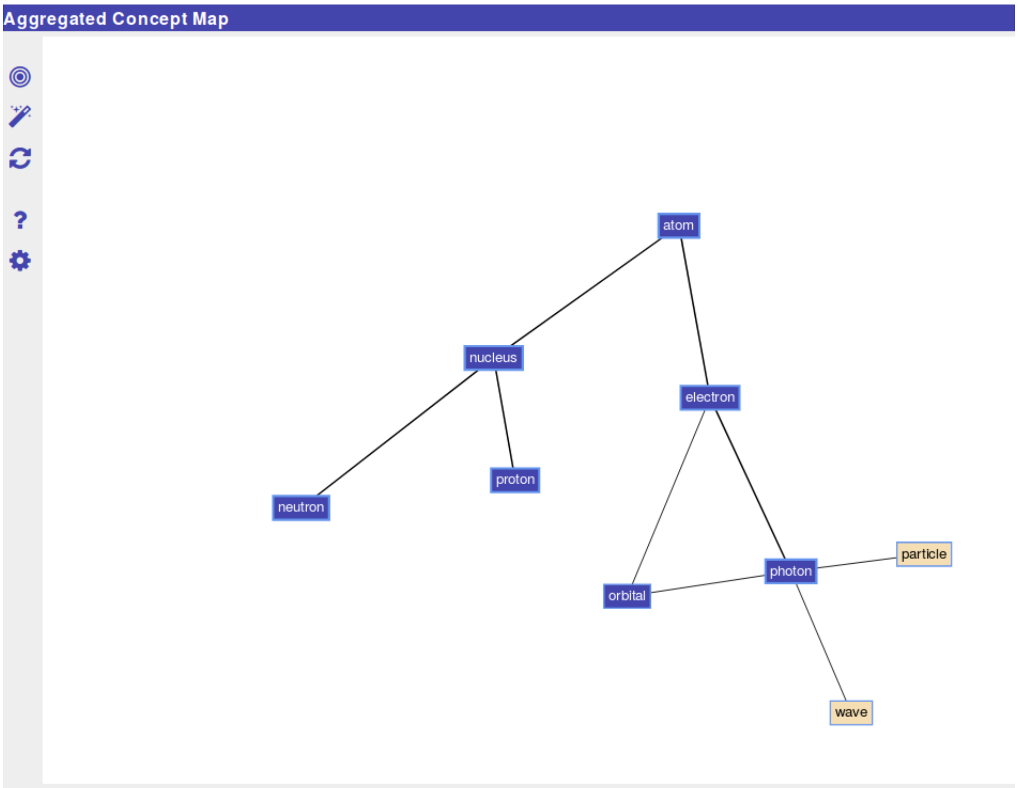


Figure 33: The aggregated concept map

2.2.3.2 Concept mapper dashboard

The figures above (Figure 32 and 33) are examples of what the student sees when using the concept mapper. Figure 34 represents the view of the teacher in the aggregated concept map dashboard.

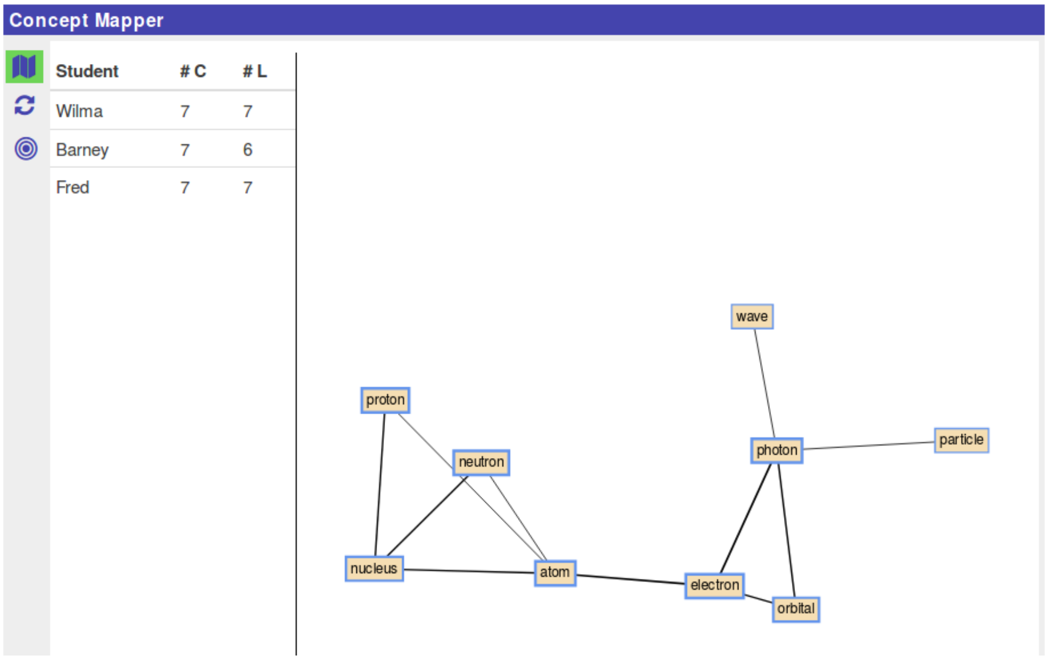


Figure 34: Concept map dashboard (teacher view)

The concept mapper dashboard for teachers shows a list of students as well as the ACM. In the ACM, the thickness of the borders for concepts, and lines for links indicates how many students used these concepts and the links between them.

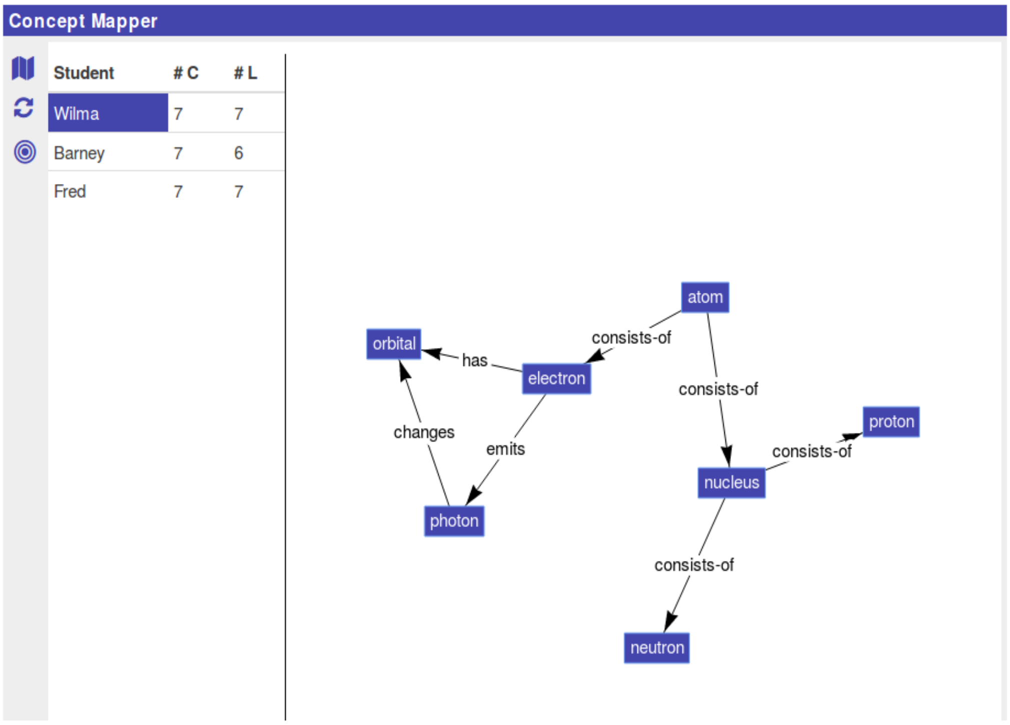


Figure 35: Concept map in teacher view with one student selected

In Figure 35, the teacher has selected one of the students and can now see the concept map created by that student. The teacher can also select a concept, which then causes all the students who used that concept to become highlighted.

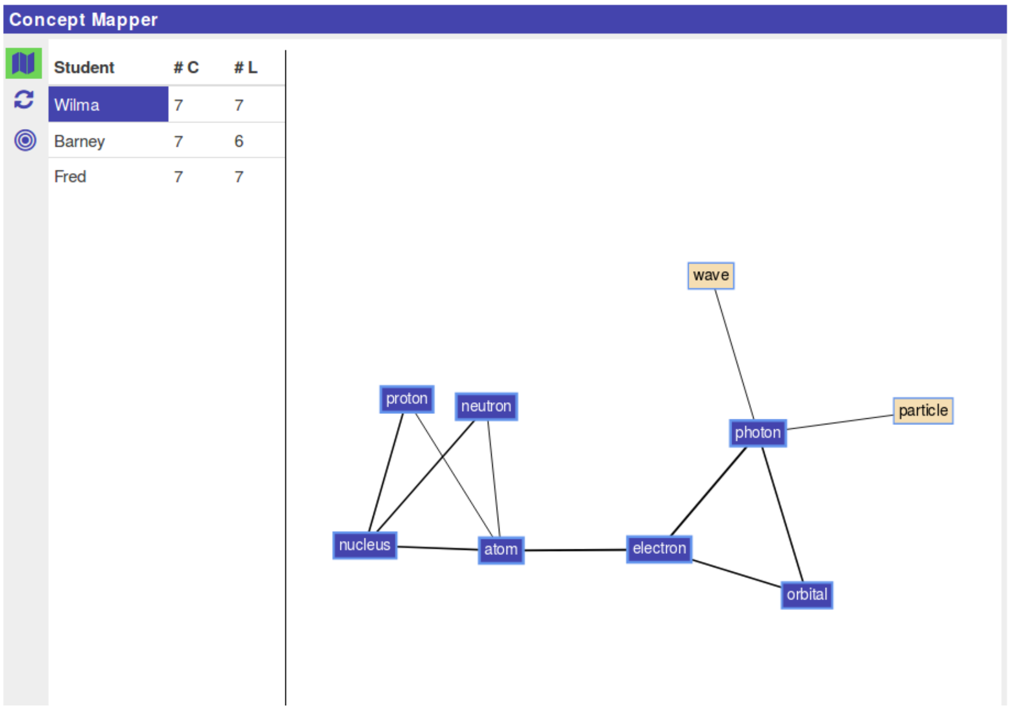


Figure 36: Aggregated concept map in teacher view with one student selected

The teacher can also select a student and then see the difference between the selected student and the aggregated concept map (Figure 36).

2.2.4 Phase transitions

The phase transitions app (Figure 37) shows the student which phases he or she visited and in which sequence. The time spent in each phase are shown as a bar chart in which time is on the x-axis and the phase names are on the y-axis, indicating where and when transitions happened. The visualization is slightly different from the timeline teacher view (Figure 21), because for the phase transitions tool there is only a single student and there is room for a separate bar for each phase. An example is shown in the screenshot below (Figure 37). Reflection questions can be added, see Section 2.2.5.

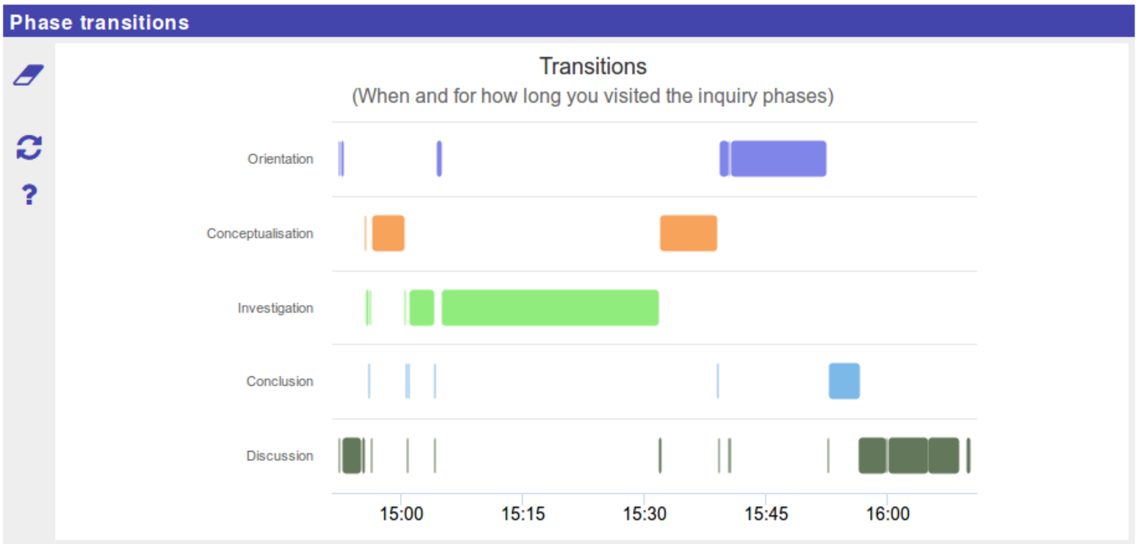


Figure 37: Phase transitions

2.2.5 Reflection questions

Each of the apps in the preceding sections provided students with a visualization of their product or process and in most cases (with the exception of the phase transition app) presented a norm with which students can compare their own product or process. To further guide the reflection process, a teacher can choose (in the configuration of the app) to add reflection questions which students have to answer. An editor to create these questions is provided and for each of the apps a set of dedicated example questions is provided.

Reflection questions editor

Reflection questions prompt the student to reflect. A question consists of the text of the question, an optional image, and interface elements through which the student can provide an answer. The question text is entered either as plain text or using a rich-text editor. The question editor supports scientific notation: sub- and superscripts for mathematics and chemistry. The answer options depend on the type of question. The following question types are available:

- *Open answer question.* Let's the student type a plain text answer.
- *Left/right or yes/no question.* The student has to choose between two options. Optionally the teacher can provide feedback when an answer is selected.

- *Select from multiple options.* The student is presented with a list of options, and can select zero or more options from this list. An example would be "Which of these particles are not in your concept map?" with the list of answer options being "neutron, electron, proton, photon"
- *Slider.* The student is presented with a slider or multiple sliders, and drags these sliders to enter numerical values. Common usage in reflection is a confidence interval (0-100%) or rating one's performance on a task (see Figure 38).
- *Tabular question.* The idea for this type of question is that the student creates a table in which each row reflects on a "thing". An example is the question on identifying important concepts in Figure 40. In the editor the teacher configures the columns of the table with fields for an open answer (where the student can then type the name of a concept for example), a choice between multiple values (checkbox) and a yes/no answer. When the student fills in the last open answer field, an empty row is added automatically.

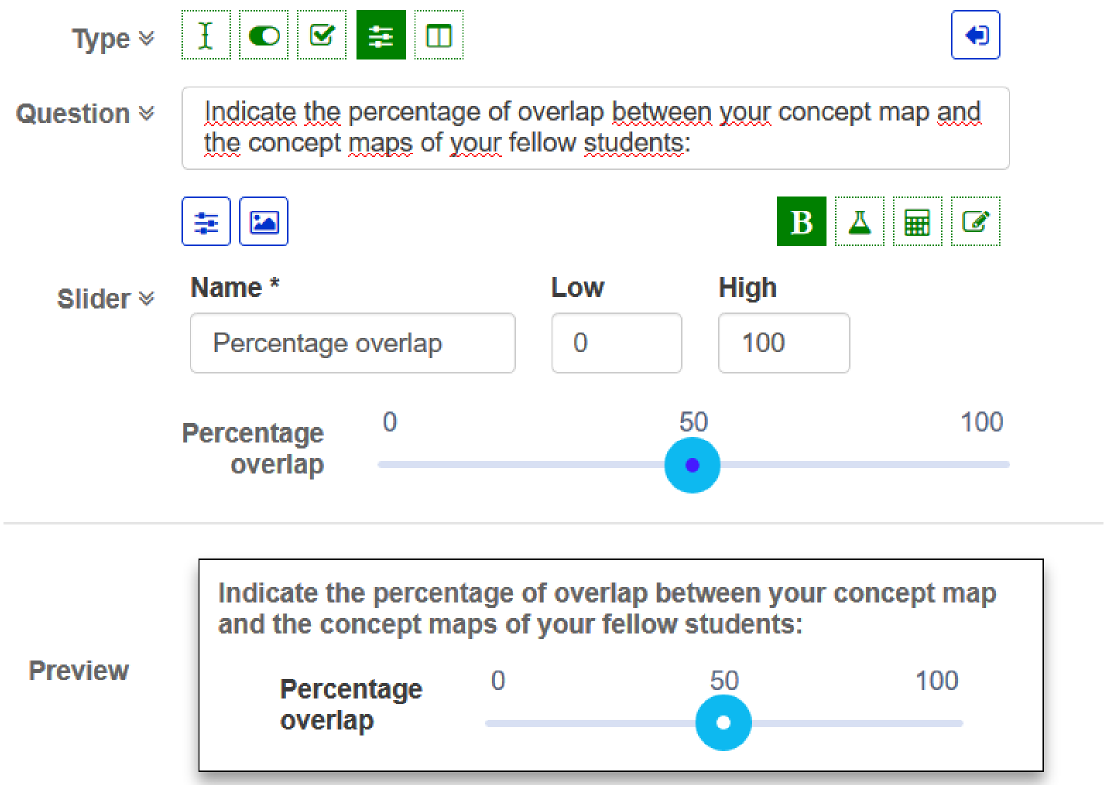


Figure 38: Screenshot of the reflection question editor

An example of the user interface of the reflection question editor with the tabular question is given in Figure 39.

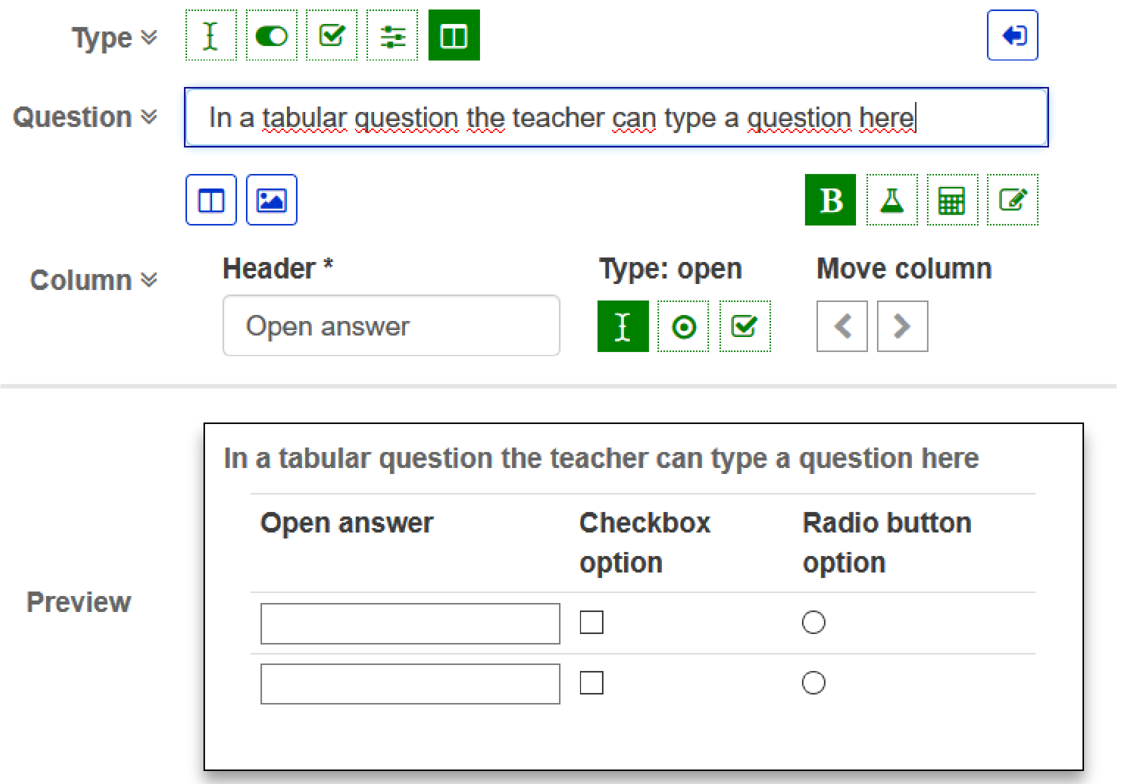


Figure 39: The tabular question editor

Aggregated concept map

In the aggregated concept map app students can compare their own concept map to the aggregated concept map of all students (see Section 2.2.3.1 for details). Example reflection items are:

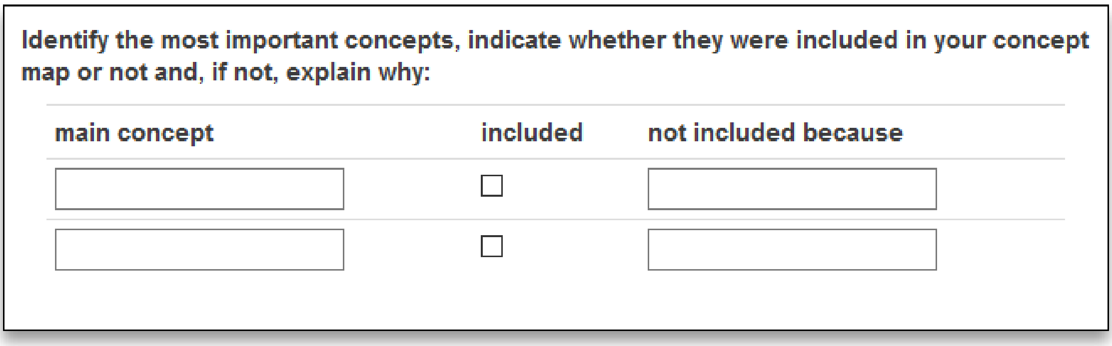


Figure 40: Example questions for the aggregated concept map

Timeline

With the Timeline app students can compare their own process/approach to the process/approach of other students (see Section 2.2.1.1 for details). The example reflection items are:

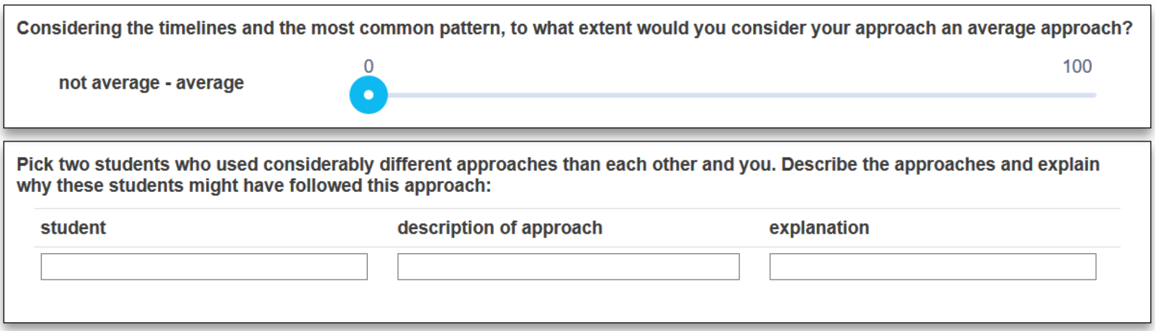
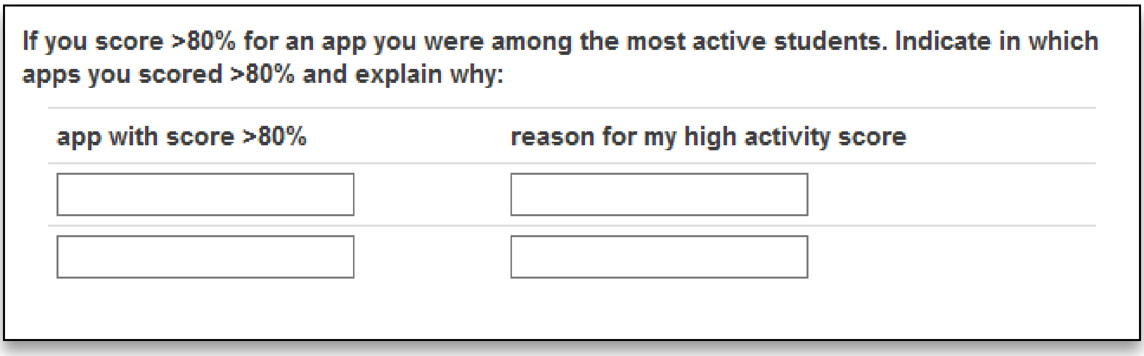


Figure 41: Example questions for the Timeline app

Activity plot

With the Activity plot app students can see their activity in the apps, relative to the most active student in that app and the average number of activities for each app (see Section 2.2.1.3 for details). Example reflection questions are:



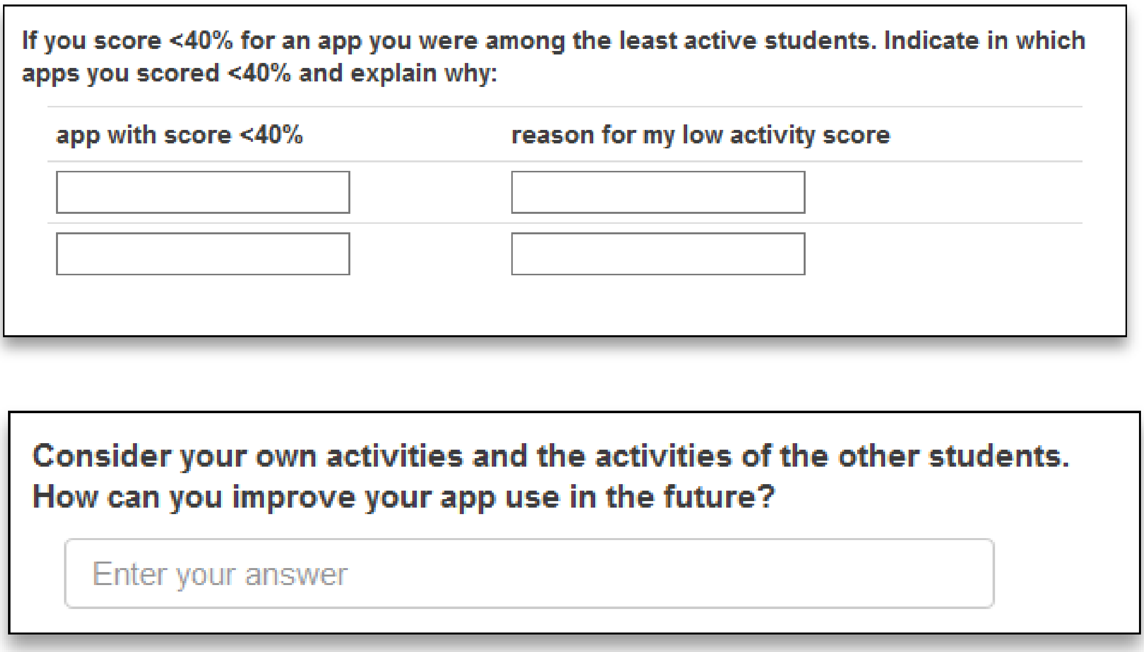


Figure 42: Example reflection questions for the Activity plot app

Phase transitions

With the phase transitions app students can see how they navigated through the Inquiry Learning Space (see Section 2.2.4 for details). Example reflection items are:

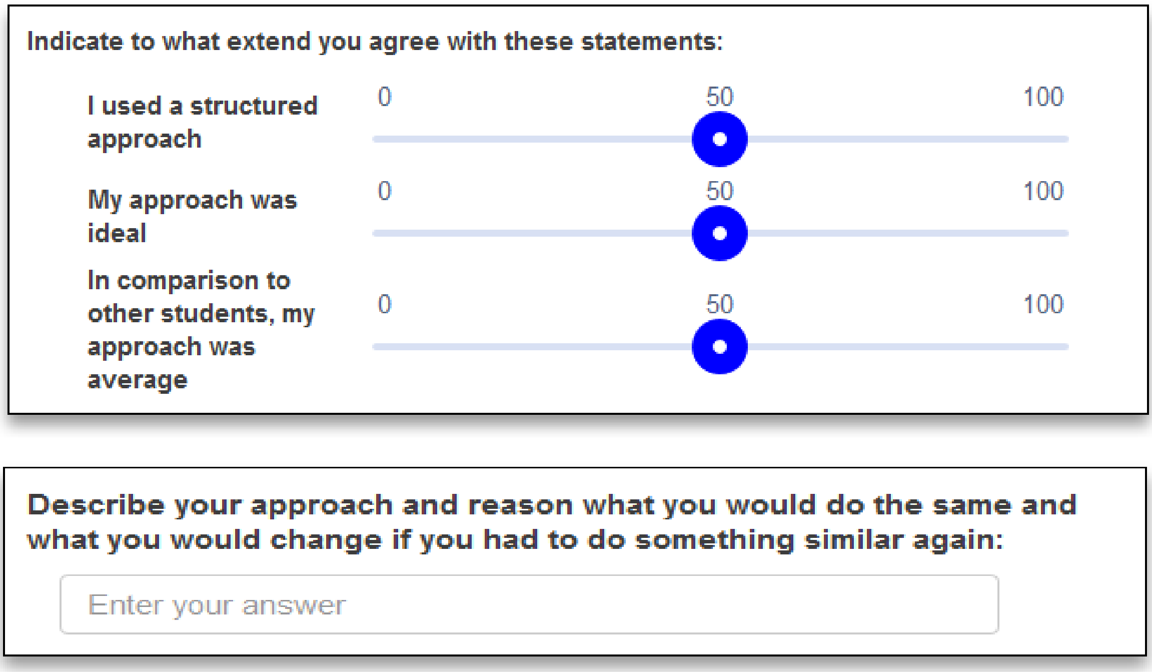
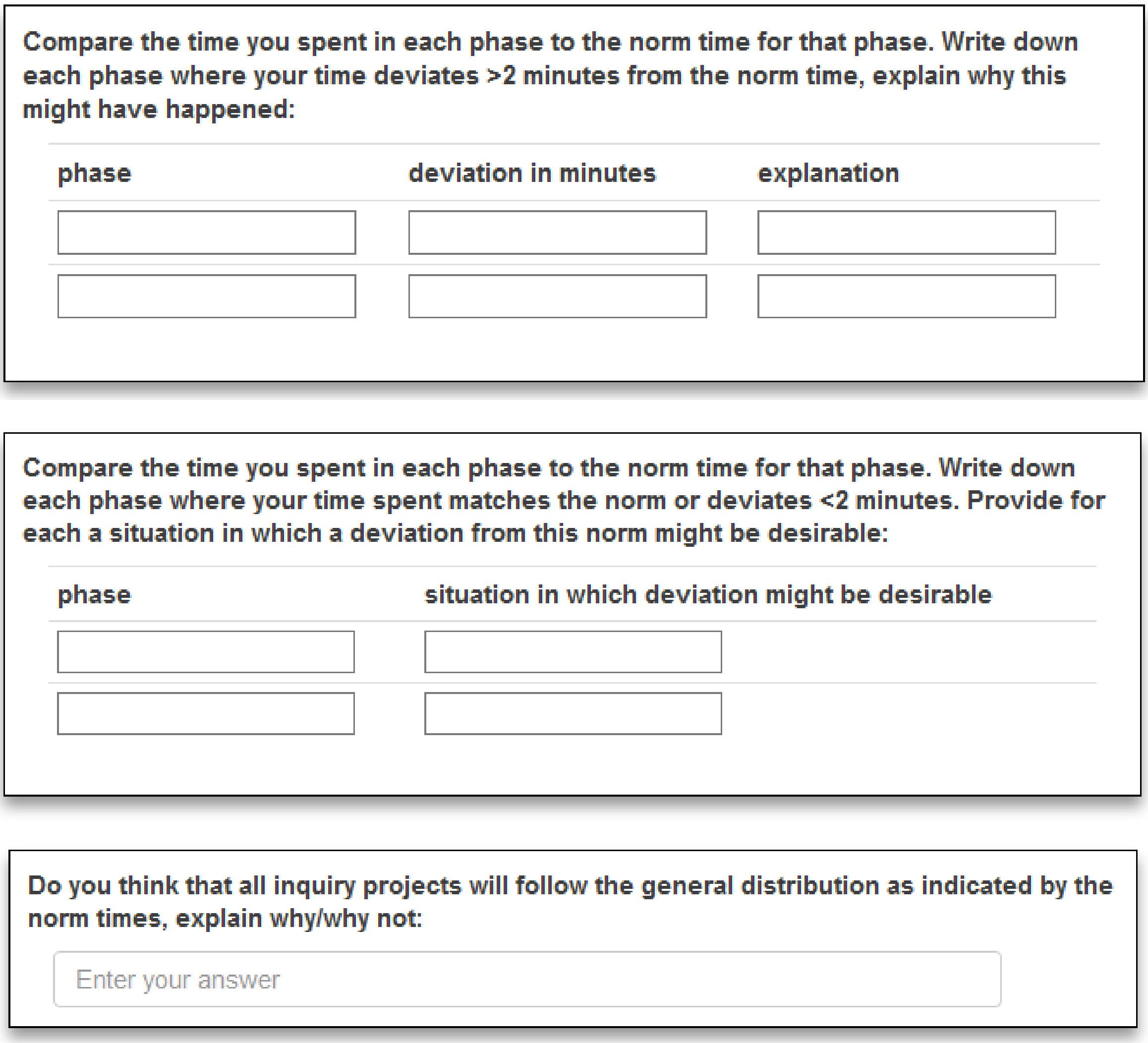


Figure 43: Example reflection questions for the Phase transitions app

Time spent

With the Time spent app students can see how much time they spent in each phase in total and compare it to an expert defined norm (see Section 2.2.2.1 for details). Example reflection questions are:



Compare the time you spent in each phase to the norm time for that phase. Write down each phase where your time deviates >2 minutes from the norm time, explain why this might have happened:

phase	deviation in minutes	explanation

Compare the time you spent in each phase to the norm time for that phase. Write down each phase where your time spent matches the norm or deviates <2 minutes. Provide for each a situation in which a deviation from this norm might be desirable:

phase	situation in which deviation might be desirable

Do you think that all inquiry projects will follow the general distribution as indicated by the norm times, explain why/why not:

Enter your answer

Figure 44: Example questions for the Time spent app

Time planner/checker

With the Time planner/checker app students can see how much time they spent in each phase in total and compare it to their own planning (see Section 2.2.2.2 for details). Example reflection questions are:

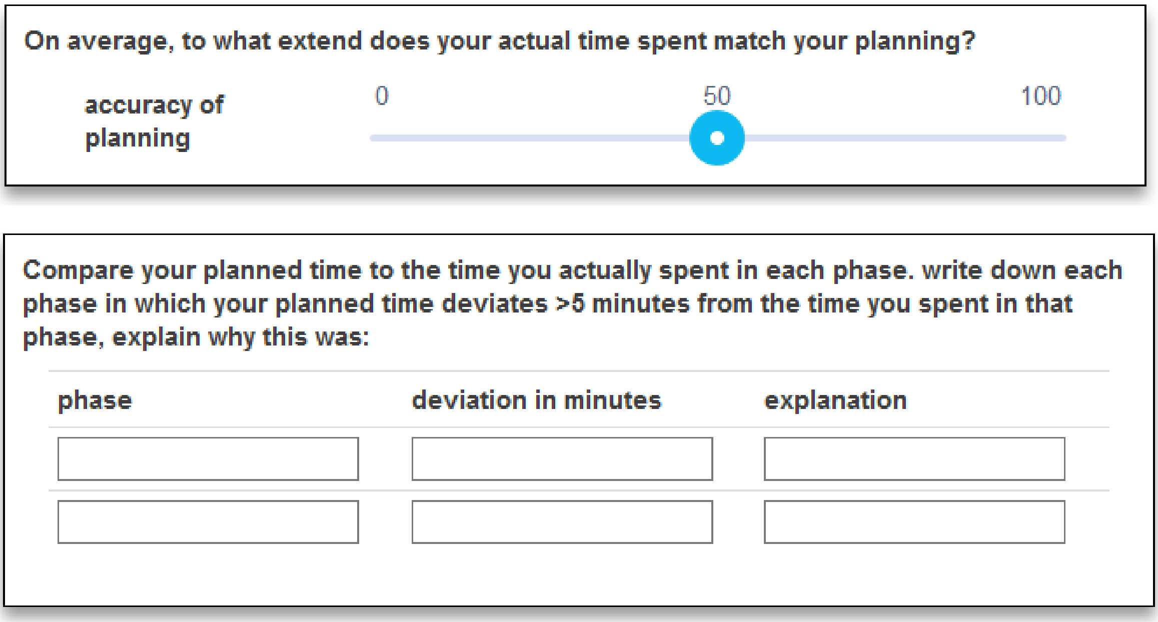


Figure 45: Example questions for the Time planner/checker app

3. Peer assessment

3.1 Main goal

The Peer assessment app can be used to engage students in the peer assessment procedure. This may include a reciprocal arrangement involving two roles for all students: The role of peer assessor, where students use peer assessment criteria to assess the learning products of their peers; and the role of peer assessee, where students will receive the peer feedback and review it to improve their learning products. This interchange between the two roles is beneficial and insightful as long as it promotes comparison between own and peer learning products and reflection upon one's own work. The learning products that can currently be assessed by means of the Peer assessment app (currently) include concept maps created with the Concept Mapper, student hypotheses formulated in the Hypothesis Scratchpad, and tables created using the Table Tool.

3.2 Workflow

The workflow for the peer assessment procedure involves a series of subsequent steps and engages students and the teacher. This sequence of activities needs to be timely planned and carefully orchestrated, since each next action is dependent upon one or several prior actions that precede it.

3.2.1 Creating learning products as a main prerequisite

A main prerequisite before starting the peer assessment procedure is that students will need to have constructed the learning products to be assessed. This will provide them with the necessary experience to act as peer assessors (i.e., they have been familiarized with the challenges of the relevant tasks) as well as the necessary motivation for acting as peer assessees (i.e., they will expect input from peer feedback to improve their learning products themselves).

3.2.2 Training for enacting peer assessment

Before engaging students in a peer assessment procedure, the teacher should have planned for a training session, especially if students are novices at performing peer assessment. Even in the case of students with experience in peer assessment, a training session may be necessary to elaborate on assessment criteria. Especially if new learning products are to be assessed, which have not been assessed in previous peer assessment procedures.

3.2.3 Asking for feedback

For the apps for which peer assessment is available, students can ask for peer feedback. This is done in the respective app, for instance in the Hypothesis Scratchpad, after having formulated one or several hypotheses. When students ask for peer feedback, they act as peer assessees (their learning products are to be assessed).

3.2.4 Giving feedback

Students can use a series of criteria to score learning products created by peers and provide comments explaining their scores. When giving feedback, students act as peer assessors (they assess learning products of a peer which have been assigned to them). A prior action before giving feedback and after students have asked for feedback is that the teacher has to assign learning products to be assessed to peer assessors.

3.2.5 Revising learning products

After peer feedback has been received, students should review it and decide which recommendations and suggestions of their peers are instrumental for improving their learning products. In this case, students act as peer assessees and make use of peer feedback to revise and increase the quality of their learning products.

3.3 Procedure

Teachers first need to add the Peer assessment app to the ILS, for example, to the teacher dashboard in Graasp. Second, teachers need to select the app(s) for which peer assessment will be available in the ILS. This will also determine the type and number of learning products to be assessed and influence the total time that needs to be invested in peer assessment. After selecting them in the Peer assessment app, the individual apps used to create the learning products to be peer assessed will get an additional entry in their configuration to activate and customize the peer assessment. Figure 46 presents the configuration in the Hypothesis Scratchpad, where teachers can choose the option to enable peer assessment (Peer feedback options; Use peer feedback checkbox). Teachers can have an overview of the menu with explanations presented to students and assessment criteria to be employed. Both can be customized by the teacher if this is considered necessary.

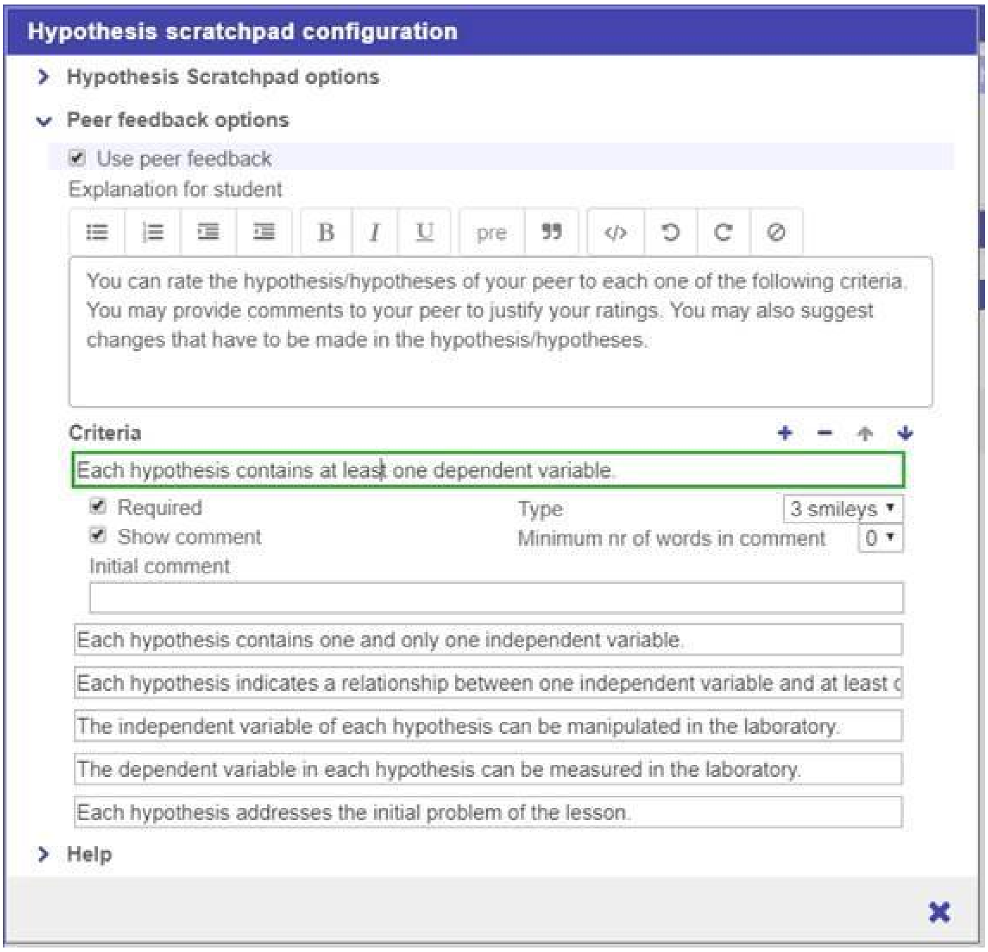


Figure 46: Activating the option for peer assessment in the Hypothesis Scratchpad

When a student intends to ask for peer feedback on the hypothesis he/she has formulated, then he/she should click on the icon with the bubbled question mark and submit the request (Figure 47).

All requests for peer feedback are forwarded to the Peer assessment tool on the teacher dashboard in Graasp, where the teacher can assign learning products to peer assessors (Figure 48).

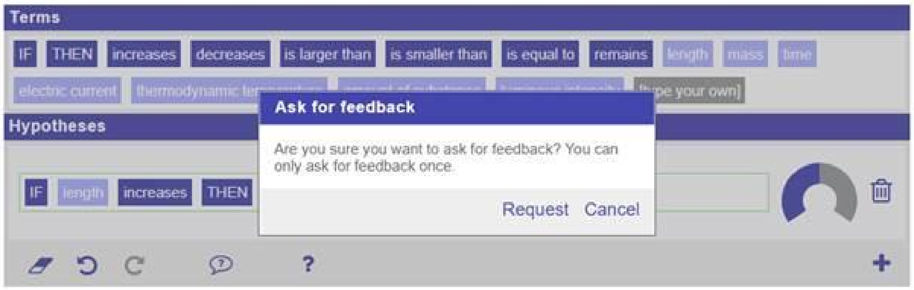


Figure 47: Asking for feedback in the Hypothesis Scratchpad

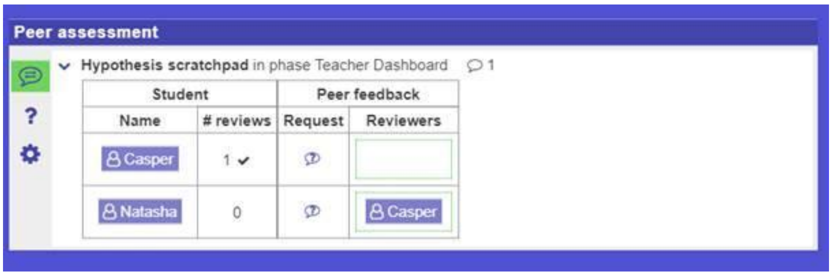


Figure 48: Assigning learning products to peer assessors

After learning products have been assigned, peer assessors receive a notification that a peer feedback request has been assigned to them, which is shown as a browser alert message (Figure 49; text and appearance of notifications will be improved later on). In the future, a notification system will also be operationalized to provide a general overview of peer feedback requests across the entire ILS.

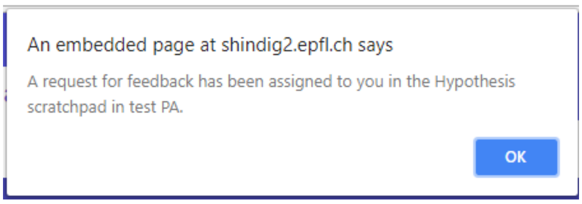


Figure 49: Notification indicating that a peer feedback request has been assigned

To review the learning product to be assessed and go through the assessment criteria, the peer assessor needs to click on the icon with the pen in the app where the request has been assigned, in our example, the Hypothesis Scratchpad (Figure 50). By clicking on the "pen" icon, peer assessors are presented with the learning product to be assessed and the assessment criteria to be used to provide peer feedback (Figure 51).

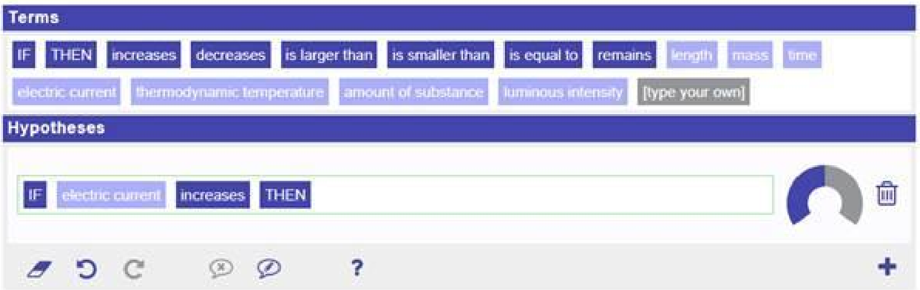


Figure 50: "Pen" in speech bubble icon in the bottom bar of the Hypothesis Scratchpad notifying the peer assessor that a peer feedback has been assigned to them

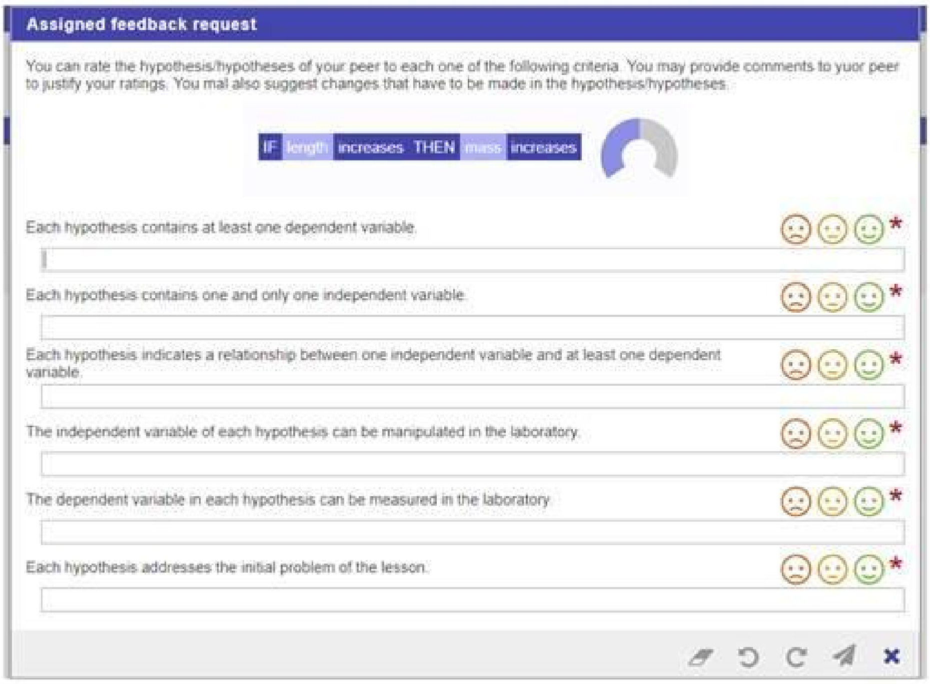


Figure 51: Learning product to be assessed (hypothesis) and assessment criteria to be used by peer assessors

Another notification is given to the peer assessee, when the requested feedback has been submitted by the peer assessor. To review peer feedback, the peer assessee needs to click on the "eye" icon (Figure 52). Then they can change their product based on the feedback, if they want to.

The teacher can have an overview of the original learning product of the peer assessee, the peer feedback that has been submitted by the peer assessor and the revisions that were made by the peer assessee. This overview is given in the Peer assessment app in Graasp by clicking the "question mark" icon (Figure 53).

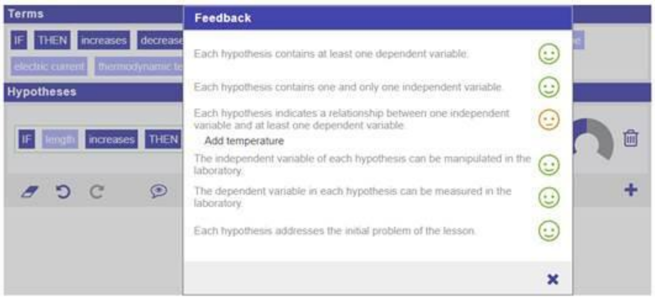


Figure 52: Viewing received feedback

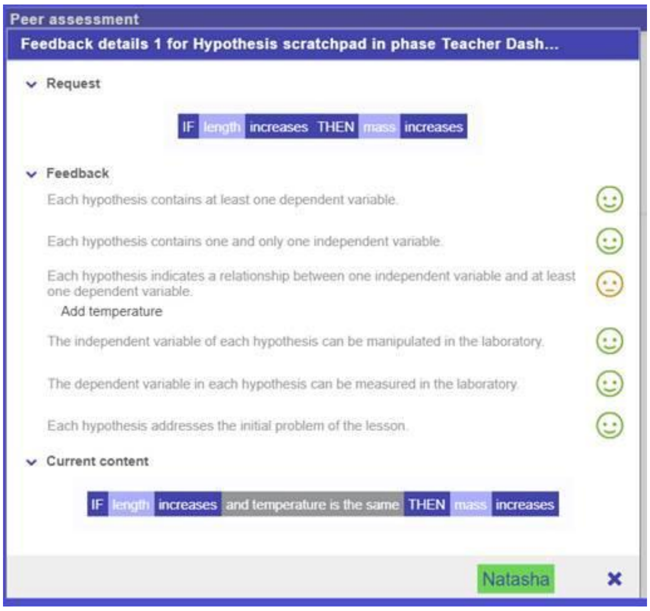


Figure 53: Teacher's overview of the original learning product, peer feedback, and the revised learning product

It is a significant amount of work for the teacher to assign all the feedback requests, especially if it has to be done in real time during the lesson. Therefore, automatic assignment options will be added. There are multiple ways to assign feedback requests, such as first come, first serve; pairing students based on student level, product properties, etc. There are also the corner cases such as the last feedback request, where all other feedback requests have been assigned and all the other students have already got the number of designated feedback requests. Perhaps in this case the teacher should act as a peer assessor and give the feedback him-/herself.

3.4 The peer feedback tool in practice

The peer assessment tool has been tested with various domains and age groups of secondary school children. First tests contributed to the development of the tool making it more intuitive for students to use. Further studies aimed at gaining a deeper understanding of a peer assessment process and what influences its effectiveness.

An experimental study using pre-rest – intervention – post-test design was conducted with secondary school children (M_{AGE} = 14.64) in the Netherlands (N = 58) and in Russia (N = 81). Participants learned about a topic from the curriculum using an ILS which included an online lab about convection and several tools and apps. The tools included the concept mapper and the peer assessment tool. During the lesson, among other things, students individually created concept maps, then gave feedback to fictitious peers' concept maps and finally could improve their own concept maps. The process of giving feedback was supported by providing assessment criteria. Students were randomly divided into two conditions – giving feedback by grading (with smileys) or giving feedback by commenting.

Analysis of the post-test scores in domain knowledge showed that students from the commenting condition outperformed students from the grading condition (see Figure 54).

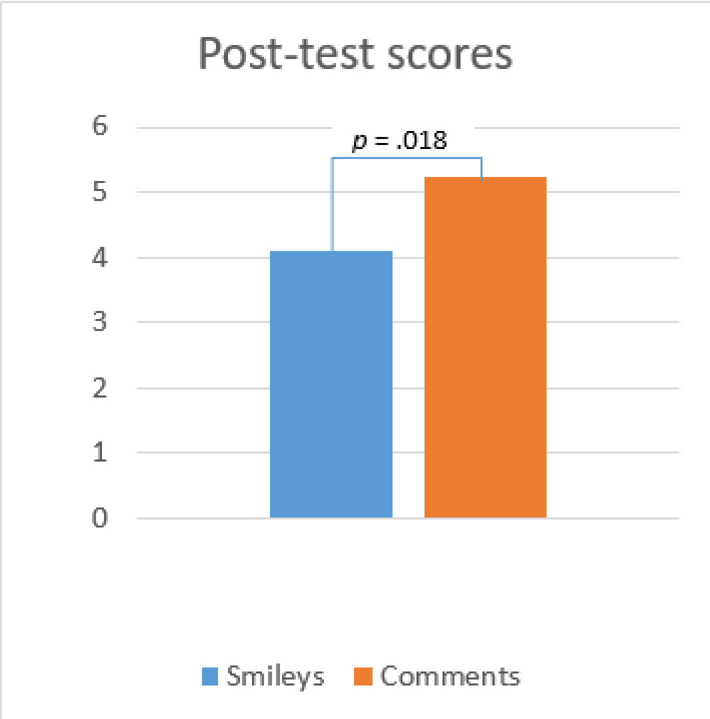


Figure 54. Post-test scores for both groups

In addition to the main effect of the condition, an interaction effect between condition and prior knowledge level was found (see Figure 55). This means that the intervention has a different effect for different groups: students with lower prior knowledge benefiting from commenting the most.

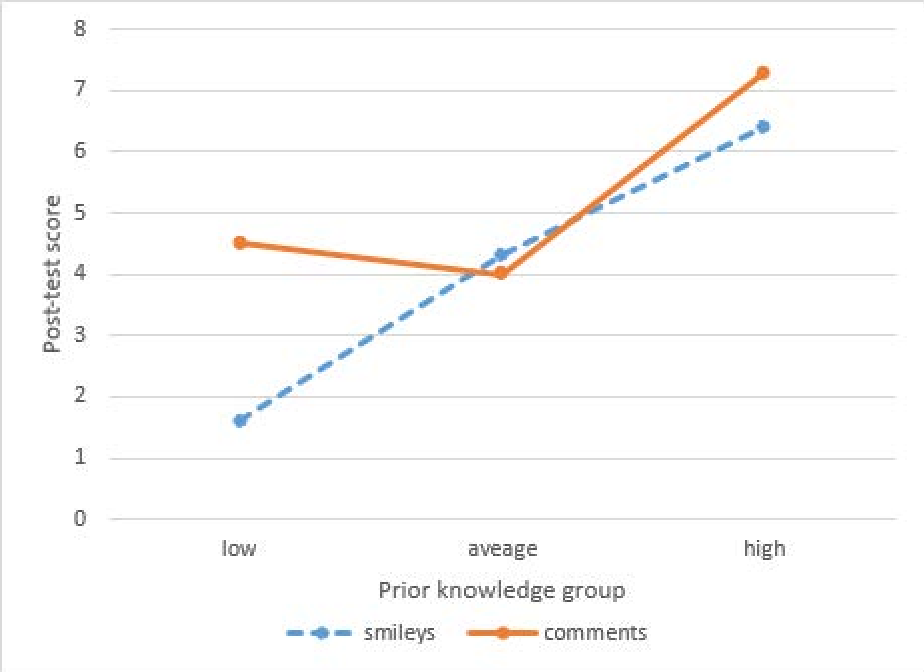


Figure 55. Post-test scores for the two conditions for students with low, average or high prior knowledge

4. Providing students with automatic feedback

Providing automated feedback to students can help students stay on-topic, and free up time for teachers. An automated feedback tool has been developed for hypotheses (Kroeze, 2019[5]), and is being developed for concept maps.

In both cases, feedback can only be given after an inquiry artefact (a hypothesis, concept map, or something else) has been evaluated. This evaluation can also serve as an indicator for further adaptivity in learning environments, or as an input for a teacher dashboard - allowing teachers to identify and help students in need.

4.1 Automated feedback on hypotheses

An altered version of the hypothesis scratchpad was created for the purpose of providing students with automated feedback. First, hypotheses are parsed using context-free grammars, leveraging the intrinsic structure of hypotheses to extract meaning.

Once the meaning of a hypothesis is known, feedback can be given based on a number of criteria.

4.1.1 Assessment of hypotheses

The context-free grammar for hypothesis evaluation is split into three parts. At the core is a language and domain independent syntax describing the basic structure of hypotheses; e.g. “if x increases, then y decreases”.

The second part defines language specific terms (e.g. “increases”, “decreases”), and any language specific extensions to the structure of hypotheses. Note that currently implemented languages are Dutch and English. Languages that follow a dramatically different structure (e.g. those outside of the Germanic language group) will likely require further extensions.

The final part of the grammar defines domain specific terms (e.g. “sinks”, “buoyancy”), and any domain specific extensions to the hypothesis structure.

By splitting the grammar into largely independent parts, it can more easily be extended to other languages and learning domains.

4.1.2 Feedback on hypotheses

Once a hypothesis has been evaluated, it is graded on the following criteria:

- contains at least two variables
- contains at least one modifier (‘increases’, ‘sinks’, etc.)
- hypothesis is syntactically correct
- exactly one variable is manipulated
- variables are qualified (e.g. mass or volume alone do not qualify volume)
- interactions are qualified (e.g. in buoyancy, the relevant variable is the interaction between density of a fluid, and density of an object)

[5] Kroeze K.A., van den Berg S.M., Lazonder A.W., Veldkamp B.P. & de Jong, T. (2019). Automated feedback can improve hypothesis quality. *Frontiers in Education,* 3:116. doi: 10.3389/feduc.2018.00116

Hypotheses are evaluated after each change, however feedback is only presented to the student when requested. Feedback can be requested by clicking a new 'speech bubble' icon, see Figure 56.

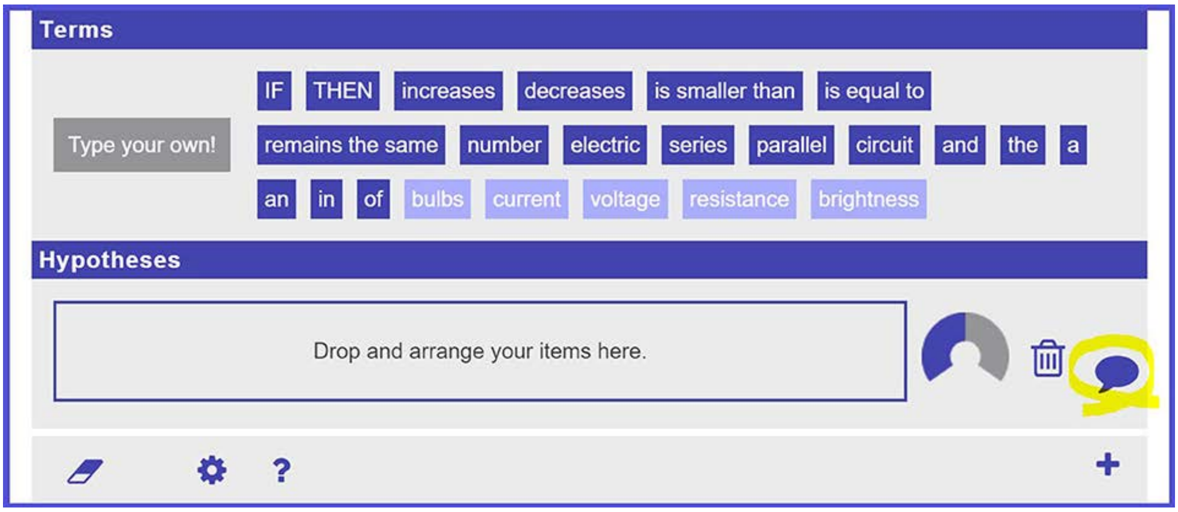


Figure 56: Example of requesting feedback by means of the speech bubble icon

Feedback is presented to the student in stages; the first two criteria are checked first, and if failed, no further criteria are checked and feedback is presented that the hypothesis does not seem to be complete. If the first two criteria pass, feedback is given for each of the remaining (relevant) criteria (Table 3).

Table 3. Criteria with the feedback provided

Criterion	Feedback	
	Wrong	Correct
Variables	Not enough variables, A hypothesis should always have at least two variables.	–
Modifier	You can only test a hypothesis if something changes. Without change, you cannot test the hypothesis.	–
Syntax	It appears you've entered an incomplete hypothesis. I can only give feedback on full hypotheses[a].	–
	I don't understand your hypothesis. Are you sure this is a correct hypothesis?; "[HYPOTHESIS]"[b]	–
CVS	If you don't change the value of [INDEPENDENT], you won't be able to test if this has an effect on [DEPENDENT][c]	You're changing the value of [INDEPENDENT] to see if that has an effect on [DEPENDENT][c]
	You're changing [INDEPENDENT] at the same time. You can't be sure which of these changes has an effect on [DEPENDENT][d]	You're changing only the value of [INDEPENDENT], so you can be certain that any change in [DEPENDENT] is caused by [INDEPENDENT][d]
Qualified	You did not describe the conditions in which your hypothesis applies.	You specified that your hypothesis only applies in a [QUALIFIER].

[HYPOTHESIS], [INDEPENDENT], [DEPENDENT], and [VARIABLE] will be dynamically replaced with the actual hypothesis and variables used by the student and recognized by the parser. The feedback has been translated from the Dutch original used in the experiments.
[a]Used when a hypothesis starts valid but is incomplete (partial parse).
[b]Used when a hypothesis cannot be parsed (nonsense, or syntax error).
[c]Used when the independent variable is not manipulated.
[d]Used when multiple independent variables are manipulated.

4.2 Automated feedback on concept maps

Concept maps are said to visualize learners' internal mental models, and as such can be a great tool to assess and improve students' understanding. In addition, concept maps are simply a network (or graph) with nodes (concepts) and edges (relations), and as such are relatively straightforward to parse and assess.

4.2.1 Assessment of concept maps

The latest version of the concept mapping tool was adapted, adding functionality to assess concept map quality based on graph- and network-theoretical indicators of the complexity and size of the concept map, as well as indicators based on the concept maps similarity to a reference concept map created by a domain expert.

The currently implemented criteria are;

- concept density (number of concepts used, in proportion to the expert map)
- relation density (number of relations used, relative to the number of concepts and expert map).
- structure (length of the largest non-circular continuous path)
- score (number of correct propositions (two concepts and a relation joining them), relative to the number of incorrect propositions and the number of propositions in the expert map.

Based on these criteria, we can assess the quality of the concept map, and give an indication of the inquiry skill and domain knowledge of the student who created the concept map.

4.2.2 Feedback on concept maps

Feedback on concept maps is split into three phases; concept build-up, relation build-up and the main expansion phase. In the first phase, the student is prompted to add relevant concepts. In the second, she is prompted to add relations between concepts. Once the student has added some concepts and relations, the third and main phase starts, where the student is prompted to add, remove and/or correct relations and concepts individually. In each case, feedback is presented to the student by an avatar, as shown in Figure 57. Feedback is generated by comparing the students' concept map to an expert reference map, and usually comes in the form of a question addressing differences between the two; e.g. "is concept X really necessary in your concept map?", or "is there a relation between x and y?". The student then has the option to respond to the question (the green buttons), which closes this specific feedback, or to 'mute' the feedback temporarily (the orange clock icon).

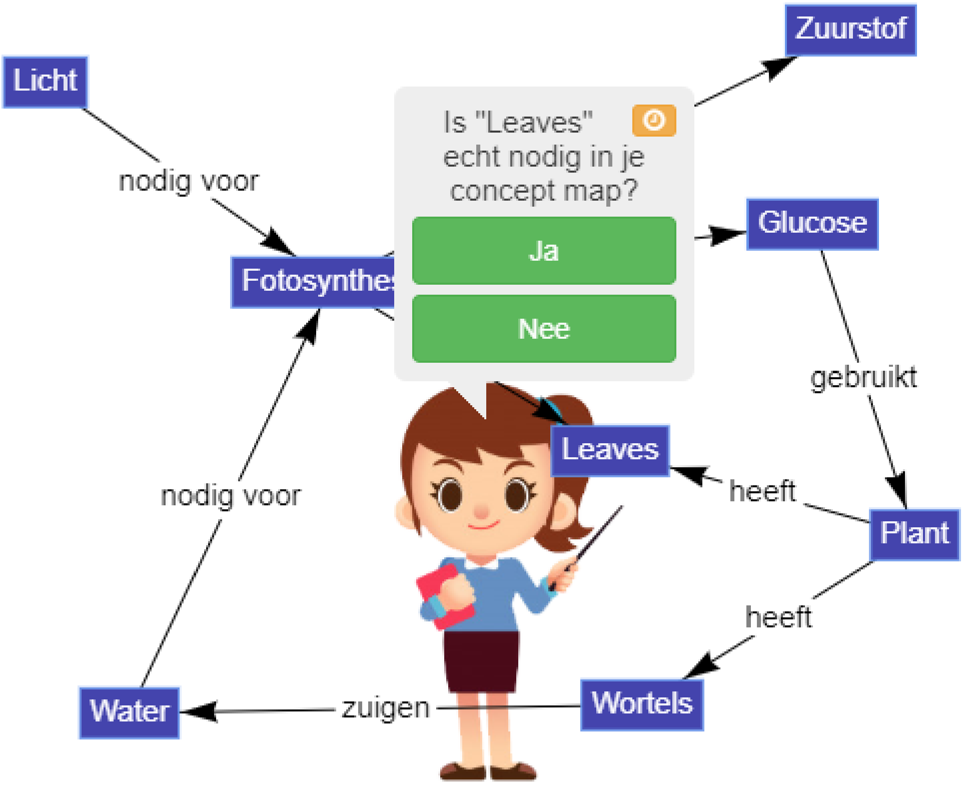


Figure 57: Automated feedback given by an avatar in the Concept mapping tool

5. Quiz overview

The Quiz overview is an app that provides a summary of all the quiz tools in the ILS. It is a premium app that will be part of a paid package for schools. The teacher can choose to view an aggregated summary or see the answers of individual students.

When a specific student is selected, the app shows the answers of that student, with the possibility to give a score to each answer (Figure 58). For some question types (yes/no, multiple choice, numeric input) the scores are automatically computed, but can also be modified if needed. For other question types (open-ended, tabular), the teacher should input the grade manually.

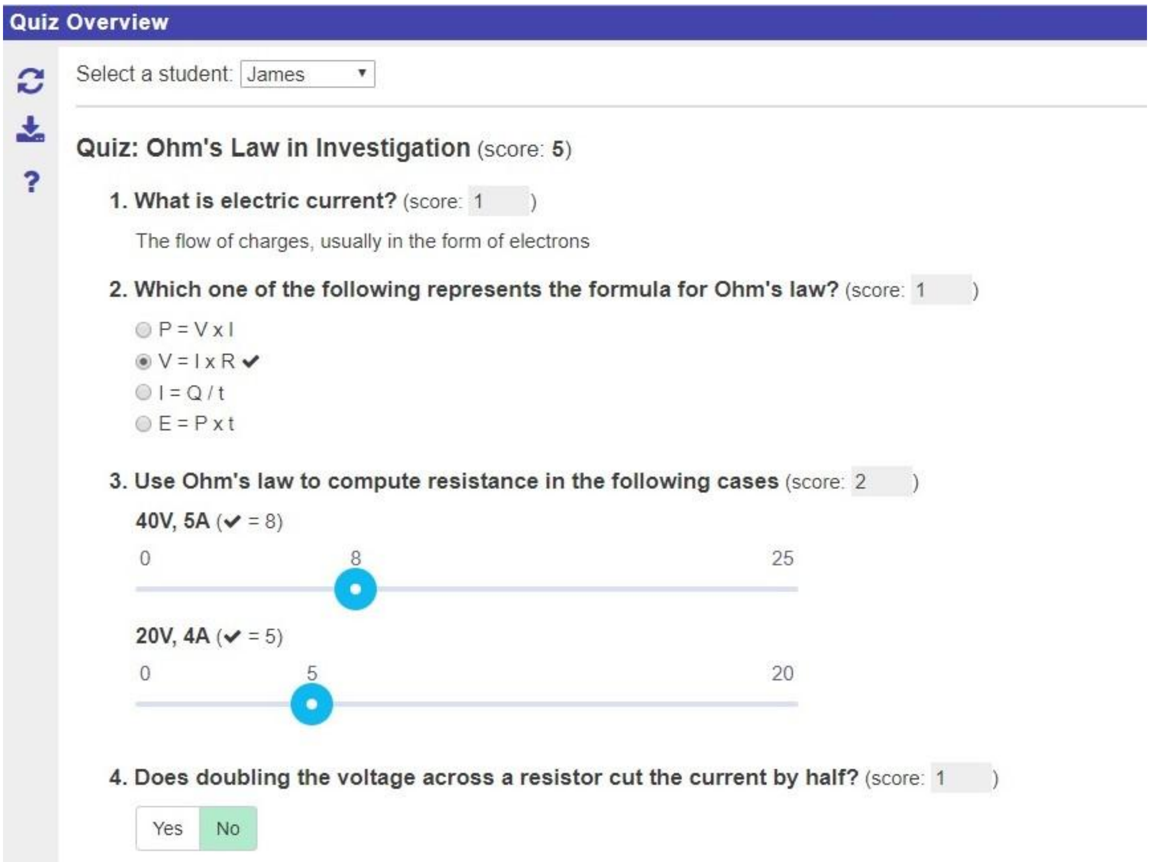


Figure 58: Answers of one student in Quiz overview

When the aggregated view is selected, the teacher gets an overview for each question, combining the answers of all the students together. Depending on the question type, the app uses a different type of graphical representation to visualize the aggregated answers (Figure 59). The teacher also gets the average score for each question and for the entire quiz.

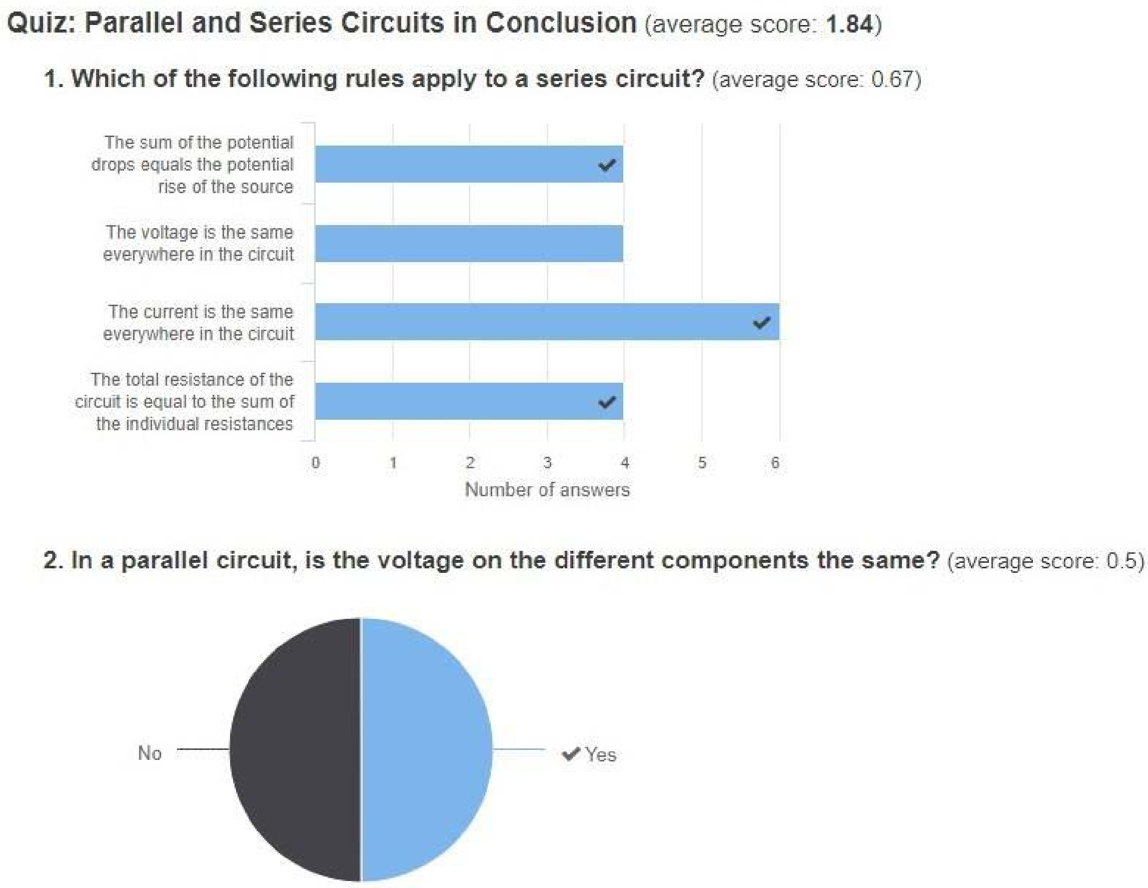


Figure 59: Aggregate mode in Quiz overview

At the bottom of the app, there is a table summarizing the total score each student received in each quiz (Figure 60). The teacher can also click on a button to export all the scores (quiz and question scores) to an excel file, which can be used to perform further analysis on them.

Student	Ohm's Law	Parallel and Series Circuits
Alice	0	2.5
Bob	1.67	0.75
Carla	3.75	1.5
James	5	3
Maria	3.75	1
Mark	1.5	2.25

Figure 60: Score summary table

6. Accompanying icons and videos

To display the new apps on Golabz a set of new icons has been designed (see Figure 61).

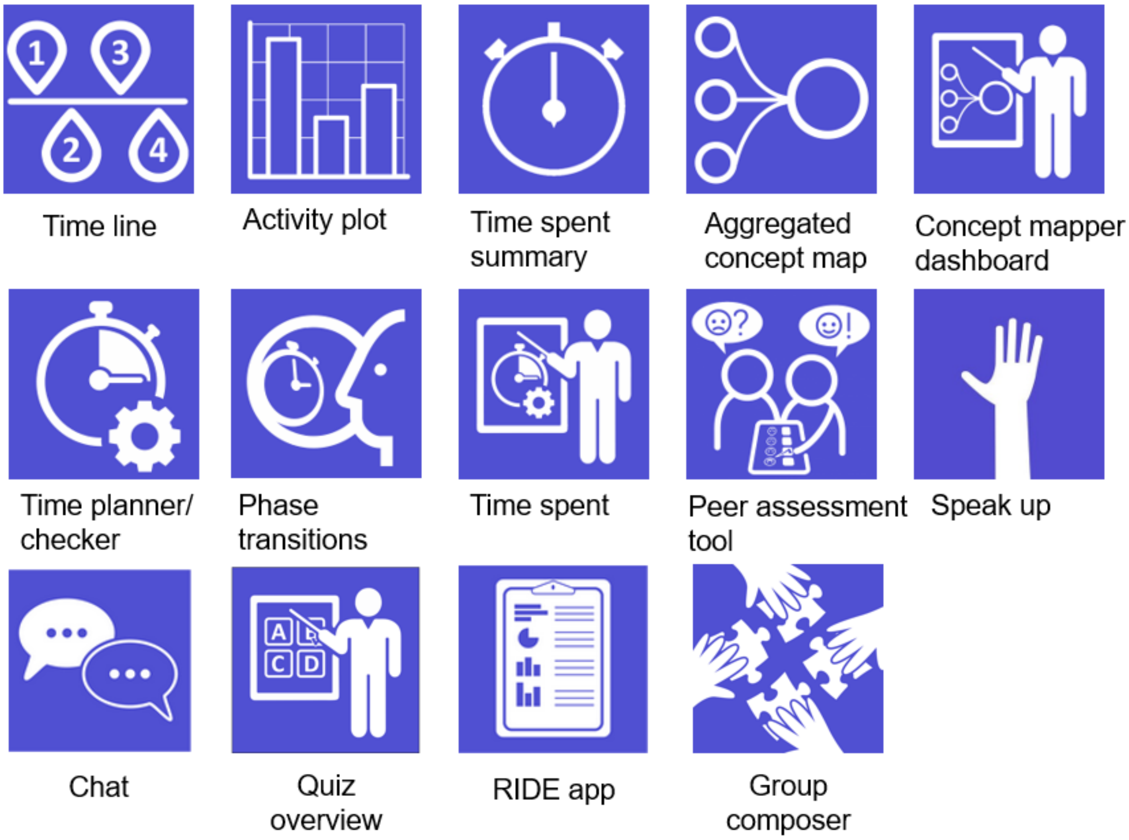


Figure 61: Icons for the apps

To support the users of the new apps a series of new instructional videos have been created. The instructional videos can be divided into two larger groups. The first group of videos will show the teacher how the app can be used. The second group of videos focusses on configuring the apps. They are available at Golabz: https://support.golabz.eu/.