Teaching Algorithms in Secondary Education: A Collaborative Approach

Eleni Voyiatzaki[1^], Christos Christakoudis[2], Meletis Margaritis[1], Nikolaos Avouris[1]

[1]Human-Computer Interaction Group
University of Patras, Greece
{evoyiatzaki, Margaritis, N.Avouris} @ee.upatras.gr

[2] Vrachneika High School
Patras, Greece
christak@dide.ach.sch.gr

Abstract: The Algorithm is a fundamental concept for teaching Computer Science in Secondary Education. There are verbal (pseudocode) and graphic (flowchart) representations of algorithms that can be used in the process. Teaching algorithms through peer collaboration is a new approach that needs investigation. The main objective of this paper is to present a case study of computer-assisted collaborative algorithm teaching in an authentic secondary school environment. In the context of this study, activities concerning algorithms exploitation and building, using a flowchart representation were designed for fifteen-year old students. These activities engaged a prototype computer-based collaborative learning environment, *Synergo*, which has been adapted especially for this study. Interesting findings of this study concern the learning impact of this didactic approach and suggestions on its effective use.

Introduction

The *Algorithm* is a fundamental concept in computer science teaching. (Tucker et. al. 1995). Various approaches have been proposed to support teaching of algorithms, involving use of graphical and verbal representations of algorithms. (Scanlan 1998). Using *flowcharts* seems to be effective in this context. Typical Secondary Education Curricula set a frame of objectives for algorithms teaching, which aim for the students to acquire new skills, while using symbolic representations to express and analyze their ideas, to develop and improve analytic-synthetic way of thinking, to get familiar with the use of symbols while representing a problem-solving procedure. As a consequence of this, students are expected to learn to use the basic constructs and concepts of a programming language. Teaching algorithms includes the use of flowcharts and pseudocode. These representations are presented and used in lectures in the class or through examples in the computer laboratory. In a typical setting, however the teacher is not expected to involve any computer equipment in algorithm teaching.

An innovative approach that is interesting to be studied is the use of collaborative peer-learning, while studying and experimenting with algorithm flowcharts. Modern approaches in teaching and learning put emphasis on problem solving activities that involve peer collaboration. It seems that there is a wider acceptance of the fact that these approaches encourage construction of knowledge and building of meaning. The main benefits of collaborative learning are related to the active character of the learning process, the deep level of information processing and the requirement of deep understanding from the students involved (Dillenbourg, 1999). Through such approaches, skills of critical thinking, communication and coordination can be developed and conscious knowledge construction mechanisms can be built (Steeples & Mayers, 1998). Network-based computer systems, offer new opportunities in supporting collaborative learning. While most of them are destined for asynchronous interaction, there is a new generation of tools that support synchronous interaction in the class. This is the case with *Synergo*, an environment that supports collaborative problem solving of small groups of students through instant messaging and a shared activity board.

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The objective of the reported here research has been to study the effect of introducing such an approach to an authentic educational setting of Junior High School (14-15 year old pupils). Questions that have been investigated include, the effect of this approach in terms of organization and technical adjustments, changes to the role of the teacher, the effect of the environment to the didactic approach, the effect on post-class diagnostic tasks, the overall educational effect to the particular classes involved. In addition, we investigated more general issues, like the influence of the tools (real or symbolic) that support human activity and communication in networked environments, the tutoring role of the teacher and the peer support when working in such an environment. These questions have been examined in a case study that concerned algorithms teaching by requesting from two classes to explore the properties of a given flowchart, in small groups using Synergo. The rest of the paper is organized as follows: first the collaborative learning tool used is described, subsequently the setting of the experiment and the methodological approach of the study are discussed. Finally, the findings of the study and the implications of the results are discussed.

Synergo: A synchronous collaborative environment

This section presents the main aspects of the functionality of the *Synergo* environment together with the main technological decisions concerning its architecture. Special focus is provided on the communication and coordination mechanisms. Synergo is based on the *Abstract collaborative applications building framework* build in ModellingSpace (Margaritis et al. 2003). Synergo architecture supports synchronous collaboration, as well as integration of collaboration analysis and visualization tools, used in this study.
The Synergo tool (www.ee.upatras.gr/hci/synergo) is a client-server distributed application, which comprises a suite of interconnected tools to support collaborative drawing activities. Synergo is an environment that supports individual and collaborative building of various kinds of graphic representations of problems. The main components of the architecture are therefore the following: (a) the *Diagram Editor*, the *Analysis & supervision tools*, residing in the client node and (b) the *Communication relay server*, to be found in the server node. The main functionality of the Synergo environment is described through fig. 1, which shows a typical problem-solving activity.

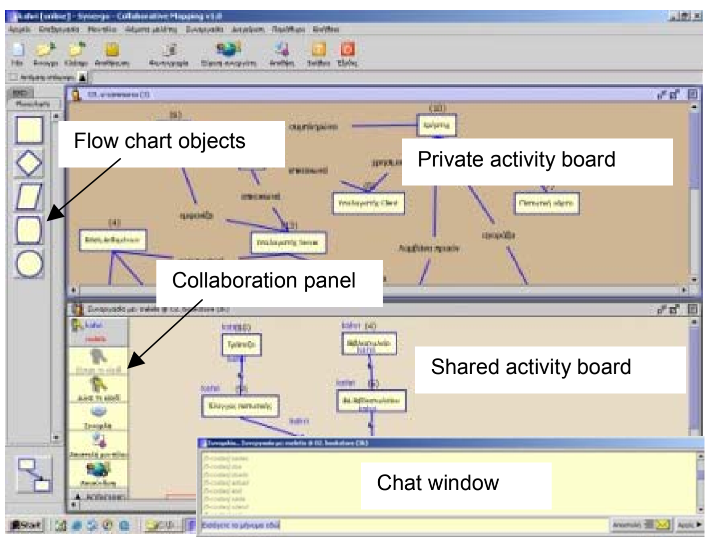

Figure 1. The Synergo environment: student view

Synergo supports building of different kinds of diagrams. It contains libraries for building flowcharts, entity-relationship diagrams, concept maps, Data flow diagrams etc. On the left-hand side column of figure 1 a library of Flowchart components is shown. Also data describing the activity can be produced in the form of logfiles and are available for inspection by the users or researchers.
Synchronous collaboration for problem solving is a case of computer-supported collaboration based on the concept of shared artefact/ work surface (Dix et al, 1998). The related notion of feed-through the artefact implies that one participant's manipulation of shared objects can be observed by the other participants. This

communication through the artefact can be as important as direct communication between participants, as observed in (Avouris et al. 2003a and Komis et al. 2002).

Various architectural decisions are related to this framework. Considering that the collaborative activity will be done mainly between partners at a distance, the direct communication mechanism has to be defined. A text communication has been used in this case, since other media like video and audio are considered not suitable as discussed in Avouris et al. (2003b). One additional decision is related to the design of the shared activity space, also discussed in the following. In Synergo a mixture of alternatives is provided. A strict WYSIWIS (what you see is what I see) is allowed in the shared problem-solving window. We believe that activity in this area should be faithfully reproduced in all participants' workstations. This is because most of communication and reasoning is based on this shared viewpoint, which becomes the main grounding mechanism of dialogue and through which eventually common understanding can occur. Deviation from this, results in confusion of partners since misunderstandings can be generated due to different views when partners are allowed to scroll to different viewpoints, while no strong coupling of the shared view and the direct communication can be achieved. However all additional operations outside this shared workspace, e.g. relating to browsing of activity sheets and other auxiliary material, saving of the flow chart or using private activity windows, like the one on the top side of fig.1, should be performed independently by partners involved, a model level coupling approach according to Suthers (2001).

Synergo incorporates a floor control mechanism. The coordination mechanism involves the notion of the *Action Enabling Key*, which is owned by one of the participants at any given time. This key owner can then act in the shared workspace, while the rest just observe this activity and make comments through the chat tool. This mechanism is supported by *key request, key accept, key reject* functions, which can be found in the Collaboration Control Panel (see fig.1). Experiments with this floor control mechanism, see also (Fidas et al. 2001) and (Komis et al. 2002), demonstrate that it supports reasoning about action, as partners need to reason and negotiate during key requests. Synergo users may opt for this mechanism or may decide to act in the shared activity space with no specific floor control, in which case locking is effected at the level of the single entity.

The main activity space of the Synergo modelling environment needs to be shared by multiple actors, permitting collaborative problem solving activities of learning actors at a distance. Sharing this activity space is achieved using a peer-to-peer connection between two or more client nodes. The size of the groups engaged in synchronous collaboration is small, so point-to-point connection is feasible.

In the frame of the collaborative use of Synergo, a *dialogue tool* has been integrated, which is based on an instant messaging protocol, using the same point-to-point connection and protocol discussed in the context of the shared activity space. Through this, text messages are exchanged during collaborative problem solving. The chat tool, is activated from the collaboration panel. Other means for exchange of text messages are the *sticky notes* (text containers positioned in the activity space) which are treated, in terms of the architecture, as special kind of entities, with internal properties: owner, time of creation, text_content. Through the sticky notes, gestures can be simulated, since a sticky note inserted in the drawing board can be related to an object in the shared activity space.

An additional feature of Synergo relates to analysis of collaboration activities. So a set of Analysis and Visualization tools are included in the environment. These are mainly used by the teachers and researchers, while limited versions of the tools may be used in some cases by students as meta-cognitive aids. For instance, the student tools permit playback of the activity while problem solving is in progress. The main functionality of the Analysis tool is the presentation and processing of logfiles, which have been produced during Synergo activities. These logfiles contain actions and text messages of all partners, in sequential order. The logfile is based on the format of the exchanged control and chat messages and is stored in XML form. This file can be viewed, commended and annotated by a researcher using an adequate analysis framework, as discussed by Avouris et al. (2003a). A related functionality of the analysis tool is its capability of posterior reproduction of the modelling activity, using the logfile, in a step-by-step or continuous way. This is complementary to the logfile inspection and annotation functionality. The activity can be reproduced using the playback tool. Annotation though this playback tool can also be done as discussed in more detail in Avouris et al. (2004).

Context of the Study

The study has taken place in a Junior High School, in the suburbs of Patras, Greece, a school of a deprived area. Most children who participated in the study had little experience with computer technology outside the school environment. The study took place in the computer laboratory that was equipped with ten personal computers and connection to the Internet. The study concerned part of the teaching of a computer science class. The class teacher, one of the authors of the paper, built an activity that involved exploring and testing by the pupils in small groups of an algorithm, that was given in a form of a flowchart.

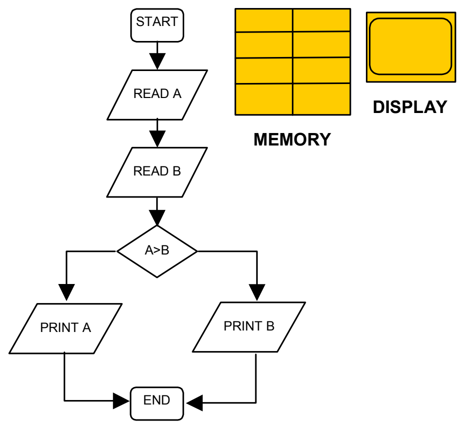

Figure 2. The flow chart included in the activity sheet

Two groups of students were given the same activity sheet, which contained the flowchart of an algorithm for finding the maximum of two integers, *A* and *B*, shown in fig.2,. Next to the flowchart, a graphical presentation of some memory cells and an output display was given. The students had to verify that the algorithm in the activity sheet solve correctly the "find the max of two numbers" problem, with completeness. To prove this they had to explore different pairs of *A,B* to verify the step by step execution of the algorithm and show the contents of the memory cells and the screen display in each case. A suggestion for three pairs of values was included in the activity sheet. The students were expected to test the algorithm for at least two different pairs of numbers (*A>B, B>A*), and assign correctly the values in the memory cells. This solution was considered acceptable, since this way they could demonstrate that they reached the first level of algorithm *correctness* check. However the *completeness* requirement was met only by students who also checked for the case of *A=B*. The study involved two groups of students of 14-15 years old. In total 20 students participated in the study. Group A, that was made of eleven (11) students, used the Synergo tool for communication and collaboration. Five (5) teams were formed in this case made of two to three pupils each. The collaborating teams, dispersed in the computer lab, interacted using the tool in order to tackle the problem. The location of the team members was such within the lab that they could interact exclusively through the provided tools, thus simulating distance problem-solving conditions. Group B, which was made of nine (9) students, also tackled the same problem in teams, using a paper and pencil environment. Three teams, of three pupils each, were formed in this case. The team collaboration was effected in a face-to-face manner. Group B was a reference group, since paper and pencil is the usual collaborative environment in the school practice. The solutions and the problem solving approaches of the two groups were compared at the end of the study.

Results and discussion

The two groups approached the problem in a comparable way. In group A the support of the teacher was requested by only one team, while in group B this was the case with all three teams. However, just two out of five of the teams of group A (40%) managed to reach the algorithms completeness check, while two out of three teams of group B reached the same result (66%). So it seemed that group B performed better. However, group B had requested much more support by the tutor, while group A was more self-sufficient.

We focus next on group A performance. The teams of Group A shared an activity board, which included the flowchart and boxes representing the memory cells and the display. The request was to use these boxes in order to fill-in the results of the algorithm, after they had completed the step-by-step execution. First, the Synergo environment did not seem to cause any usability problems to the teams. All five teams of Group A were quickly acquainted with the tool. No floor control mechanism was imposed. For this reason, during the first phase some students had conflicts when acting in the shared activity space, since it was not well understood that they were sharing the working area with the other members of their team. It was interesting also to observe that these conflicts once realized lead the teams in discussion about the tools.

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[Student A]    for these number it is NO
[Student B]    what do we do to show that it is NO
[Student A]    I will press NO, ok?
[Student B]    press it
[Student A]    wrong …we should write on the screen
[Student B]    I have made a mistake
[Student A]    you have erased NO?
[Student B]    yes!!!!!!
[Student A]    I thought I have done it. Search if there is 'undo'
[Student B]    don't think so
[Student A]    Shall I ask
[Student B]    ask… I can't help
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Figure 3 Part of Chat session (original in Greek)

For example, in the chat session of Figure 3 there was a misunderstanding on the use of the flowchart, as a result Student-B selected a part of the flowchart and deleted it. It seems that the students had decided after a short argument, to ask for help, from their teacher. This is a rare case for request of assistance for group A. It is interesting to point out, in this part of chat session, that students were wondering if they can 'undo' their wrong action, as they were used to in other applications.

Collaborative Problem Solving

The problem solving strategies included tasks relating to coordination of the activity, with selection of adequate pairs of values for *A, B*, running the algorithm, while assigning values to variables and deciding the results displayed on the screen. Some observations relating to these tasks were the following:

Decision to start collaborative activity: Asking each other if they are ready, proposing the first pair of values or discussing their strategy: "What shall we do first?"

Decision on the pairs of values for A, B: This task was very important for the problem solving, since a strategy on the selection of values was expected, to cover all possible alternatives. The students have not created this kind of strategy. In fact, they were selecting values, following the recommendations in the activity sheet for three different pairs of values, but they did not necessarily select alternatives. In all the groups, the decision on the pairs of values has been a point for discussion and negotiation among the partners.

Algorithm test and assignment of values to the memory cells and the screen: There were no conflicts observed in this task. Usually a team member proposed a pair of values and the others would accept them. It was usual the one who started with the initial proposal for A,B, to continue having the leading role in this task, until the end of the collaboration activity. It has been noticed that the duration of the collaboration session of those teams that reached the end of the activity correctly, did not necessarily negotiate longer than the other teams. Their actions were targeted, as if they had solved the problem individually in the private activity space first and then they copied the correct solution in the shared activity space.

In the teams with three students, we have noticed that one of the students had comparatively limited involvement. This team member lost interest and started to send off-task chat messages. This caused the reaction of the team members. The team leader, who started with proposing pairs of values to the other team members, was assigning the values to the memory cells by him, or was asking someone from the group to do it. He was controlling and leading his group, and he was the one to complain for the attitude of the member of the group referred before.

In a typical team of two, which solved the problem correctly, after the initial phase, having assigned the first pair of values to *A,B*, the student who took the initiative proposed the values and after the agreement, interleaving of actions and chat messages exchange was observed. It seemed that both team members had already solved the problem, mentally. Subsequently, they just used the tool to prove their solution.

The ratio of chat messages among team members was 40-60% in the 2-members teams and 25-44% in the teams of three students, which shows that generally the members of the collaborating teams have used the chat

tool for discussion in a uniform way.
The involvement of the teacher was important in both groups. In the teams of group A, working with Synergo, the involvement was basically in the phase of familiarization with Synergo, because the students followed the given rules, and tried to work using the instant messaging facility of the tool. In this case they were so absorbed by the activity, that where there was practically no involvement of the teacher requested.
In group B, working with paper & pencil there was a strong demand of the students for continuous support from the teacher, to answer questions, as it usually the case in everyday class activity. However the students of group A have discussed and negotiated their own ideas, more that the teams working with paper-pencil. In the case of Synergo working teams, there was a very laborious and quiet atmosphere in the class, where the students were communicating with chat. The students comments at the end of the class has been that even if they had faced some problems while using Synergo, their majority asked to use the same tool again, and they have proposed in the future to collaborate with students from other schools over the Internet using the same environment.
The collaboration activity of the groups, was analyzed by the teacher, off-line, using the logfiles and the Synergo analysis tools. This capability was not possible for the group B teams, since no record of their activity was kept. An observation by the teacher has been that with Synergo, it has been much easier to go back and study the interaction and identify examples of misconceptions, and typical mistakes in strategies, as they have become explicit through the students dialogues. Using this material the teacher has worked the subsequent class and improved the activity sheet. Diagnosis is a really hard task for teachers in this context, and an aid of this nature, is considered significant both for teaching and learning (Petrou & Dimitracopoulou 2003). This has been one of the main reasons, for pursuing further the experiment in a larger number of students, and an extended set of activities, as discussed in the following section.
In this collaborative learning experiment the role of the teacher changed, compared to traditional approaches. Using a collaborative learning tool, that does not necessitate the continuous involvement of the teacher, the teachers role was transformed from teaching a class as a whole to instructing small groups, to supporting separate students and groups, from collaborating with the most capable students, to collaborating with all and better understanding their capabilities and weaknesses. A request was expressed for an on-line monitoring facility that would enhance this feature of the Synergo environment.
Teaching using a collaborative environment, changed drastically the structure of the lesson. Both the roles of the teacher and students changed, as students had more active involvement and collaboration. The possibility of involvement with these virtual environments where students meet without disturbing the whole class, the shift of focus from the private to the share activity space, seemed to thrill the students. It was interesting also to observe that the interaction was focused in the activity and they did not sidetrack to social or off-task matters.

Study of tutoring activity during collaborative problem solving

Based on the findings of this study, a follow-up study was conducted in order to focus of the tutoring activity during collaboration. The students' activity was compared to a reference dyad involving the teacher and a student. A model of analysis of collaborative interaction was defined, according to which, the text messages and the actions of the team members were classified, so that interesting patterns of interaction, like those shown in fig. 4, emerged. The actions and messages were annotated as follows:

1. Collaboration-related actions and messages (lines 1 and 11, shown as ◆ in figure 5)
2. Problem solving actions (lines 5, 15, shown as ✱)
3. Actions implying tutoring activity related to the problem:
    a. Questions (lines 3, 13, shown as ▲)
    b. Justified proposals (lines 2, 14, shown as ■)
    c. Proposals without justification (lines 4, 14, shown as ✕)

We have compared the patterns of interaction of the teacher-student with typical student dyads. As seen in fig. 5b, uring the collaboration between the *Teacher* and a *Student* there was a lot of tutoring activity especially in the first half of the session, while in the student-student dyad, shown in fig. 5a, the tutoring activity was limited. So the student-student dyad was less collaborative. This indicates that the tutoring role of the teacher has been maintained in the Synergo environment. This was also the case with the paper & pencil groups, as discussed in the previous section, since groups sho used the paper & pencil approach also sought intervention of the tutor throughout the activity. In the Synergo environment the requests for support by the tutor were decreased in the as the activity progressed, while peer tutoring activity was rare in the student dyads, as the group members were quite symmetrical and no students attempted to play tutoring roles.

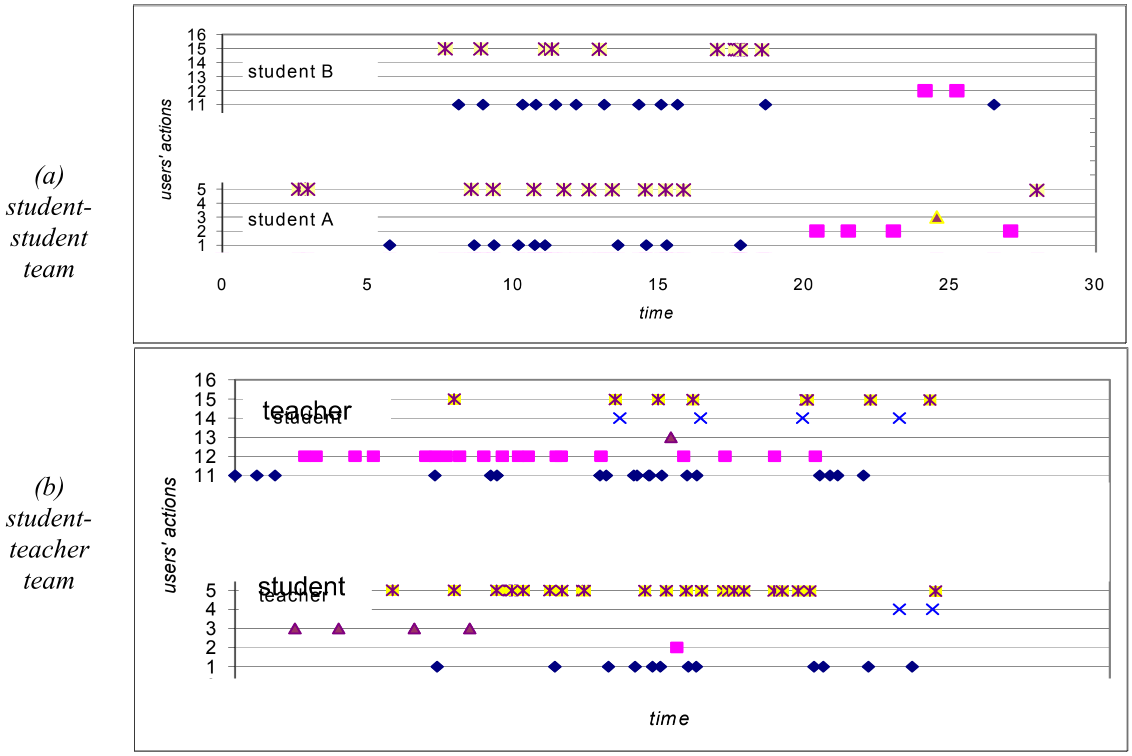

Figure 4. Actions and messages in: (a) Student-Student and (b) Student-Teacher dyads

Conclusions

The experiment of algorithms teaching using the collaborative learning environment *Synergo* has helped us reach some interesting conclusions in relation to the effectiveness of this approach.
First, the students of this particular school, despite their lack of background computer experience and of previous experience with synchronous collaboration technology, seemed to adapt to this way of interaction and communication and participated in the experiment. The innovative nature of the technology used did not seem to influence their problem solving activity.
The time allocated for the activity was limited to that of a typical class session (approximately 45 min), within which they were introduced in the concept of flowcharts and were introduced to the Synergo tool and the rules of using it for the specific activity. Despite the limited amount of time, the performance of the Synergo group compared to that of the reference group, was very similar, considering that the teacher intervention was less intense.
The problem solving strategy of the Synergo teams was the result of negotiation of the partners. The leading role seemed to remain with one of the team members for most of the cases, while for groups of three, the less involved partner seemed to drift out of focus of the activity as the time passed. Therefore, a conclusion seems to be that group size of two is most suitable for this kind of approach. Another conclusion related to the roles of the students. It seems that all group members should be given certain responsibilities, to support the problem solving procedure in a more symmetrical way (Begona, 2001).
In addition, the chat tool that was used within Synergo, seemed a very effective way of interaction. Despite the limited expressiveness compared to face-to-face collaboration, the textual interaction necessitates externalization in a more formal way the partners' views which results to deeper reasoning and meaning making, thus it is hoped that can lead to improved learning.
Finally the off-line diagnostic capabilities of the Synergo environment seemed to be a very useful feature that the teaching staff found particularly useful for reflection on the didactic strategy and improvement of the

activity sheet. This capability was suggested to become more interactive and be used as a monitoring and diagnostic tool by the teacher during the class session in future versions of the Synergo tool, in order for the teachers to be able to receive an immediate feedback on the process.

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