DEMONSTRATING, GUIDING, AND ANALYZING PROCESSES IN DYNAMIC GEOMETRY SYSTEMS

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Process-oriented mathematics education focuses on learning processes rather than on their outcomes only. These processes should be monitored, guided and supported by the teacher. In addition, feedback should be given on the students' activities, not only on their results. Groups of 30 (school) up to more than 600 (university) learners render it impossible to support processes without appropriate technology. This paper describes the tool CleverPHL that allows for designing process-oriented learning scenarios: processes can be recorded, replayed, completed, guided, and analyzed. These features are demonstrated with dynamic geometry systems (DGS).

PROCESS-ORIENTED MATHEMATICS EDUCATION

Process-oriented mathematics education focuses on processes in addition to mathematical content. For example, the NCTM standards consist of content standards as well as process standards including *problem solving*, *reasoning*, and *communicating* (NCTM, 2000). Students should not only acquire mathematical knowledge. They should also learn how to create and use this knowledge; they should learn to *think mathematically* (cf. the *teaching thinking* approach; Costa, 2001; Bowkett, 2006; Brady, 2008). Besides these thinking skills, students have to learn genuinely mathematical skills like *calculating*, *reducing fractions*, and *constructing geometric figures*. When computers are used in the classroom, students also have to learn how to use the tools like spreadsheet calculators and dynamic geometry systems (DGS) in order to solve mathematical problems.

In process-oriented mathematics education, processes should be focused in instruction. That means that the teacher must demonstrate processes, he should support the processes of the students with scaffolds, and he should give feedback not only on the products (e.g. the solutions) but also on the way they were produced. Having 30 students in a class at school or even about 600 students in a lecture at university, supporting and monitoring the processes of all students individually cannot be accomplished without computer support. In this article, the tool CleverPHL is described which allows for demonstrating, observing, completing, guiding, and analyzing processes in computer-based mathematical tools like DGS. First, the basic principles of the tool are explained. Afterwards, its features are exemplified with the use of DGS in mathematics classes.

CLEVERPHL

CleverPHL is a capture & replay tool for applications written in the programming language Java (Schroeder & Spannagel, 2006). It allows for recording actions in any Java-based application, for example in a DGS, which will serve as an example in the following. Every mouse motion or click and every keyboard action is recorded and stored in a log file (called *recording*). When a recording is replayed, the DGS is started from scratch, and all recorded actions are replayed in real-time in the DGS. That means that the DGS will end up in the same state as when the recording was stopped when the replay has been finished. Then the DGS can be used again by the replaying user, and he or she can continue work on whatever the recording user did. It is also possible to stop the replay in the middle to start over from an intermediate result.

Thus, the replay is like a hybrid of a screen video and a macro: Processes can be watched in real-time or other speeds, but they are executed directly within the DGS and create real objects instead of pure images. Similar solutions have been possible only with special extensions of individual software (cf. Kortenkamp (2005) for a description of the CINErella extension to Cinderella that offers the same functionality), but CleverPHL offers this for any Java-based application and consequently is a much more general solution.

DEMONSTRATING PROCESSES

Not every student needs an introduction of the usage of DGS. Thus, demonstrations should only be given to novices or to students who explicitly ask for an introduction. With CleverPHL the teacher can record and store demonstrations of processes in DGS and hand the recordings over to the students who can choose to watch the recording if they want to.

For example, the teacher can record how the circumcircle of a given triangle is constructed in a DGS involving the construction of perpendicular bisectors, intersections, and circles. In addition, he may add an audio comment where he explains his strategies in order to communicate expert thinking. Thus, the recording can serve as *process-oriented worked example* (van Gog, Paas, & van Merriënboer, 2004, 2008). These examples focus on the expression of expert problem solving strategies and heuristics. Students can watch the demonstrations and listen to the audio comment. Afterwards, they can try to transfer the demonstrated strategies on similar problems. Because of the hybrid approach described above, they are also free to take over at any time if they feel confident enough.

COMPLETING PROCESSES

It is also due to the fact that actions are replayed directly in the DGS (and not as video), that a teacher can create a demonstration showing only the beginning of a solution process. For example, he can demonstrate the initial steps of the construction of the circumcircle. After the student watched this demonstration, he or she can directly proceed with the construction without the need to redo all actions seen in the demonstration. Thus, CleverPHL recordings may serve as *process-oriented completion problems*. Completion problems only show an incomplete solution to be completed by the learner (Sweller, van Merriënboer, & Paas, 1998). Given process-oriented completion problems as CleverPHL recordings, students can choose to "let the teacher do the beginning", or to try it on themselves. Offering demonstrations and incomplete demonstrations enables learners to decide how much help they need (*help on demand*; cf. Bescherer & Spannagel, in press).

GUIDING PROCESSES

CleverPHL offers means to create an environment in the DGS in order to guide the processes of the students. For example, a teacher can disable or hide buttons and menu items to reduce the complexity of the interface (*training wheels interface*; cf. Carroll & Carrithers, 1984), even if the software itself does not provide configuration preferences. Thus, students are not distracted by features unnecessary in the current problem context. In addition, the teacher can draw directly on top of the user interface of the DGS. For example, he can use a drawn arrow to point to a button that should be used, and he may comment on the current task by writing text directly on the interface. Disabling features and drawings on the interface may serve as scaffolds especially for novices.

GIVING FEEDBACK ON PROCESSES

An important point in a process-oriented approach to mathematics learning is that the teacher monitors the processes of the students. In addition, he or she should give informative feedback on the processes. For example, he or she should tell the students which parts of the solution processes should be improved by which means. Obviously, the teacher cannot observe all processes of the students. Using a computer however it is possible to analyze the processes and to give individual feedback.

Another problem is that for a given task there usually exist several solution processes. Thus, the computer-based analysis tool should be able to detect both standard solutions and standard mistakes and give feedback on them. Whenever the solution is exceptional, it should be forwarded to the teacher for assessment and personal feedback. This kind of computer-supported feedback is called semi-automated assessment (Bescherer, Kortenkamp, Müller, & Spannagel, in press).

Not only the teacher, but also students can record their own solution processes with CleverPHL. Afterwards, CleverPHL can analyze the recording and group successive actions together in order to build actions on a higher level (which again may be part of higher-order actions themselves, and so on). Thus, the list of actions is transformed into a hierarchy of actions on different levels. For example, a list of mouse actions can be categorized as "circle constructed" which may be a part of an action called "perpendicular bisector constructed" and so on. For this analysis, the general tool CleverPHL needs information that is only known by the specialized tool DGS (e.g.

the Euclidean coordinates of constructed points). Therefore, CleverPHL offers means to record "semantic events" which are created by the hosted application, the DGS. In addition, one can add detection algorithms for higher-order actions that are specific for a DGS.

DGS-specific detection algorithms have been implemented exemplarily for the DGS Cinderella (Richter-Gebert & Kortenkamp, 2006). Standard action sequences which are used to construct a perpendicular bisector for two given points can be automatically detected anywhere in a recording. But if a student solves the task of creating a perpendicular bisector in an extraordinary way, which is not detected by CleverPHL, the recording can be forwarded to the teacher for assessment and feedback. Furthermore, these extraordinary solutions are good candidates for worthwhile classroom demonstrations and discussions.

CONCLUSION AND FUTURE WORK

CleverPHL is a capture & replay tool which offers means to support process-oriented mathematics education. Solution processes can be demonstrated by teachers and completed by students. Processes can be guided by reducing the number of features or by drawing and writing on the interface. Furthermore, analysis features of CleverPHL allow for the implemention of semi-automated assessment.

For a manual review of CleverPHL recordings it is desirable to be able not only to fast-forward or stop constructions, but also to rewind them. This is much more difficult than rewinding a video stream, even if it is stored with a progressive encoding, because the reversal of actions particularly in a software like a DGS is semantically unclear.

Especially the semi-automated assessment features are currently researched in the project SAiL-M, funded by the German Federal Ministry of Education and Research. In this project, semi-automated assessment tools are used in introductory mathematics courses with about 100 students in order to give feedback on the students' processes.

For educational research, it would be desirable to be able to record not only an audio, but a video stream synchronously with the users' actions. This video could capture the students' gestures and expression.

CleverPHL is part of the Java capture & replay toolkit *Jacareto* and can be downloaded from http://jacareto.sourceforge.net.

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