EARLI SIG 20
COMPUTER-SUPPORTED INQUIRY LEARNING

Theme: Promoting Science Through Inquiry

CONFERENCE SUMMARIES
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The creation, modification and evaluation of models are core ingredients of a scientific world view (Louca & Zacharia, 2011). Trying to grasp phenomena by modeling them and then investigating those models through reasoning and simulation is an important way of building scientific knowledge. Representations are the mediating link between mental models of the learners and real world systems. Consequently, an effective representation for modeling is one in which the properties of phenomena and their relationships are made explicit and visible for learners. In the current paper we explore the benefits of drawing for modeling, in order to support learners in expressing their models and engaging in a realistic cycle of representing, executing and evaluating models. We present systems for collaborative drawing in a pre-modeling stage, for domain specific drawing-based modeling and a system in which the drawing “talks back” when the learner specifies drawing elements, their properties and relations.

As drawing facilitates idea sharing, disambiguation of conceptual understanding, and assists students in attaining a shared focus (Ainsworth, Prain, & Tytler, 2011), there is benefit in creating collaborative drawing environments. To fully benefit from collaborative drawing, it is important that students engage in task-focused (Anjewierden, Gijlers, Kolloffel, Saab, & de Hoog, 2011) and elaborated meaning making activities. Two possible means of supporting the drawing and collaborative processes were investigated (Gijlers, van Dijk, & Weinberger, 2011): awareness support and scripting. In the first case the learners were prompted on missing elements in their drawings, in the second, the script made learners create individual drawings first, to serve as input for a joint drawing. Study findings indicate that students in the scripted condition perform significantly better on the concept recognition test and drawing quality than their peers in the control group.

With GearSketch (Leenaars, van Joolingen, Gijlers, & Bollen, 2012) young learners can explore the domain of gears and chains by creating simulations. As such simulations require precision drawings, learners are assisted by converting circles to gears as well as automatic snapping of gears and shrinking of chains. GearSketch has an internal representation of gears and chains to compute turning speeds and directions of gears and chains. GearSketch offers learners integrated instructions, questions to answer and puzzles to solve. These offer students guidance in their exploration of the gears domain. Puzzle selection is done based on a Bayesian learner model. In a study with 78 fifth grade students, the effectiveness of a version of GearSketch with simulation-based support was compared to a version without this support. These results show that simulation-based support in a digital drawing environment can lead to higher learning gains.

As a third approach to be presented here, the tool SimSketch aims at turning a learner’s informal, external representation into a formal model and let the “drawing talk back”: Learners are confronted with the consequences of their ideas and can revise the drawing and the underlying model when the outcome is not what they expect. In these situations, learners will iteratively sharpen their ideas and gain deeper rooted knowledge about the domain they study. In SimSketch, the learner is implicitly guided by the feedback and results of their externalized mental model in the form of a working, executable model. In this approach, we try to bridge the gap between informal, sketch-based representations and formal, executable models. To this purpose, SimSketch provides an interface to create simple drawings and add labels to elements in the drawing, thus superimposing an “operational semantics” and making it “executable”. Learners can draw strokes, use different colours, delete strokes, group strokes together and move these groups to externalize their mental models of a phenomenon. In addition to traditional drawing tools, learners can place “stickers” on their drawing, each representing a behavioural primitive, such as movements, reproduction,
avoidance and pursuance, removal of other objects etc.
The model that has been created by combining the learner’s drawing and the behavioural annotations can be executed and simulated. SimSketch is targeted at learners in primary and secondary education and is suitable for numerous domains and educational subjects, since the behavioural primitives are highly generic and applicable to various phenomena, such as the movement of celestial bodies, predator-prey systems, swarming behaviour, traffic systems and many more.

Technically, SimSketch is a multi-agent simulation system based on qualitative model specifications. Its strength lies in the easy combination of behaviours that can be specified in a simple manner by dragging stickers over model elements. The fact that the drawing itself becomes the platform of animation provides an intimate relation between model specification and evaluation supporting a natural represent-run-revise cycle.

The presented tools are available on http://modeldrawing.eu.
The Virtual Performance Assessment Project, also known as VPA, is a research project at the Harvard Graduate School of Education (vpa.gse.harvard.edu). In this project, we are studying the feasibility of using Virtual Performance Assessments to measure middle grade students’ science inquiry skills and practices (US grades 7-8). Such process-oriented skills are difficult to measure with multiple-choice and open-response tests. Specifically, we are interested in students’ ability to investigate a problem, gather data, and then build a claim using evidence.

The virtual performance assessments are designed in the Unity game development engine (http://unity3d.com). The immersive nature of the three-dimensional (3D) environment allows for the creation and measurement of contextualized performances. Students take on the identify of an avatar (see images below) and have the ability to walk around the environment, make observations, gather data, and solve a scientific problem in a context. In one assessment, students have to investigate why a frog has 6 legs. In a second, they have to investigate why the bees are disappearing.

Students work individually on the assessments. They access the assessments via a web browser and work through the problem in 45 minutes or less. On the back-end, we capture students’ actions and use them to build arguments for what students know and understand about building claims and using data as evidence. The goal of the research is to provide the field with working examples of reliable and valid technology-based performance assessments linked to frameworks and standards for science content and inquiry processes. This research is funded by the Institute of Education Sciences and the Bill & Melinda Gates Foundation.
Janice Gobert

Learning with scientific simulations: Affordances for performance assessment and adaptive intelligent tutoring of scientific inquiry skills

(Abstract)

Our computer-based learning and assessment environment, Science Assistments (http://www.scienceassistments.org), for Physics, Life Science, and Earth Science supports middle school students’ scientific process skills, namely, generating hypotheses, designing and conducting experiments, data interpretation, warranting claims with data, and communicating findings. Leveraging from the logging functionality of our infrastructure and our inquiry tools, we apply educational data mining and knowledge engineering algorithms to analyze students’ log files in real time in order to provide assessment reports to teachers on students’ inquiry skills, as well as to provide adaptive intelligent tutoring to students via our pedagogical agent, Rex. By reacting to students’ inquiry learning in real time, we hypothesize that students’ science process skills are positively impacted. I will present data from several classroom studies and discuss the specific affordances of technology-based microworlds for both performance assessment of inquiry skills as well as intelligent tutoring of scientific inquiry in real time.
We present our computer-based learning environment, Science Assistments (http://www.scienceassistments.org; NSF-DRL # 0733286, # # 1008649; NSF-DGE #0742503; U.S. Dept of Ed. # R305A090170, #R305A120778), for Physics, Life Science, and Earth Science that assesses and scaffolds middle school students’ scientific process skills, namely, hypothesis-generation, design of experiments, data collection, data interpretation, and warranting claims with evidence. In our project we have developed 25+ microworlds, an assessment reporting system, and a suite of inquiry tools to support students’ inquiry in terms of the five skills mentioned above. Together, the logging functionality and the inquiry tools provide the basis for automated web based assessment and adaptive scaffolding of students’ inquiry in real time on the basis of knowledge-engineering and educational data mining (EDM). Our infrastructure is flexible, easy to deploy, and can be implemented in, but not limited to, existing course management systems such as Assistments and Moodle. By reacting to students’ inquiry strategies in real time, we hypothesize that it will be possible to positively affect both students’ science process skills, shown by more goal directed inquiry and more systematic experimentation, measured through log files of detailed student actions, system evaluations of student actions based on EDM and knowledge engineering rules, as well as students’ content learning, as measured by pre-post test gains. We are testing our adaptive scaffolding in a series of randomized controlled studies in our partner schools; the demographics of these students represent a wide range of SES and ethnic backgrounds, and thus, our data should generalize well. Goal outcomes include empirical data regarding the efficacy of our system at improving students’ science learning, namely, inquiry skills and content learning, across several dependent measures in each content domain.
Engagement is critical to learning. Two key factors hypothesized to drive differences in disengagement are affect (Craig et al., 2004) and attributes, i.e., goals, attitudes, and beliefs. There are findings about the relationships between affect and engagement, between student attributes and engagement, and between student attributes and affect; however, there is little data about how these three inter-relate, the focus of the current study. We conceptualize disengagement behaviorally by identifying “engaged” and “disengaged” behaviors using student actions, including off-task behavior, i.e., engaging in an unrelated activity; gaming the system, i.e., misusing learning software to succeed; and on-task conversation, i.e., seeking or providing help to peers.

Participants conducted authentic scientific inquiry with physical science microworlds (Gobert et al., accepted) to determine if a particular independent variable affects various outcome variables. Participants were 389 students, 10-14 years old, from 17 sixth-eighth grade classes from 4 different public middle school districts in Central Massachusetts.

We measured:
- Student Attributes (11 variables measured by Likert-scale surveys): learning goal orientation, performance-approach goal orientation, performance-avoidance goal orientation, academic efficacy, avoiding novelty, disruptive behavior, self-presentation of low achievement, skepticism about relevance of school for future success, grit, work-avoidance, and self-efficacy for self-regulated learning.
- Engaged and Disengaged Behaviors (4 variables measured by quantitative field observations, cf. Baker et al., 2010): on task, on-task conversation, off-task, and gaming the system.
- Affective States (4 variables measured by quantitative field observations, cf. Baker et al., 2010): confusion, engaged concentration, boredom, frustration.

The 104 inter-correlations were calculated using Spearman’s rho, ρ. We corrected for multiple comparisons using the post-hoc False Discovery Rate (FDR) method (Benjamini & Hochberg, 1995); significance was tested based on the resultant q-values.

We found statistically significant relationships between semi-stable student attributes, affective states, and engagement/disengagement, in particular between the categories of affect and engagement, including positive correlations between boredom and on-task conversation, between confusion and on-task, and between frustration and gaming the system.

Of the student attributes, disruptive behavior, grit, and self-efficacy are correlated with more than one engagement variable. The positive relationship between disruptive behavior and on-task conversation is surprising, and may reflect a focus on social relationships for the student. Curiously, neither grit nor self-efficacy is correlated with on-task. Each of these three student attributes is correlated with on-task conversation and off-task, either both positively or negatively.

Of the affective states, only frustration and boredom were found to be correlated with student attributes. Both frustration and boredom were found to decrease as grit or self-efficacy increases, as was previously shown in traditional learning settings (e.g., Compeau & Higgins, 1995; Duda & Nichols, 1992).

Another interesting finding was yielded between goal orientation and engagement. Past studies not conducted with educational software have found strong relationships here, whereas past studies with educational software have failed to find such relationships (cf. Rowe et al., 2009). Here, we
again fail to find relationships, suggesting that educational software changes the relationship between goal orientation and engagement relative to traditional curricula.

In summary, our data suggests that in the context of computer-based science inquiry, there is a complex set of inter-relationships between student attributes, affective states during learning, and engagement or disengagement with the learning system; and that these are different from such relationships during classroom activities. Continuing this study, we plan to apply temporal analysis to explore how engagement and affect change during the learning task, and how they change for students with different attributes. By understanding these relationships, we may be able to design learning environments that can leverage data about attributes, affect, engagement and disengagement.

References
a) Research question
Our research examined whether metacognitive scaffolding in invention activities improves students’ learning of domain-level and inquiry skills. We hypothesize that faded levels of scaffolding will have no effect on domain-level learning (that is, with conceptual or procedural test items) compared to unguided invention activities, but will improve students’ deeper reasoning abilities as measured through transfer tasks.

b) Methods and techniques
This study examined the effect of metacognitive scaffolding during invention activities. An invention activity is an inquiry-based learning activity where students are asked to invent a solution to a problem before being taught the expert solution. Typically, this involved using contrasting cases to create a mathematical model to describe a feature of the data, such as the quality of straight-line fits to data, as in Figure 1. Students also apply their general formula to each of the contrasting cases to obtain a quantitative index for each case. Invention activities take about thirty minutes, and are followed by a traditional lesson on the expert solution by the course instructor at the front of the classroom. It has been found that the combination of invention activities followed by direct instruction leads to better learning and improved performance on transfer problems, compared to direct instruction alone (Roll, et al., 2009; Schwartz & Martin, 2004). A first-year physics lab course, with 128 students, used invention activities in order to teach various data analysis tools such as least-squares fitting. Students would then work on a physics experiment and use the expert solution as part of their final data analysis. These three activities (invention activity followed by direct instruction and practice) make up the Invention as Preparation for Future Learning framework (Schwartz & Martin, 2004).

Five invention activities were provided over a four-month period to students in two conditions: without scaffolding and with scaffolding-levels fading across the five tasks. Details of the scaffolding and methods of delivery are described in section c. Assessments included a pre- and post-statistics test. Conceptual and procedural items aimed to evaluate basic understanding of the domain-level knowledge, and evaluation items required deep understanding of how the concepts fit with the technical features of the equations. It was hypothesized that stronger use of inquiry skills, rather than domain-knowledge, would improve performance on the evaluation items. In particular, these items presented variations on the formulas used in the study with deliberate flaws that connected to conceptual features of the domain. Students were asked to identify whether the formulas were valid for the specific domain and to justify their choice. Performance on the Concise Data Processing Assessment (Day & Bonn, 2011) was used as a covariate in between-group analyses to control for background knowledge.

c) Data sources, evidence, or materials
All invention activities were delivered using the Invention Support Environment (ISE; Holmes, 2011), a computer-based system designed specifically for invention activities. The ISE was developed using Cognitive Tutor Authoring Tools (CTAT; Aleven, et al., 2009), a development environment for creating computer-based learning systems. CTAT provides opportunities for adaptive feedback, interactive behaviours, and loggable actions.

The ISE was designed to guide students through the key stages of the invention process as defined by Roll, et al. (2012). The key stages of scaffolding were task definition, analysis of data, planning and design of inventions, application of the inventions to the data provided and interpretation of the
results, and evaluation of the invented solution. Most of the scaffolding stages involved prompted self-explanations, while the analysis and implementation stages also included rankings of the data sets based on the index they’re being asked to invent. The group without scaffolding received a version of the ISE that only had explicit prompts to invent a formula using the equation editor and to implement the results. No self-explanation or ranking prompts were provided. The second condition received scaffolding on all invention stages for the first two invention activities, received similar scaffolding with several self-explanation prompts removed for the next two activities, and then received the final activity with the lowest level of scaffolding received by the first condition throughout the study.

d) Results
Students overall demonstrated significant gains of about 11% on performance on the statistics test: Pre-test M = 2.15, SD = 1.14; Post-test M = 2.71, SD = 0.90, t(249) = 4.45, p < .001. In addition, performance on the evaluation items demonstrated that the guided invention group (M = 0.66, SD = 0.69) outperformed the unguided invention group (M = 0.45, SD = 0.61), F(1, 126) = 5.42, p = 0.021. This signifies that, while invention activities help students learn domain knowledge, scaffolding invention activities helps students acquire deeper understanding of the mathematical representations associated with the conceptual features.

In fact, the individual evaluation questions where students in the Faded-Guidance condition outperformed the Control condition were the only items that corresponded to invention activities where they received high levels of scaffolding. This suggests that high-level scaffolding must be present for students to extract deeper understanding of the domain.

e) Scientific or scholarly significance of the study or work and limitations
This research provides insight into how invention activities lead to better learning, and shows that guiding students through the inquiry process via metacognitive prompts can further increase student learning, especially of inquiry behaviours and deeper reasoning skills. The online system constructed acts as an accessible and transferable resource for introducing invention activities in a variety of classrooms, independent of the instructor’s experience with such activities.

References


Simulations are considered promising tools to help students learn science by (guided) inquiry; simulations provide the students with an idealized model of a real-world phenomenon or entity and allow them to investigate that model by setting up virtual experiments and controlling parameters.

An important design consideration for the development of pedagogical computer simulations for inquiry learning is determining how concrete simulation elements should be made, as the physical fidelity of a simulation can greatly affect what the students learn from the simulation and how well they can utilize that knowledge. Physical fidelity of a simulation may vary on a continuum from highly concrete, detailed, and realistic representations to simplified and formalised abstract illustrations. A simulation with perceptually concrete elements is easier to understand, but at the same time it can make it more difficult for students to generalize the findings and apply them beyond the original context. The objective of a more abstract simulation is to highlight the generalizability of representations and findings at the expense of realistic and contextual details; the cost here is it becomes more difficult to understand. Goldstone and Son (2005), for instance, report a study where undergraduate students learned about the principles of competitive specialization in a context where the perceptual concreteness of simulation elements was varied: The elements either remained concrete throughout the experimentation, remained abstract, or switched midway from concrete to abstract (concreteness fading) or vice versa (concreteness introduction). The outcome of the experiment was that transfer was better when the appearance of the elements switched (independent of the direction of the switch) and the best transfer was observed when the elements were faded from concrete to abstract and the worst for constantly concrete elements.

This paper describes two studies that attempted to replicate the findings of Goldstone and Son in a different domain and with children from different age group as the benefits of including perceptually abstract elements in a simulation might be less obvious and pronounced in the elementary school context than in the college context. The studies investigated how the perceptual concreteness of simulation elements affect students’ learning outcomes and transfer in elementary school context in the domain of electricity using the two extreme conditions from the original study, concrete and concreteness fading.

**STUDY I**
In study I students constructed and studied electrical circuits in two simulation-based inquiry learning environments.

In the concrete condition (N = 26) simulation elements remained perceptually concrete throughout the experimentation; students were instructed to construct circuits with bulbs, observe changes in bulb brightness, and measure the potential difference across bulbs.

In the fading condition (N = 26) simulation elements switched from concrete to abstract during the experimentation; the students were instructed to construct circuits with bulbs in the very beginning of the experimentation (/intervention), but after that they were instructed to construct circuits with resistors, and measure the potential difference across resistors.

Thus, the main difference between the conditions was that in the concrete condition the students received both quantitative (voltage across bulbs) and qualitative (brightness of bulbs) feedback for their actions whereas in the fading condition they received only quantitative feedback (voltage...
across resistors; though the students used bulbs in the beginning, they were never in the position to observe changes in bulb brightness, because the introductory circuits consisted of single bulb circuits.

The participants of the study were 52 5th and 6th grade students (11- to 12-years-old). Student allocation to learning conditions was based on matching; set of two students were matched on domain pre-test scores, with one student from each pair allocated randomly to one of the conditions. The students had 90 minutes to construct and study a fixed amount of electrical circuits in the above simulation learning environments. In order to measure and compare how the perceptual concreteness of simulation elements affected students’ conceptual understanding of circuits, a subject knowledge assessment questionnaire was administered before and after the experimentation.

The results of Study I showed learning from pre-test to post-test in both conditions (p < .001), but the size of the effect was considerably larger in the concrete condition (d = 1.31) than in the fading condition (d = 0.66). Concrete condition outperformed the fading condition in the post-test, F (1, 49) = 4.42, p = .04, g = .57. It appears that the abstract elements made the inquiry process more difficult: only 30.7% of the students in the fading condition were able to construct all circuits during 90 minutes, whereas in the concrete condition 84.6% of students were able to construct all circuits, ¹² (1, N = 52), 15.44, p < .001. Moreover, detailed analysis shows that the learners in the fading condition seem to have difficulty connecting their learning to bulb related test items, F (1, 50) = 3.92, p = .031, g = .54.

STUDY II
The results of Study I were conflicting with the positive outcomes for the fading condition of Goldstone & Son with indications that the students lost the connection to bulbs in the fading condition. Therefore in Study II it was decided to give students in the fading condition an opportunity to observe changes in bulb brightness; the switch from bulbs to resistors was slightly delayed compared to Study I with the idea that this change would help students to maintain the connection to bulbs after switching to resistors. The participants were 125 4th, 5th, and 6th grade students, and they were matched to the conditions just like in Study I.

The results of Study II show that the apparently small change in the fading condition (N = 62) that allowed students to observe changes in bulb brightness in one circuit had a considerable impact on students’ learning and transfer. Compared to Study I, the learning effect was notably larger, p < .001, d = 1.01. Furthermore, no differences were found between conditions in learning outcomes, F (1, 122) = .308, p = .58, g = .10. As 88.7% of the students in the fading condition were able construct all circuits during 90 minutes, it can be further argued that the opportunity to observe changes in bulb brightness seems to have made the inquiry process significantly easier compared to Study I, ¹² (1, N = 88), 30.23, p < .001.

DISCUSSION
The results of the two studies show that inclusion of perceptually abstract items in a simulation environment is not a simple design principle, but a sensitive process that might vary across domains and age groups. Even though from Study I to Study II the results from the fading condition improved considerably, we were not able to reproduce Goldstone and Son’s findings, as fading did not seem to provide notable benefits compared to the use of concrete elements throughout the whole inquiry process. Detailed analysis of the post-test results will reveal whether the two learning environments have different affordances towards particular aspects of the domain.
Online search competence is an important component of scientific literacy. However, searching and finding credible, impartial and scientifically acceptable information on the Web to form well-grounded positions in science debates is a challenging task (Lazonder, 2005). Gerjets, Kammerer and Werner (2011) describe a successful search process to consist of five steps: (1) Realizing an information need and setting a search goal, (2) choosing a search engine and selecting key words, (3) scanning and evaluating the results page, (4) scanning and evaluating a selected website, and (5) comparing and integrating of information found on different websites. At each step, quality criteria need to be applied to arrive at a high-quality search result. For example, during step 4, searchers need to consider the source of the presented information to make informed judgments concerning whether to trust the information or not.

One promising approach to foster high school students’ online search skills is (web-based) inquiry learning. Yet, inquiry learning typically needs to be scaffolded (de Jong, 2006). When implemented in authentic classroom settings, two types of scaffolds can be distinguished: (a) scaffolds on the classroom level (e.g., classroom scripts that distribute learning activities over the social planes of the classroom, such as plenary level, small group level, individual level; see Dillenbourg & Jermann, 2007) and (b) scaffolds on the small-group level (e.g., small-group collaboration scripts that specify, sequence and distribute learning activities and roles among the members of a small group; Kollar, Fischer & Hesse, 2006).

Research questions and hypotheses
We examined the effects of a small-group collaboration script (present vs. not present) and two classroom scripts (group level classroom script, i.e. all online search activities to be conducted in dyads vs. plenary-plus-group level classroom script, i.e. online search activities alternately modeled in front of the class and performed in dyads) and their different combinations in a web-based inquiry unit on the acquisition of online search competence. We expected the combination of small-group collaboration script and the plenary-plus-group level classroom script to lead to the highest competence levels.

Methods
174 9th graders participated in the study, which was conducted within their regular Biology lessons. Students worked on a web-based inquiry curriculum unit to develop a well-grounded opinion about whether Genetic Engineering should be allowed or not. The learning phase spanned seven regular Biology lessons and included three online search activities. We implemented a quasi-experimental 2x2-factorial design with the independent factors “small-group collaboration script” (present vs. not present) and “type of classroom script” (group level vs. plenary-plus-group level classroom script). Classes were randomly assigned to experimental conditions. Both independent variables were manipulated during the three collaborative search phases. In all groups, collaborative browsing was realized, i.e. both partners of a dyad always watched the same websites on their laptops. The small-group collaboration script distributed prompts related to the current step in the search process among the two partners, for example asking learner A to suggest a link on the hit list to follow and learner B to reflect upon the credibility of the web site. The type of classroom script systematically varied on which social levels search activities were to be conducted. In the plenary-plus-group level classroom script, single steps of the search strategy were modeled in front of the class before this activity was conducted within student dyads. In the group level classroom script, no modeling took place; instead, the students performed all online searches within dyads.
**Data sources**

Online search competence was measured by the students’ performance in an individual test that asked them to describe how they would use the Internet to form a position in a different science debate. Responses were analyzed using a coding scheme capturing adequate steps and important quality characteristics during successful online search. The agreement of two independent coders determined on a subset of the material was sufficient (ICC = .83).

**Results**

An ANCOVA with the scores in the online search skills post test as the dependent variable, the small-group collaboration script and the type of classroom script and classes nested within the four combinations of the two instructional support factors, and prior online search competence as a covariate showed a significant interaction effect (F(1,165) = 12.41; p < .01; partial $\eta^2 = .07$): Students who learned with the plenary-plus-group level classroom script, but without the small-group collaboration script reached the highest levels. Adding a small-group collaboration script to the classroom script that included plenary (i.e., modeling) phases did not further improve students’ online search competence. If, however, the group-level classroom script was employed, the small-group collaboration script had positive effects over unscripted collaboration, F(1,90) = 10.06, p < .01, partial $\eta^2 = .10$).

**Significance of the study**

The results demonstrate that online search competence as a component of scientific literacy can be fostered by inquiry learning, but that careful structuring is needed. To provide structure, learning activities should cover different social planes of the classroom. Further structuring on a small-group level may then become obsolete. Yet, small-group collaboration scripts are an effective means to foster online search competence when only small-group collaboration is realized (without plenary phases). The combination of the small-group collaboration script and the plenary-plus-group level classroom script may have produced “over-scripting” (Dillenbourg & Jermann, 2007). Process analyses are underway to test this assumption.

**References**


Combining traditional instruction and simulation-based inquiry learning in secondary vocational technical education: Effects on understanding

Introduction
Traditionally, engineering curricula about electrical circuits use direct instruction and hands-on lessons, which are effective approaches for teaching students terms and definitions, the procedural use of formulas, and the capacity to build circuits. However, students often lack conceptual understanding.

If traditional instruction stimulates the acquisition of procedural knowledge but is less suitable for fostering the acquisition of conceptual understanding, using a combination of different instructional approaches within the curriculum might provide a solution (Papadouris & Constantinou, 2009). De Jong (2006) argued that using a combination of instructional approaches can lead to the construction of better organized, multifaceted knowledge. For example, combining direct instruction for the acquisition of procedural knowledge with inquiry learning for building deep, conceptual understanding. Another advantage of such a combination might be, as some authors suggest, that the acquisition of conceptual understanding and procedural knowledge can mutually affect and support each other. This process is sometimes referred to as bootstrapping (Schauble, 1996) or iterative knowledge development (Rittle-Johnson, Siegler, & Alibali, 2001).

Learning with simulations can have a positive effect on the acquisition of conceptual knowledge in the domain of electricity and simple electrical circuits when the simulations are used as a substitute for or in combination with using real equipment (see e.g., Başer & Durmuş, 2010; Farrokhnia & Esmailpour, 2010; Finkelstein et al., 2005; Jaakkola & Nurmi, 2008; Jaakkola, Nurmi, & Lehtinen, 2010; Jaakkola, Nurmi, & Veermans, 2011; Zacharia, 2007). Not much is known about the effects of simulation-based inquiry learning in secondary vocational engineering education. Vreman-deOlde (2006) characterizes students of secondary vocational training as as do-ers, students with a visual orientation, who are mostly interested in the practical application of their knowledge. They learn by experience and have difficulty with abstract theoretical models and methods (Slaats, Lodewijks, & van der Sanden, 1999).

The main question addressed in the current study is: how can the acquisition of conceptual understanding be fostered in the context of secondary vocational technical education? It is hypothesized that adding an extra, different instructional method (i.e., simulation-based inquiry learning) to the curriculum that specifically targets the acquisition of this kind of understanding is more effective than relying on traditional instruction only.

Method
The study was an integral part of a complete electricity curriculum. Two conditions were compared to each other. In both conditions, students followed the same traditional electricity curriculum. In the traditional condition the traditional instruction was enriched with additional, computer-based practice about topics treated in the basic curriculum. The software used in the traditional condition offered summaries of lesson topics and series of exercises. After completion of each exercise, students received feedback about the correctness of their response as well as an explanation of the correct answer. In the simulation condition the traditional instruction was supplemented with simulation-based inquiry learning, also about the topics treated in the main curriculum. The software contained simulations of electrical circuits and assignments that aimed at making and testing qualitative predictions about the behavior of electrical circuits.
Two knowledge tests were used in the experiment: a prior knowledge test and a post-test. The prior knowledge test was an entrance test that contained 27 items. The post-test contained 19 items and was meant to measure the effects of instructional method on learning outcomes. The post-test contained 14 conceptual items and 5 procedural items. Since understanding will be most prominently needed in answering more complex items we included both simple and complex items in the post-test. At the end of the semester, the school provided the experimenters with the examination results the participants had obtained in the following related curricular courses: Electricity Theory, Measuring Electricity, and Workplace Practice.

The experiment was carried out in a real school setting. There were nine sessions in total, including a prior knowledge test session and a post-test session. The sessions were separated by a one-week interval.

**Results**

With regard to prior knowledge, no differences were observed between conditions. Post-test results showed that participants in the simulation condition outperformed participants in the traditional condition on conceptual understanding (Cohens d = 0.65). Principal component analysis of the scores on conceptual understanding, procedural knowledge, and the examination results of the other curricular activities showed that procedural knowledge scores and the examination results for the other curricular activities all loaded heavily on one component, indicating they are all largely co-determined. Conceptual understanding did not load at all on this component. Procedural knowledge scores and examination results for the other curricular activities did not load at all on the component upon which conceptual understanding loaded heavily. This result indicates that conceptual understanding is fundamentally different from the other knowledge and skills the students acquire in the electricity curriculum.

Participants in the simulation condition also outperformed participants in the traditional condition with regard to procedural knowledge (d = 0.76). This finding was unanticipated because all assignments in the simulation aimed at making and testing qualitative predictions about the behavior of electrical circuits; none of those assignments targeted the acquisition of procedural knowledge. It could be an indication that bootstrapping took place. Some evidence for bootstrapping was found in the domain of mathematics, but not before in engineering education (Streveler, Litzinger, Miller, & Steif, 2008).

It was also found that participants in the simulation condition scored significantly better on solving complex problems, both complex conceptual (d = 0.71) and complex procedural problems (d = 0.86). Students in the traditional condition had more difficulty when two or more principles had to be taken into account simultaneously. This could be an indication that learners in the simulation condition had better synthesized the basic electrical concepts into a coherent framework.

**Significance of the study**

The current study shows that including a simulation-based inquiry component in the traditional curriculum stimulates conceptual understanding. Although it is often assumed that simulation-based inquiry learning is too demanding for students in secondary vocational technical education, our study shows that if the inquiry component is well supported it will also work in these vocational training settings.
Subject – context – tool: Emerging connections – the role of ICT in foreign language pedagogy

Introductory comments and key concepts

Current pedagogic and socio-cultural theories emphasise the notion that human action is interactive and fundamentally connected to social and cognitive tools. Similarly, the acquisition of a foreign language, like communication per se, is an intrinsically interactive endeavor and fundamentally different to learning, which is considered non-authentic and artificial. (Bleyhl 2009; Krashen 1985, 1987, 2009).

In education, the concept of affordances (originally Gibson 1955, 1977) generally refers to the relationship between the pedagogy within a subject area (i.e. the practice of the setting), the subject domain and its culture (i.e. the ecology of the setting), and the technology (i.e. the tool) (John & Sutherland 2005). Gibson developed an interactionist view of perception and action that focused on information that is available in the environment. The nexus between ICT and affordances is fundamental to the question of how ICT as a tool can promote an interactive classroom environment and thus enhance the FL classroom. Put differently, ICT as a mediating tool has the potential to produce a “gesteigerte Fähigkeit, die handlungsauffordernden Gegebenheiten („affordances“) einer Fremdsprache zu erkennen.” (Kretzenbacher 2009, p. 88)

Collaborative inquiry learning and productive failure, two of the key themes of the SIG20 conference, take on a particular hue in foreign language pedagogy. Collaborative inquiry presents unique challenges in a target language environment, and productive failure are key concepts in a number of second language acquisition theories, dating back to Krashen’s seminal work on the distinction between mistakes and errors, which are considered productive and necessary failures for the successful acquisition of a foreign language. Against this backdrop, learning affordances may be seen as instructional interventions which are aimed at supporting learning in a learning environment. Here, an ICT-based learning interface is the prima facie intervening tool that manipulates the setting as well pedagogic practice.

Monash University’s Virtual Learning Environment

Monash University has recently developed a strong, university-wide commitment to online teaching and learning. There has been a slow but steady shift away from systems efficiency to pedagogic intent. Playing a top-down catalytic role, the university first introduced unit websites via the BlackBoard/WebCT LMS in 2001, and by 2008, WebCT Vista was used in the delivery of 6,400 units (Weaver, et al., 2008, p. 31). In 2011, the first of three waves of Moodle 2.0 implementation was rolled out to replace BlackBoard as part of the university’s Virtual Learning Environment (VLE) strategy, with an aim to provide more intuitive, mobile, and innovative learning and teaching online for both staff and students (http://vle.monash.edu/). More recently, there has been significant investment in new interactive high-teaching spaces. These new facilities encourage a more flexible style of learning and afford improved exposure to more realistic language acquisition contexts. These learning spaces have been conceived as a learning environment that directs attention to where it is needed and tries to include and emulate authentic acquisition scenarios, directing attention to the informal as well formal foreign language learning.

Methodology and Data

The presentation will utilise three sets of data, based on

1. a 2011 survey yielding 97 responses from 72 undergraduate language and linguistics students;
2. results from a qualitative survey from 30 advanced German language and linguistics students;
3. observational data from the German foreign language and linguistics classroom.
**Preliminary Results**

While the present study is still a work in progress, patterns are emerging. Quantitative survey data strongly suggests that students wish to relocate some of their interactive language learning experiences away from the face-face classroom, thus capitalising on the affordance created by emerging technologies. Initial in-class observational data indicates that the use of electronic Smartboards is not conducive to collaborative learning activities and joint foreign language text production. Subscribing to the notion that interactive discourse (written and spoken) and successful conversation is collective action, a discourse analytical framework is being employed and the analytical focus is on joint text production and discourse management.

It is anticipated that collaborative nature of these FL discourses, enabled by and observed through the prism of affordances and ICT, students’ FL communicative discursive rather than grammatical competence, will improve at a higher rate than the control group which will be exposed to identical curriculum content in a traditional classroom setting.

The hypothesis that productive failure (Krashen’s developmental interlanguage errors), can be employed as a meaningful strategy in the development of second language discourse competence is emerging as a tenable proposition. Joint text production in learner-language German, where deixis, cataphoric and anaphoric devices constitute surface realisations of collaborative inquiry in a target language environment, deliver a fertile environment for our exploration of the link between technology-enhanced foreign language learning.

A generation ago, Wenger (1990) surmised that “for technology to be used effectively in any learning process it must be highly visible as a learning tool but at the same time highly invisible as a mediating technology.” (cited in John and Sutherland, 2005, p. 408). The next step of the evolution of MFL and linguistics teaching will indeed be increasing invisibility of our LMS and the emerging its potential of ICT as a mediating environment.

**References**


Introduction
The SCY-Lab inquiry learning environment enables students to learn science content by creating and exchanging objects. The concept of having students share and use each other’s work is relatively new and denotes one of the innovative features of the SCY pedagogical approach. Previous research has shown that students use the learning objects of their peers sparingly and thoughtfully. However, their search in and evaluation of these resources could certainly benefit from additional support. To illustrate, students mainly used their peer’s learning objects to extend their own learning objects; goals related to refining, improving, and checking their own ideas against those of other students were relatively rare. The selection of peer-created learning objects often occurred at random, and their quality was mainly assessed from surface features. These judgments were very critical and had (too) far-reaching consequences: if a peer-created learning object fell short in one respect, it was disqualified altogether.

The present study continues along these lines of investigation by examining the effects of scaffolding on students’ use of learner-generated content. The study compared two groups of students who worked on an inquiry-based science project. All students had to articulate their evolving understanding of the topic of inquiry in a concept map, and could consult four peer-created concept maps on this topic. Students in the experimental condition also received a worksheet that scaffolded their search for and evaluation of the peer-created concept maps. The worksheet was designed according to cognitive models of document search. It outlined the steps in searching and using the peer-created concept maps, and provided specific directions for the steps that, according to previous research, require additional support. Students in the control condition did not receive the worksheet.

Hypotheses pertained to students’ use of the peer-created concept maps and the quality of their own concept map. Students in the experimental condition were expected to consider more peer-created concept maps, and search, evaluate, and use their contents more proficiently and thoughtfully. As a consequence, the quality of the concept maps created in the experimental condition was predicted to be higher than that in the control condition.

Method
Forty-three high school students (aged 15-17) participated in this study as part of their regular course work. Students were randomly assigned to conditions, leading to 20 students (13 boys, 7 girls) in the experimental condition and 23 students (13 boys, 10 girls) in the control condition. The students’ teachers confirmed that domestic CO2 emission, which was the topic of inquiry, had not yet been taught in the students’ science classes.

Students worked within the SCY-Lab learning environment to investigate and design a CO2-friendly house. This project spanned 20 lessons and comprised three concept mapping activities. The first concept mapping activity served to assess students’ prior knowledge of domestic CO2 emission; the second and third enabled them to adapt their concept map on the basis of the knowledge they had acquired in the project. During the second and third concept mapping activity, students could consult a set of four well-developed concept maps on domestic CO2 emission; a different set was available in each session. These peer-created concept maps were created by students who had previously participated in this science project, and selected on the basis of the number of relevant concepts and their interconnectedness.

Students in the experimental condition received a worksheet that aimed to scaffold the use of the four peer-created concept maps. The worksheet was embedded in the learning environment and supported students in (1) formulating a search goal, (2) selecting appropriate peer-created concept maps for inspection, (3) extracting relevant information from these concept maps, (4) evaluating the usefulness of the extracted information, (5) adapting their own concept map, and (6) recycling...
through these steps until the requirements of the search goal are fulfilled. Every step had a short introduction, an assignment or question, and a template to write down the answers.

**Results**

Results show that students in the experimental condition made regular and prolonged use of the worksheet during the second and third concept mapping activities. (The first concept mapping activity served to assess prior knowledge and was performed without the worksheet and peer-created concept maps). Contrary to expectations, however, students in both conditions inspected the same number of peer-created concept maps for the same amount of time. The descriptive statistics indicate that this equivalence occurred because control participants checked the peer-created concept maps rather extensively.

Analysis of students' own concept maps showed that students in both conditions had comparable levels of prior knowledge, and acquired new knowledge during the course of the project. The overall knowledge gains did not differ significantly among conditions--despite the considerably higher gain scores in the experimental condition. Analysis of the second and third concept mapping activity, when the worksheet was used, revealed that the concept maps created in the experimental condition represented a more differentiated and interconnected conceptual understanding. It thus seems that the worksheet helped students from the experimental condition to consider the contents of the peer-created concept maps in greater depth. However, correlations suggest that some students did not find the right balance between documenting and motivating their changes on the worksheet, and actually making these changes to their concept maps.

**Conclusions**

Scaffolding students' search for information in peer-created learning objects enhances their use of these resources and improves the structural quality of their own learning objects. The effectiveness of this support depends on students' ability to co-ordinate the time spent on the scaffold, the peer-created learning objects, and their own learning object. This might require some practice or additional regulatory support from the teacher or via timed prompts in the learning environment.
Characterizing the incorporation of bioinformatics into high school biotechnology curricula through a scientifically authentic learning environment

Background
Scientific practices lay at the core of inquiry-based approaches and are used to establish, extend and refine our understanding of the world [1]. Providing learners with opportunities to engage in activities that resemble authentic research requires the simultaneous coordination of practices. It can contribute to deeper and contextualized understanding of the scientific knowledge and how it is acquired and developed, and to invoke the reasoning that scientists employ and the epistemology underlying authentic inquiry [2]. Proper performance of scientific inquiry tasks requires the synthesis of different types of knowledge, such as declarative, procedural, situational and strategic knowledge [3]. A BLE that is aimed at introducing bioinformatics into a high-school biotechnology curriculum through engaging learners in scientifically authentic inquiry activities was developed [4].

Objective
To evaluate high-school students' learning outcomes and attitudes following engagement in scientifically authentic inquiry activities through a BLE, in terms of acquisition and coordination of various types of knowledge, appropriation of a bioinformatics approach, and their point of view towards the BLE.

Modes of inquiry
Bioinformatics is an elective topic in the curriculum of biotechnology majors and is taught by a BLE. The BLE invites students to take part in 5 inquiry activities using 8 bioinformatics tools. Activities were developed based on authentic investigations that are aimed at improving human life quality and expectancy. In each multistep activity, students are introduced to the rationale and goals of the research at hand, and learn how to utilize bioinformatics tools and databases, resembling the original research plan. The bioinformatics tools are introduced to the learners in a virtual "Tool-Box" that includes detailed interactive tutorials and written texts. The selected bioinformatics tools are basic yet fundamental and commonly used by scientists. The BLE includes the relevant subject matter, scaffolding and assessment means through introductory units, interactive reflections on students’ answers, scientific dictionary, and short exercises to practice skills and considerations for the use of bioinformatics tools and databases. As learners progress through each of the inquiry activities and answer the questions embedded in them, they experience authentic scientific practices and are required 1) to coordinate between the acquired procedural knowledge, declarative subject-matter knowledge, context-dependent situational knowledge, general strategy and their prior content knowledge; 2) to reason scientifically; and 3) to make decisions following the strategic plan and findings. These features are at the heart of performing authentic scientific research, yet rarely appear in most school learning materials [2].

Data sources
Each of two BLE activities was enacted by 12th grade biotechnology majors (n=44) of two different classes, instructed by their teachers. Both quantitative and qualitative methodologies were used to evaluate students' learning outcomes and attitudes. Questions embedded in the two activities were analyzed based on the following classification criteria: 1) type of question; 2) the scientific approach; 3) type of domain-knowledge [3]; and 4) the cognitive process dimension [5] required to answer each question. Similarly, students' answers to these questions were also analyzed. Pre- and post-activity questionnaires were used to evaluate students' prior knowledge, their newly acquired knowledge, their ability to apply this knowledge in a novel inquiry setting, and their appropriation of the bioinformatics approach. Semi-structured interviews with students were conducted.
Results
The questions included in the two selected BLE activities were characterized using the different classification criteria described above. Distribution of questions (Table 1) was in line with the goal of introducing students to the bioinformatics approach and the procedures of using bioinformatics tools.

Analysis of students' answers to questions embedded in the BLE revealed that the BLE activities are in line with students' abilities as the average grade for 65% of the questions was above 85 (Fig. 1A). Open-ended questions (Fig. 1B), or questions which require the use of a biological approach (Fig. 1C), or of declarative or strategic knowledge (Fig. 1D), or questions associated with the higher cognitive processes (Fig. 1E) were more challenging, as evident by lower average achievements.

Analysis of students' questionnaires revealed that students' performance in solving a research problem in a novel inquiry setting was improved following the activity (Fig. 2A). Noteworthy, while prior to the activity students have taken a biological approach to solve the research problem, following the activity most students were able to apply newly acquired knowledge and skills to solve research problems, while appropriating the bioinformatics approach, either solely or in combination with biological experimental approaches (Fig. 2B). Furthermore, students gained biological content knowledge through the activity, as their ability to define and explain biological terms in genetics was improved (Fig. 2C).

Students' attitudes towards the BLE, as evident in the questionnaires and interviews, were very positive. Students claimed to understand how bioinformatics is integrated in and contribute to biotechnological research, research subjects were found as interesting and intriguing, active learning and hands-on practice during the inquiry process "as real scientists" were appreciated, and the contribution of BLE components (tutorials, feed-back to students' answers, annotated print-screens) was highlighted. Few students faced difficulties in working with computers in general and with authentic tools in English in particular. This aspect is related to personal orientation.

Scientific significance
This work shed light on how high-school students perceive and engage in scientifically authentic inquiry activities. Engagement in such activities requires the coordination of various types of knowledge. Our approach to analyze BLE characteristics and learning processes based on the theoretical framework of classifying types of knowledge may be applicable for the analysis of other authentic educational initiatives.

Limitations
This work is based on an in-depth analysis of only 44 students from 4 different classes who enacted BLE inquiry activities. The scope of the study is now being broadened in terms of teachers, students, and BLE activities.

References
**A. BACKGROUND**

Since 2002, the PhET Interactive Simulations project has been engaged in research around effective simulation (sim) design strategies for supporting inquiry-based learning. PhET’s design philosophy is rooted in the theoretical perspectives of Piaget, that people “construct their own understanding” by actively engaging with content, and Vygotsky, that tools (e.g. sims) play an active role in mediating the learner’s engagement with the content [1,2]. Thus, we design sims to encourage and support the active process of *constructing* knowledge, an interactive exchange between the student(s) and the content, rather than *transmitting* knowledge. Further, PhET strives to design sims that support process and participation goals - science inquiry skills, student ownership of the learning process, and perceptions of science as accessible and enjoyable - in addition to content goals.

Productive inquiry learning is difficult to achieve, and researchers actively debate how the amount and type of guidance influences an inquiry-learning experience [3,4]. Pure discovery-based learning is often cited as having too little structure to be productive [3]. Researchers in education technology (e.g. [5]) have studied animations and simulations, and produced a number of design guidelines for increasing content learning (e.g. the contiguity effect). With the goal of supporting both content *and* process goals through design, the PhET project has merged perspectives of pedagogical scaffolding with intuitive interface design, resulting in an overarching design approach which we call *implicit scaffolding*. Using implicit scaffolding through sim design, students are cued through design elements, rather than explicit directions, toward productive sim exploration, enabling the desired, simultaneous support of process and content goals.

**B. RESEARCH QUESTION**

Can the use of *implicit scaffolding* in a sim allow students to engage in exploration that is simultaneously productive and student-driven – able to accomplish both process and content goals? PhET’s design approach leverages opportunities to design-in implicit scaffolding. We utilize perceived affordances and constraints – what users can and cannot do in the sim [6]. We also pay significant attention to the context used to present the topic, the choice and placement of controls, and the design of visual representations and feedback. Finally, an intuitive interface is critical for implicit scaffolding to be effective.

Here, we demonstrate the utility of implicit scaffolding using PhET’s ‘Build a Molecule’ sim (http://phet.colorado.edu/en/simulation/build-a-molecule). Learning goals include: coordinating symbolic and particulate-level representations of molecules (e.g. drawing 2NH3) and recognizing that the type, number, and connectivity of atoms determine a molecule. Examples of implicit scaffolding in ‘Build a Molecule’ include: buckets that hold atoms; ability to attach atoms together; repulsion of an atom when its addition will never form a molecule; display of molecule name only if a complete molecule; multiple representations of molecule name, formula, and particulate model; and multiple tabs to scaffold from single to multiple molecules. Each of these design elements provides scaffolding for productive use and concept development without explicit directions, maintaining the student as the driver of the learning experience. The use of molecule collection boxes provides a motivating, but optional, challenge – where achievement of the challenge (collecting specific molecules) directly ties to the learning goals.

**C. METHODS AND DATA**

We examine qualitative data collected during 8 individual interviews of middle school students, where students are asked to talk about what they are thinking and doing as they explore the sim. In these think-aloud interviews, the interviewer remains silent except for an occasional “can you tell me what you’re thinking?” if the student stops talking. We capture video and audio, and screencapture sim use.
D. RESULTS
Analysis of student actions and utterances during the interviews demonstrates that the built-in implicit scaffolding is appropriately cuing students’ actions and inferences, while supporting individualized, exploratory pathways. All students successfully built molecules, discovered that order matters, and deduced the meaning of the coefficient and subscript. Many students verbalized their own questions and deduced answers during play. Here, we detail an episode characteristic of how all the interview students interacted with the sim. This student is an 8th grade female. She had used PhET sims 1-2 times before in class, but never the ‘Build a Molecule’ sim. The student immediately begins dragging out atoms and attaching them.

Episode 1 (3:23 into play):
[Student puts together C-O.]
S1: ‘Carbon monoxide, ooh.’
[Adds a second O to the O in CO, making COO. No molecule name appears.]
S1: ‘I put that on wrong.’
[Breaks apart atoms.]
S1: ‘See they have to be a certain way.’
[Breaks apart molecule, adds O’s to the C. ‘Carbon Dioxide’ appears above molecule.]
(3:34) S1: ‘There, that’s better.’
[Drags CO2 molecule into collection box.]
In this example, the representations and feedback provided by the sim are implicitly scaffolding student’s sense-making about molecules. She expects to see the ‘carbon dioxide’ name appear. When it does not, she realizes that the way atoms are connected matters.

E. SIGNIFICANCE AND LIMITATIONS
The challenge of effective “guided-inquiry” instruction is to provide an amount and type of guidance that allows students to engage in inquiry productively, avoiding either unproductive inquiry – inquiry that is off-task or directed at scientifically unproductive ideas – or scripted behavior – a follow-the-directions response. Using sims that include implicit scaffolding allows educators to reconsider what makes for effective, external guidance – e.g. the structure of a written activity or the facilitation methods of a teacher. We posit that by leveraging the implicit scaffolding provided by a sim, educators can construct effective activities and learning experiences that are more student-centered and student-directed – fewer explicit directions, and more open-ended and discovery-oriented questions. In these implicitly-scaffolded environments, students can explore freely, following their own learning path, and not a prescribed sequence of steps.

Our classroom study with 5th graders using ‘Build a Molecule’ supports this assertion [7]. In this study, pre-post assessment of 58 students across 3 5th grade classes showed significant student learning, with shifts from lack of understanding (pre-test scores of 0-22%) to significant mastery (post-test scores of 59-78%) across questions probing students ability to translate between chemical formulas that include both coefficients and subscripts (e.g. 4Nsub2) and molecular pictures. Future research will focus on effective approaches and strategies for activity design and classroom facilitation that leverage the implicit scaffolding in sims.

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Scripting collaboration in web-based collaborative inquiry in face-to-face classroom settings

THEORETICAL FRAMEWORK
When implementing web-based inquiry projects in authentic classroom settings, face-to-face dyadic collaboration is suggested since student dyads are generally better in applying (information) problem solving strategies and yield higher learning outcomes compared to students who work individually (Lazonder, 2005). Yet, successful collaborative learning depends upon effective interaction amongst learners. The fact that students are assigned to work together in F2F-dyads on the computer doesn’t guarantee that they engage in collaborative knowledge construction and in shared regulation (Rummel & Spada, 2005; Vauras, liskala, Kajamies, Kinnunen, & Lehtinen, 2003). In this respect, this study focuses on how we can improve these collaborative processes from an instructional approach. Providing students with a collaboration script is put forth as a way to support computer-supported collaborative learning since collaboration scripts facilitate social and cognitive processes of collaborative learning by shaping the way learners interact with each other (Kobbe et al., 2007). For this study a computer-mediated collaboration script was developed based on the framework of Kobbe et al. (2007). The script particularly focuses on roles and the mechanisms of task distribution and sequencing. The script provided the students with two appropriate roles: 1) the role of ‘executor’ assigned to operate the computer and typing the answer and 2) the role of ‘web detective’ assigned to critically supervise the online search activities and foster the regulatory skills that critical information problem solving on the web entails (Brand-Gruwel, Wopereis, & Walraven, 2009).

Students were prompted through the learning platform to switch roles during the project. The main question in this study is whether integrating a collaboration script can improve the quality of collaboration and joint information processing and subsequently, if this also leads to improved individual learning outcomes.

DATA & METHODS
The effects of the integration of such a collaboration script were investigated through a quasi-experimental field study. In total 206 students from 12 different secondary school classes were involved. The intervention consisted of the implementation of a web-based collaborative inquiry project lasting 4 sessions. During the first session, secondary students completed an individual pretest and were introduced to the Web-based project. They were free to choose their partner and worked in the same dyads during the whole intervention. Finally, all students completed an individual posttest. In our analysis of students’ learning, we examined knowledge integration about the topic under investigation, and metacognitive awareness during information problem solving, which are the two targeted learning outcomes of the intervention. In the posttest students also filled out a questionnaire to self-assess the quality of their collaboration processes based on the nine dimensions of collaboration i.e. sustaining mutual understanding, dialogue management, information pooling, reaching consensus, task division, time management, technical coordination, reciprocal interaction, and individual task orientation presented (Meier et al., 2007).

Six classes were provided with a collaboration script embedded in the WISE-project (experimental condition, N = 98 students), six classes were not provided with this collaboration script (control condition, N = 108 students).

A mixed-methods approach is used in which quantitative and qualitative sources of evidence are triangulated. The quantitative part of the study focuses on the total dataset (n=206 students), the qualitative part focuses on the collaborative processes of 32 dyads from who the interaction was videotaped.

Since the students worked in pairs within classes, and as such, the problem under investigation has a clear hierarchical structure, multilevel analyses were performed to model students’ learning performance and students’ self-reported quality of their collaboration processes. Using multilevel
modeling we carefully assess the main and interaction effects of dyad’s properties alongside individual student and class characteristics (Cress, 2008). Next to this large scale quantitative analysis, a more in-depth qualitative analysis was performed to get insight in the collaborative processes. These quantitative results can give insight in how students deal with the embedded collaboration script and how this influences their learning performances and outcomes.

RESULTS
Preliminary results show that the implementation of Web-based inquiry in science education can positively affect student’s individual learning outcomes, i.e. their knowledge integration score and student’s metacognitive skills. However, implementing a collaboration script has no significant main effect on students’ group performances and their individual learning outcomes. Nevertheless, some significant effects are found regarding the self-assessed dimension of qualitative collaboration, i.e. joint information processing. The more in-depth qualitative results based on the interaction analysis of 32 dyads from the different classes revealed that although provided with the collaboration script in the experimental study, students didn’t strictly follow the script or even neglect the prompts. On the other hand, some dyads in the control condition spontaneously divide tasks by mutual agreement. We are expecting more detailed results out of ongoing analysis, both quantitative as qualitative. These results will be presented at the conference and implications for practice and further research will be discussed.

REFERENCES
Towards a shared grammar: Logging and analyzing interactions across a variety of inquiry environments

(Abstract)

Inquiry learning environments offer an exciting opportunity to study learning at finer grain-sizes and over longer periods of time than previously possible. Tracing students' learning trajectories action-by-action allows the system to adapt to individual students' characteristics (e.g., Dragon et al., 2006; Luckin & du Boulay, 1999; Manlove et al., 2007; Roll et al., 2010; Veermans et al., 2000; Weinbrenner et al., 2010) while documenting how students learn science over time (Mulder et al., 2009; Sao-Pedro et al., 2011). Yet, so far, most analysis of students' learning behaviour is done within individual systems. The data systems collect is unique to each system, and researchers operationalize their own construct in different ways. Paraphrasing a common saying, “inquiry environments are like toothbrushes: everyone has one and nobody uses anyone else’s.”

Our field lacks common formats and tools for data logging and analysis. While progress towards shared data repositories and toolboxes was made in coached problem-solving environments (i.e., PSLC DataShop; Koedinger et al., in press), to the best of our knowledge, this is not the case with inquiry environments. One reason may be the complex and rich nature of interaction in inquiry environments.

The goal of this suggested symposium is to begin conceptualizing a shared format for data collection in inquiry environments. Specifically, this participatory session will address the following questions:

a. What information do you collect about your students' learning process? (video, audio, log files, screen capture, chat transcripts, etc). Specifically, what information is included in the log files? Please show an example of a couple of actions in the system and how they appear in your logs.

b. What behaviours can you infer from this data?

c. What information are you missing, and how does it limit your ability to learn about students' learning?

d. Can you identify bits of information that are common across inquiry environments? What are the key properties of a unified format for logging? (basic information, unit of analysis, etc).

e. Should we strive to establish standards for logging from inquiry environments? If standards for logging data could be identified, how would you benefit from these sources?

Last, we will identify additional steps towards the goal of shared data across inquiry environments.
Alexander Scholvien, Daniel Bodemer
Cognitive group awareness support for collaborative discovery learning

Introduction
Current multimedia learning environments often combine dynamic features with interactive components such as the possibility of modifying input variables or manipulating certain visual elements. This combination was largely investigated in the field of individual scientific discovery learning and showed to be quite effective for flexible and self-regulated learning (De Jong & Van Joolingen, 1998). If dynamic and interactive visualisations are embedded in collaborative learning scenarios, even more potential arises: Different information, ideas or opinions can be identified and discussed to produce novel, alternative knowledge (Gijlers & De Jong, 2009). However, such scenarios imply specific collaborative challenges for the learners. In order to learn successfully, they have to interrelate complex learning material and communication, to build a common ground, and to structure the collaborative process in a goal-oriented way (Bodemer, 2011; Dillenbourg & Betancourt, 2006; Fischer, Bruhn, Gräsel, & Mandl, 2002).

A promising approach to support learners overcoming these challenges is to provide them with cognitive group awareness tools that gather and visualise knowledge-related information about their learning partners (cf. Bodemer & Dehler, 2011). Referring to the extended SDDS model (Gijlers & De Jong, 2005; cf. Van Joolingen & De Jong, 1997) such information can potentially enlarge each learner’s individual hypothesis space and domain space. Furthermore, cognitive group awareness information can help to compare hypotheses and their subjective correctness between learners.

With regard to learning with multiple external representations it showed that group awareness information can foster learning by facilitating grounding processes and by implicitly guiding learners to discuss controversial assumptions (Bodemer, 2011; Bodemer & Scholvien, 2008). Regarding simulation-based discovery learning Gijlers and De Jong (2009) developed a tool that comprised information about learning partners’ propositions in a discovery learning scenario. While this tool showed to be effective, the specific benefit of the group awareness component stays unclear, as this component was not varied in isolation.

Based on these findings of Gijlers and De Jong (2009) and Bodemer (2011) the presented study systematically examines the effect of cognitive group awareness on collaborative discovery learning processes. The following assumptions are investigated:
(1) Group awareness support enhances learning and task performance in collaborative discovery learning settings.
(2) Group awareness support facilitates detection and resolution of knowledge-related conflicts.
(3) Group awareness support leads to more meaningful communication behaviour.

Experimental Study
Two experimental conditions were compared, differing in the level of cognitive group awareness support that was provided. While learning dyads in one experimental group were provided with a hypothesis tool that contained each learner’s assumptions (group awareness support), learning partners in the other group could only see their own assumptions (cf. Figure 1).

In a preliminary phase two spatially separated learners individually generated hypotheses regarding the analysis of variance. During the following collaborative phase both learners worked in dyads and were provided with the collaboration environment: A shared application which contained an interactive ANOVA visualisation (VANOVA; Oestermeier & Barquero, 2001) and the hypothesis tool they had used earlier (cf. Figure 2). Learners could manipulate several variables within the visualisation to test different scenarios which had been depicted in the hypotheses. During this collaborative phase both learners were able to individually and independently change their previous settings and to adapt the hypotheses to their current understanding of the concepts.
Thus, four different constellations could occur (cf. Figure 3): (1) none of the learners formulated the hypothesis (OO), (2) both partners formulated an identical hypothesis (XX), (3) only one of the learners formulated the hypothesis (XO) and (4) both partners formulated the hypothesis differently (XY). Furthermore, communication was possible by using a text-based chat tool.

72 psychology students (61 females and 11 males) of the University of Tübingen, aged 19–29 years (M = 23.04, SD = 2.33), were randomly paired into 36 dyads and subsequently randomly assigned to the two experimental groups.

Results and Discussion

ANOVA showed that the experimental groups did not differ with regard to potential confounding variables like time on task or initial distribution of hypotheses. Referring to the assumptions stated above the following results arose:

(1) The first assumption was investigated by measuring individual learning in two knowledge tests which had to be performed prior and subsequent to the collaborative phase (cf. Table 1 for means and standard deviations). An ANCOVA with prior knowledge as a covariate was conducted. As expected, learners scored higher if they were provided with their learning partner’s hypotheses (F(1, 68) = 5.510, p = .022, f = 0.283).

Furthermore, task performance was determined by the number of correct final hypotheses learners had created by the end of the collaboration. The according means and standard deviations are shown in Table 2. An ANCOVA showed that more correct hypotheses were generated if there was group awareness support by displaying the partner’s hypotheses (F(1, 68) = 6.628, p = .012, f = 0.311). The number of hypotheses created prior to the collaborative phase was included as a covariate but had no measurable effect on the prediction.

(2) To identify the level of knowledge-related conflict resolution within a dyad the number of final constellations of their hypotheses was analysed. Due to low case numbers the OO- and XO-constellations were not included in the analyses (cf. Table 3). Two ANCOVAs with the number of initial constellations as covariates were performed. As assumed, learning partners solved more knowledge-related conflicts (F(1, 32) = 3.879, p = .057, f = 0.343) and showed higher agreement on their assumptions if they were supported with the group awareness component (F(1, 32) = 7.765, p = .009, f = 0.484).

(3) To preliminary investigate the effect of group awareness support on communication behaviour, chat protocols of eight contrasting cases were chosen and qualitatively analysed. The results indicate that learners with group awareness support seem to put less effort in matching their own with their partner’s assumptions, leaving more resources to discuss in a content-related way.

Overall, the results of this study revealed that cognitive group awareness support can improve discovery learning in collaborative scenarios. However, there are still several open questions regarding the potentially beneficial mechanisms underlying the effects, such as how learners use the given information for collaboratively interacting with each other and with the given simulation. For further insight into those mechanisms, interaction analyses of the whole sample are currently conducted including references to the constellations of hypotheses.

References, Figures, and Tables

For a full version of this paper including references, figures, and tables please visit the following website: http://www.uni-due.de/psychologische-forschungsmethoden/publications.php
This paper describes a pilot intervention with 13 high school students and the teacher at the end of the school year (June 2011). The students and teachers had participated in environmental science classes over the school year. Based on results from previous interventions [1] we wanted to investigate how the students could conceptualize science with different new media tools afforded by the use of the mobile devices, sensors, digital still and video cameras, and a visualization tool. The rationale behind the research has grown out of previous interventions that have focused on the implementation of mobile and visualization tools [2]. Based on our previous findings, we believe that in order to utilize these tools in everyday classrooms we also need to provide opportunities for digital skills building. The main research aim of the paper, relates to our efforts in trying to better understand how to design learning activities that introduce digital skills to the science classroom. Therefore, the main research question is:

- How can we better support students’ conceptualization of science with new media tools?

Following this line of investigation other research questions emerge:

- Do the students understand the representational potential of the different types of media tools? Are they able to understand which conceptual elements can be best represented with different types of media and external representations?
- Do group dynamics issues in collaborative activities influence the way the digital artifacts are used and the digital media objects are created?

Summarizing, considering the importance of recent developments in social media and its impact in education, we believe there is an urgent need to better understand how to support and design for the students representation and understanding of science through the use of digital media making and, especially, be able to integrate such activity as part of the inquiry process raises new design implications and challenges. The intervention consisted of 4 sessions with the students over 5 weeks in the late spring of 2011. The subject of the students’ fieldwork was local water quality. The students decided themselves on how to break into four groups leading to the creation of two groups of four students and the last group with five. The first session introduced the ecology project and the concepts behind mobile science inquiry collaboratories along with the inquiry problem for the students to investigate: “Are local bodies of water clean or polluted”? The instruments, for these learning scenarios were the mobile phones, digital cameras and different scientific sensors. The students then conducted a small classroom inquiry to determine the quality of three different water samples to get familiar with the tools and methods. In session 2, the students got a quick refresher on the instruments and then headed out to sample four local bodies of water. Each group was assigned a different location. Additionally, groups 1 and 3 used a still digital camera to capture the inquiry process and to further document the location, while groups 2 and 4 recorded video. After the fieldwork the students, teacher, and researchers had a group discussion about the water quality and the methods used to collect the data using the visualization tool.

The following week for session 3, the groups rotated to a new location and investigated the water. The groups rotated the documentary methods as well. This was again followed by a discussion that included the comparison of the different locations and the changes in water quality across temperature, pH, conductivity, and dissolved oxygen. In the final session students made scientific reports in the form of presentation with several slides that incorporated the data and the digital media. Each of the students’ presentation led to a class discussion about the different factors that influence water quality across the locations and the level of pollution in these different bodies of water.

A pre and post explorative survey focused on investigated how students can conceptualize science using different media. Additionally, we collected the students’ photographs, videos, and final presentations. We also observed the discussion between teachers and students and discussed the
The preliminary results reported in this paper concern the two surveys run. The aims of the first survey were to inquire learners about the following topics: (a) experience with the media at their disposal, (b) their understanding of the pros and cons of using the distinct media and producing meaningful learning content. In the second survey, the idea was to follow up some of the questions initially posed concerning the use of the different media. For the second survey, only seven of the initial sample fully answered the questions posed, due to end of the school year obligations for some of the graduating students.

The overall results seem to suggest that: The participants had strong confidence in making images, but no formal or informal experience in using digital tools. There seems to be a lack of digital media creation in the classroom and minor experience of creating artifacts outside of school. Furthermore, the use images or graphic charts for schoolwork could be further encouraged. This seems to lead to a lack of skills in using digital artifacts to conceptualize science. Observation and informal discussions with students, illustrate their lack of experience in doing inquiry learning and reflecting about the results in the larger context. In conclusion, providing students, teachers, and everyday classrooms with mobile science inquiry collaboratories can provide new ways to integrate science and new media skills, but require a broader understanding and different design strategies of how these technologies can provide tools that support the inquiry process beyond more efficient data collection. In relation to future work, we are planning new studies generally involving a similar research design approach but trying to tease out more explicitly the potential connections between the ways to represent the relevant knowledge and the possibilities afforded by the different media. In other words, we want to explore in more detail to what extent the students understand the representational potential of the different types of media. Furthermore, we also think that the influence of group dynamics processes can be investigated further since we need to go beyond students' perceptions of group processes to the actual processes "in the wild". There is, however, a major challenge to be overcome: we need to create a conceptual and methodological framework that will enable us to analyze the students' creations, their interactions with peers and technologies and relate all these to their knowledge understanding.

References:
Inquiry learning is a prominent learning approach in which a learner discovers scientific phenomena by engaging in a cycle of inquiry. An inquiry cycle typically starts with an orientation phase that presents the research question. Next, the learner generates hypotheses, which are then tested in an experimentation phase. The cycle ends with inferring results from experimental manipulations, resulting in conclusions and a new question. It is agreed that as students engage in scientific practices, they need to be guided throughout the process. One important feature of inquiry learning that separates this approach from others is to actively involve learners in knowledge construction by utilizing tools that are commonly used by scientists. Simulation-based learning environments allow learners to engage in scientific practices as scientists do and at the same time provide guidance to benefit from those practices. Learners can investigate variables and their causal relationships and thus discover concepts and principles that underlie these variables. Especially during the experimentation phase, learners actively manipulate variables and thus influence the process and outcome of the experiment. The level of interactivity determines the extent to which a learner controls the process and outcome of the experiment. On the one hand, research has shown that learners benefit from running experiments resulting in deeper processing and motivational gains (Xie et al., 2011). Interactivity might be very important for acquiring intuitive knowledge, because it is knowledge that is generated in dynamic contexts (Swaak & de Jong, 1996). On the other hand, there is substantial evidence that learners often do not profit from possibilities of interaction. If a learning environment offers too many possibilities of experiment manipulation, learners tend to be mentally exhausted. How can mental exhaustion be avoided? Benefitting from actively running experiments, presumes that the learner already needs to have some idea about the relationships between variables relevant to the experiment. Hence, interactivity shouldn’t take place solely during the experimentation phase. The experiment should be embedded in a cycle of active scientific practice that prepares the learner to actively relate variables to each other (Lehrer, Schauble, Petrosino, 2001). In our study, we expected that students, who were prepared before experimentation begins, benefit more from interactions than those who were not prepared. Furthermore, we expected that the level of interactivity affects learning positively with respect to intuitive knowledge.

Altogether, 118 students (age 13 to 15) from four chemistry classes from a secondary school in Münster participated in the study. The four classes were randomly assigned to one of three conditions: the interactive-preparing group (I++), the interactive-non-preparing group (I+) and the low-interactive group (I-). The teacher and pretests confirmed that chemical reactions were not part of the curriculum at that age level. Students worked with an adapted version of the project “chemical reactions” in the simulation software “Molecular-Workbench” (Xie et al., 2011). In four inquiry cycles of a 135 minute class session, students investigated bond energy, activation energy, pasteurization and catalysis. Before students were distributed to conditions, all students participated in the first cycle to acquire sufficient knowledge. Students in interactive-preparing group (I++), were prepared for experimentation by an active hypothesis phase in which they selected a hypothesis from a multiple-choice menu. In terms of interactivity, the students had the possibility to control for variables and to start, pause and restart the simulation. Students in the interactive-non-preparing condition (I+) were not prepared and were provided with the correct hypothesis. The interactivity level was the same as in I++. The low-interactive group was not prepared for experimentation. The interactivity level was low, because students had only the possibility to start, pause and restart the simulation (as in animations), but not to control for variables. We expect that students who were in the I+ group and I++ group will outperform students from the I- group. Results showed that both interactive groups, I++ and I+, outperformed the low-interactive group, I-. In other words, interactivity led to knowledge gain in terms of intuitive knowledge. Results regarding mental effort indicate that indeed students working in the interactive groups perceived it to be more mentally exhausting as students in the I- group. However, this difference did not gain statistical significance.
There was no advantage for the I++ group in comparison to I+ group. Contrary to our expectations, preparing the students before running experiments did not help them to benefit more from experimentation. In terms of motivation, students in the I+ group reported that they were significantly more motivated. Surprisingly, this motivational profit cannot be attributed to activities in the I++ group. Motivation in the I++ group was almost as low as in the I- group. It seems that the preparatory activities in the I++ group did not motivate the learners, but rather lowered motivation. In conclusion, preparing students for experimentation by engaging them in an active hypothesis phase does not prepare them better. Allowing learners to actively manipulate variables in a simulations environment has a positive effect on learning with respect to intuitive knowledge. Concerning mental effort our Results support notion of desirable difficulty (Bjork & Linn, 2006).

References
David Tobinski, Annemarie Fritz-Stratmann, Walter Hussy
Transforming a problem space: Planning behavior through inquiry learning or instruction? The digital zoo-game approach

Research question
Problem solving abilities are seen as core-competencies and nearly every school subject keeps them in focus (Klieme et al. 2005). One final goal behind problem based learning (PBL) can be seen in successful appliance of knowledge respectively epistemic practices (Hussy, 1998; Hmelo-Silver et al. 2007), which brings up error-free planning behavior and fruitful interpolation. But leading a learner to those abilities poses a major question: taking the guided or the unguided path? Following the research question of comparing learning effects from inquiry learning and instruction on problem solving abilities, a new problem solving paradigm had to be found.

Methods
Driven by the question of comparability the authors used a standardized diagnostic tool for interpolation problem solving, named as ZOO GAME. Before expanding this approach for an inquiry learning phase, it had to be converted from an analog test instrument into a computer-based assessment test (De Jong & Van Joolingen, 1998). Within the ZOO GAME approach the participant has to transform a well-defined problem from a beginning state to a goal state by using a special set of complex rules (Fritz & Hussy, 2000). Six different animals have to be transported paired in consideration of special combinations, which leads to four correct sub-goals. The traditional ZOO GAME approach, which is standardized, utilizes an instructional phase for preparing the participants for the planning phase, analogue to the TOWER-OF-HANOI paradigm (Klahr, 1985). In a second step the instructional phase has been replaced by an inquiry learning scenario. Within this minimally guided scenario the participants explore the context-facts by observing the animal behavior and use inductive reasoning for knowledge acquisition. This design of different pre-phases leads to a comparable planning phase, in which central indices measure the effectiveness and efficiency of interpolation problem solving. The score of effectiveness sums the sequence of error-free sub-goals, which spans from 0 to 4 and is named as planning span. The index of efficiency measures the time duration of the complete task under control of motor skills.

Study
Two studies have been arranged in eleven schools of North-Rhine Westphalia in due consideration of balanced social state. In the first study at three primary schools 76 female and 62 male subjects (N=138), ranging in the age from 89 to 155 month (M = 109.34, SD = 8.95), participated. The second study contains 100 female and 77 male participants in the age from 83 to 140 month (M = 106.67, SD = 8.38) at eight primary schools. The ZOO GAME approach is an individually administered test, hence it was situated in calm rooms adjacent to the regular classroom. The experimenters were three female students who interacted with all the children and teachers and supervised the technical equipment.

Results
A first view on the planning span means of the group «instruction» (M = 2.12, SD = 1.17) and the group «exploring» (M = 2.23, SD = 1.64) doesn’t tell a significant difference. But comparing the dispersions of planning span between the groups a high significant difference is given, χ2 (4, n = 138) = 26.01, p < .001 with an effect power of Eta2 = .43. Under the «exploring» condition the numbers of best planners as well as the numbers of worst planners double. A new feature of computer-based problem solving assessment is measuring time duration. The fact of a high degree of freedom in combining sub-goals leads to an immerse variance of time duration. Therefore only the correct sub-
goal sequences are comparable. There is a significant effect of guided learning on time duration after controlling for the effect of psychomotor abilities, \( F(2, 70) = 43.92, p < .001, \) partial \( \eta^2 = .57 \). While the mean is 54 seconds for interpolating the whole problem space in the instructed group, the unguided group needs 77 seconds in the middle for best results.

**Discussion**

It becomes apparent that inquiry learning leads to better results in planning behavior concerning the effectiveness, but it is also widening the division between good and bad planners. The scores of time duration point out, that good planners profit from instruction in respect to efficiency. These facts lead to the assumption that inquiry learning generates a different quality of knowledge. The underlying encoding processes of inquiry learning might be nearer to construction and lead to a reconstruction in the planning phase, which would explain the huge differences in time duration. Instruction might be nearer to elaborated rehearsal and seems to activate brilliant recalls in the planning task. The current results apply for further studies, consequently the authors actually transfer this approach to the TOWER-OF-HANOI paradigm. Transfer of learning is one of the most important topics in education, the accumulation of better planners after an exploration phase shows the potential of inquiry learning. The present studies also highlight the benefit of instruction for good participants regarding efficiency. Instruction will ever be available in well-defined problem spaces, but the question for the future will be, how to prepare students for ill-defined problems. There is only one path leading through, the unguided.

**References**


Creating models is at the heart of any scientific endeavor and therefore should have a place in science curricula. However, creating computer-based models faces resistance in early science education because of the difficulty to create the formal representations required by computational systems. In this keynote I will present SimSketch, an approach to integrate the creation of drawing into the process of inquiry and modeling. In SimSketch, drawings are used by learners to represent their ideas about phenomena they investigate. Assisted by the learner, SimSketch converts these drawings to computational models, that generate animations that behave according to the learner’s specification. Children in age ranging from 8 until 15 have used SimSketch in several domains: astronomy, traffic and biology. I will report on the results of these studies in terms of the effect on domain knowledge as well as scientific skills and attitudes.
(Abstract)

In this interactive demo, we will present two modelling and drawing applications - SimSketch & GearSketch, which exemplarily demonstrate our approaches to sketch-based learning and modelling in early (science) education. Since drawings and sketches denote are very basic and fundamental way of sharing ideas, of externalising and disambiguating mental models and conceptual understanding, they constitute a convenient tool in learning. Even more, creating and understanding drawings is a skill which is trained and used in very early education, and since drawings are free of syntactical constraints, they can be used in numerous domains and school subjects. Today, modern technology (tablet PCs, touchscreens, pen-based input devices) paved the way to go beyond the possibilities (and limitations) of pen & paper - to keep the feeling and practice but add computational components and features. The presented tools go further than simple drawing and sketching on a computer - SimSketch and GearSketch enable the learner to create drawings “that talk back”: The drawing software is able to give immediate feedback on the learner’s sketch by creating an executable model from the drawing which can be simulated - the drawing becomes “alive” and confronts the learner with the results and consequences of his externalised mental model.
An important goal of science education is to prepare learners to participate in debates about socioscientific issues. An important competence in this respect is online search competence. Computer-supported collaborative inquiry learning provides an appropriate context to foster such domain-general competences (de Jong, 2006). However, learners’ spontaneous collaboration is often suboptimal (Cohen, 1994). In prior research, computer-supported collaboration scripts have been developed to provide structure for successful collaborative inquiry learning (e.g. Kollar, Fischer & Slotta, 2007). Laboratory studies have shown that scripts can stimulate productive interaction and thereby positively affect learning outcomes (e.g. Rummel & Spada, 2005). These findings stimulated the question whether similar effects can be obtained in real-world inquiry learning settings with an extended timeframe, and whether gradually fading a script may help learners take over the regulation of their activities and thereby foster learning outcomes even further. Furthermore, we focused on the role of learners’ performance of the strategy suggested by a collaboration script for their development of online search competence.

Therefore we investigated the following research questions in a quasi-experimental field study:

1. What are the effects of continuous and faded collaboration scripts on the performance of the strategy during the learning phase?
2. What are the effects of continuous and faded collaboration scripts on the performance of the strategy during the learning phase?
3. How is the performance of the strategy related to the development of online search competence?

We predicted positive effects of continuous and faded collaboration scripts on both the performance of the strategy and on online search competence, and a positive relation between learners’ performance of the strategy to the development of online search competence.

Method
Participants and design. The sample comprised 131 students (53 girls, 78 boys; age: M = 14.7, SD = 0.75) from six ninth-grade classes from three urban high schools in three experimental conditions: No script, continuous script, and faded script.

Learning environment, task, and procedure. A seven-lesson curriculum unit about Genetic Engineering was implemented by the classes’ Biology teachers. The unit comprised three cycles about economic, ecological and health-related issues of Genetic Engineering. Each cycle consisted of three steps: background information on Genetics, online searches on the Web for arguments about the issue in face-to-face dyads, and a whole-class discussion. Each student was equipped with a laptop. During online searches, both students in a dyad always saw the same web pages on their computers. Students completed pre- and posttests.

Independent variable. In the condition without script, students did not receive any support during collaborative online search. In the condition with a continuous script, students received complementary prompts in their web browser for five (partly iterative) stages of collaborative online search. One of the learners had the role of suggesting initial arguments, search terms, hits etc., whereas the partner had the task of commenting on these suggestions. In the condition with a faded script, initially the same prompts were presented as in the condition with the continuous script, but their degree of specificity was reduced over time.

Dependent variables. Screen-audio-capturing software recorded learners’ utterances and activities on the computer. A time sample of 10 minutes from the beginning of the online-search phase of each cycle was selected for analysis. Occurrence of the activities suggested by the script for this phase was coded separately for both members of each dyad for segments of 10 seconds (Cohen’s d= .71 to .94). The proportion of segments in which one of the activities belonging to the first step of the script was
performed was used as an indicator of the performance of the strategy. Online search competence was measured in the pre- and posttests where students described how they would use the Internet to arrive at a position about a specific socioscientific issue. The occurrence of the elements of the strategy suggested by the script in the solutions was coded and counted (pretest: ICC = .51; posttest: ICC = .83).

Results
RQ1: Effects of continuous and faded scripts on performance of the strategy. A significant effect of script support on the performance of the strategy was found, F(2; 109) = 8.11; p < .01; partial $\eta^2 = .13$. Compared to unscripted collaboration, both continuous and faded script had positive effects on the performance of the strategy, continuous: F(1; 64) = 18.73; p < .01; partial $\eta^2 = .23$, faded: F(1; 79) = 9.91; p < .01; partial $\eta^2 = .11$.

RQ2: Effects of continuous and faded scripts on online search competence. A significant effect of script support on online search competence was found, F(2; 124) = 5.43; p = .01; partial $\eta^2 = .08$. Again, both continuous and faded script had positive effects compared to unscripted collaboration, continuous: F(1; 72) = 10.59; p < .01; partial $\eta^2 = .13$, faded: F(1; 92) = 7.44; p = .01; partial $\eta^2 = .08$.

RQ3: Role of performance of the strategy for online search competence. Controlling for prior online search competence and the learners’ partners’ performance of the strategy, the learners’ own performance of the strategy significantly predicted online search competence, $\eta^2 = .25$; p = .02.

Discussion
The findings indicate that both continuous and faded collaboration scripts positively affect the learners’ performance of the strategy suggested by the script and, thereby, foster online search competence. The association of the performance of the strategy with online search competence in the posttest makes it unlikely that scripts affect learning outcomes merely via exposure to and recall of either script prompts or their partners’ activities experienced before. Although faded scripts do not seem to raise online search competence more than continuous scripts do, sustained performance during fading, i.e. increasing self-regulation, may yield more robust outcomes, which should be investigated in future studies.

References
One goal of the curricular standards of the German federal states is to promote mathematical reasoning (KMK, 2003; cf. also OECD). This requires problem-solving where students practice their mathematical reasoning skills by inventing own solution approaches (e.g. Leuders, Hußmann, Barzel, & Prediger, 2011). One learning approach that promotes invention activities in the context of problem-solving is Productive Failure (PF, e.g. Kapur, 2009): Students first solve problems that require application of yet unknown concepts, followed by instruction that builds on student-generated solutions. Kapur could show that students in a PF condition learnt more than students who received Direct Instruction (DI) right away and then solved practice problems. Process data of the PF condition showed that students invented a diversity of solution approaches that displayed their prior knowledge and intuitive ideas, but they usually did not develop a canonical solution. Thus, while the problem-solving phase was mostly unguided, a subsequent instruction phase with high structure was necessary to lead students towards the canonical solution. Based on the literature on guided discovery learning (e.g. de Jong & van Joolingen 1998) one could assume that guidance during problem-solving might further increase the learning outcome. Productive Failure and guided discovery learning both put students in a self-determined learning situation. However, one has to acknowledge that the two approaches have different foci that might influence the impact of guidance: Guided discovery learning emphasizes the discovery aspect, that is, learners are supposed to reveal underlying concepts or models by running experiments (e.g. de Jong & van Joolingen 1998). In contrast, Productive Failure emphasizes the two consecutive phases with a self-determined learning situation where students struggle or fail in the first phase and instruction in the second phase (e.g. Kapur, 2009).

Another open question becomes apparent upon closer inspection of the instruction provided in the studies by Kapur (2009): In the DI condition the teacher directly presented the canonical solution, rather than building on typical student-generated solutions and intuitive ideas as in the PF condition. Thus, when comparing the two conditions, the timing of the instruction and the form of instruction has been confounded. It can be assumed that the DI condition may also benefit from building on typical intuitive ideas to meet students at their specific level of understanding (Lengnink, Prediger, & Weber, 2011).

In our quasi-experimental study, we aimed to shed light on the impact of guidance during the problem-solving phase of Productive Failure and on the impact of building instruction on typical student-generated solutions and intuitive ideas. We varied the form of instruction in two Direct Instruction conditions (a regular DI condition and a DI-S condition where instruction built on typical student-generated solutions) and the amount of guidance students received when inventing solutions in two Productive Failure conditions (a regular PF condition and a PF+ condition with cognitive guidance: students received contrasting cases to their solution approaches). The topic targeted variance concepts. Participants were 144 10th graders. We calculated a MANCOVA with the factor condition and the covariate prior knowledge. We calculated three a priori contrasts: First we compared both Productive Failure conditions to both Direct Instruction conditions. Second, we compared PF and PF+ to assess the effect of the cognitive guidance. Third, we compared DI and DI-S, that is, the different forms of instruction. Concerning procedural skills (isomorphic problem-solving) the a priori contrasts revealed only one effect with a small effect size: The Direct Instruction conditions outperformed the Productive Failure conditions (F[1, 139] = 7.02, p = .01, η² = .05). For conceptual knowledge (evaluation of functional components and cross-representational sense-making) the a priori contrasts revealed two effects with large and medium effect size: The Productive Failure conditions outperformed the Direct Instruction conditions (F[1, 139] = 26.67, p < .01, η² = .15)
and DI-S outperformed DI (F[1, 139] = 19.0, p < .01, η² = .12). There was no significant difference between PF+ and PF (F[1, 139] = 0.07, p = .79). For conceptual knowledge an a posteriori Scheffé test indicated significant differences in the pair-wise comparisons between DI and all other conditions (p < .01 for each comparison with DI), but no significant differences between DI-S, PF, and PF+.

The finding that the Direct Instruction conditions outperformed the Productive Failure conditions on items testing for procedural skills is not surprising: Students in the Direct Instruction conditions who received instruction first solved eight practice problems after instruction. In comparison, students in the Productive Failure conditions solved only one problem prior to instruction. Regarding conceptual knowledge, students in the DI condition were outperformed by students of all other conditions, while we did not find any significant differences between DI-S, PF, and PF+. In these three conditions the instruction was based on students’ prior knowledge and intuitive ideas as they are externalized in student-generated solutions. Thus, our results suggest that building on students’ prior knowledge and intuitive ideas during instruction fosters conceptual knowledge. The finding that students’ problem-solving prior to instruction enhanced conceptual knowledge equally well in both Productive Failure conditions suggests that the additional cognitive guidance in the PF+ condition is not necessary. In comparison to the literature on guided discovery learning, this finding suggests a fundamental difference in the cognitive processes underlying guided discovery learning and Productive Failure. In guided discovery learning it is inherent in the method that students discover an underlying model. Thus, guidance is beneficial for learning as it leads students to the discovery. In contrast, the effect of Productive Failure does not depend on student’s discovery of the canonical solution as already indicated by the term “Failure”. Productive Failure aims to motivate students to persist in inventing solution approaches and thereby promotes students to activate their prior knowledge and intuitive ideas. In summary, our results suggest that activating prior knowledge and intuitive ideas is beneficial for learning. This might be done by classroom discussions about typical intuitive ideas or by implementing invention activities. During invention activities cognitive guidance does not seem to be necessary as students are led to the canonical solution during subsequent instruction.

References:

An inquiry learning process, rather than following a fixed routine, is usually dynamic, ill-structured, and unpredictable. However, students should learn and use the scientific inquiry skills and take appropriate problem-solving strategies when they are engaged in inquiry. It is challenging to integrate computational metacognitive scaffolding mechanisms in an inquiry-based learning environment, which not only enables students to have freedom taking their own routines, but also helps them to monitor, plan, and evaluate inquiry activities and guides them to conduct scientific inquiry processes in a systematic way. This paper reports our research work on designing and implementing a domain-generic and lightweight process scaffolding mechanism that supports metacognition in inquiry learning with focus on reasoning about task structure/selection/scheduling.

This research was done in the context of an EU FP7 integrated project, called “Science Created by You” (SCY). We argue that such metacognitive scaffolding mechanisms are technically feasible to implement and are useful to engage students in metacognitive activities and to improve their learning efficiency through providing metacognitive scaffolding on time and on demand in a flexible, open-ended inquiry-based learning environment.

We take a prototyping method to prove concepts and to demonstrate the technical feasibility to develop a pedagogical agent, called process-oriented scaffolding agent (POSA). Most existing pedagogical agents supporting metacognition were developed by adopting a typical artificial intelligence approach that emphasizes sophisticated domain-specific expert models and special pedagogical models. Thus, these systems are not only difficult to realize with high investment of time, cost, and human effort, but also difficult to be applied in science education of other knowledge domains. We exploit mainly process modeling technologies to develop the pedagogical agent that helps student capture and manage metacognitive knowledge concerning inquiry learning and perform metacognitive activities for learning various topics. Based on theories of metacognition, we designed the core of the POSA as four components: 1) a task model that represents the knowledge about organizational structure of the tasks and task-relevant information; 2) a strategy model that represents the knowledge about appropriate activity sequences and artifact dependencies in an inquiry process; 3) a learner model that represents the knowledge about work state, learning trace, and learning plan of the student; and 4) a scaffolding model that specifies the rules to judge situations and provide metacognitive scaffolding. In addition, we designed an Agenda tool that provides a user interface for students to interact with the core of the POSA. Students with one of three levels of metacognitive skills will receive appropriate prompts and awareness information on time or on demand, and will be stimulated to monitor work progresses and to reflect on and possibly re-plan their learning processes. So far the most functions of the POSA have been implemented and integrated with SCY learning environment, called SCY-Lab. In order to have a better understanding of the POSA, we use an example, called “Healthy Pizza Mission”, to explain the implementation and usage of the POSA.

In order to evaluate the usability of the POSA, we conducted a pilot study. This empirical study has been restricted to investigate the usefulness and ease of use of the prototype on the basic functions. The study employed a cross-sectional descriptive survey with a questionnaire based on the Technology Acceptance Model (TAM) for data collection. The participants of the experiment were students of the department of computer science and applied cognitive science department at the University of Duisburg-Essen, Germany. 13 students (N=13) participated in the experiment and the participation was voluntary. They were not familiar with and even had no knowledge about SCY-Lab and POSA before the experiment. The experiment was conducted through using the “Healthy Pizza Mission”. Because of time constraints and the prototype nature of the implemented agent, we created a simplified version of the “Healthy Pizza Mission”. In the experiment, the participants were asked to perform the learning activities. They produced or revised assigned emerging learning
objects (ELOs). After an ELO was completed, he or she could open the Agenda tool to monitor his/her work state and get guidance to precede the work. The main phase ended in one and a half hour while most participants had not completed the assigned learning activities. Then participants were asked to fill out the questionnaire and all responses were valid. The empirical study showed cautiously positive results. The results reveal that most of subjects found the POSA generally useful and easy to use for supporting a flexible, open-end inquiry learning process, although few of them were not fully convinced the usefulness and ease of use of the POSA. The results also indicate that the ease of use scale shows a high level of reliability and the reliability level of the usefulness is not high, but it is still in the acceptable range. In addition, we had a discussion with feedback from the students. They overall liked the idea of the POSA. They suggested opening the Agenda tool instead of the pop-up message and highlighting the latest message. Furthermore, they confirmed that it was quite tough to learn a new environment (SCY-Lab), perform the activities and judge about the POSA. We are aware that a single experiment with a simplified version does not provide conclusive evidence. Hence, it is necessary to evaluate the functions of POSA in real learning settings. Then we can improve the approach according to the feedback from evaluations.

This research proposed an innovative approach to develop a domain-generic and lightweight metacognitive scaffolding agent by adopting process modeling technologies. By adopting this approach, the task model and strategy model of the POSA will be built through extracting relevant knowledge from the specification of a domain-specific inquiry process. The POSA will build its person model through monitoring and analyzing user’s actions and then support metacognition by using knowledge in the domain-generic scaffolding model. In comparison with typical artificial intelligent approaches to support metacognition, on the one hand, it is easy (in terms of shorter time and lower cost) to develop and modify process-oriented metacognitive scaffolding mechanisms in an inquiry learning environment. The same mechanisms can be easily applied to support process-oriented metacognition in learning different topics. On the other hand, this approach is limited in supporting metacognition within reasoning about task structure/selection/scheduling. It cannot support metacognition in depth with domain-specific knowledge.