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Understanding Climate Change Through Collaborative Versus Individual Inquiry with Constructive or Example-Based Scaffolds

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We investigated a constructive and an example-based scaffold when learning from dynamic visualizations about climate change. Learners collaboratively or individually generated a diagram that represented energy flow (constructive scaffold) or observed a peer learner generating the diagram (example-based scaffold). We hypothesized that collaborative learners would benefit more from the constructive than the example-based scaffold, but that the opposite would be the case for individual learners. Seventy-one university students were randomly allocated to conditions in the 2X2 between-subjects design. Climate change understanding was measured at pre- and posttest. Preliminary results supported our hypothesis. We conclude that the constructive scaffold elicited questions that led to deep engagement in the collaborative condition, resulting in better understanding. Individual learners possibly failed to recognize crucial concepts in the constructive condition because they had questions but nobody to discuss with. They profited more from the example-based scaffold which emphasized central concepts of climate change.

Objective

The rationale for our study is that scaffolding effects are usually investigated without considering the social mode of learning. Dependent on whether learners study individually or collaboratively, specific types of scaffolds might be more or less suited. Our aim is to determine which properties of scaffolds elicit effective learning processes in individual, and which in collaborative settings.

Theoretical and empirical background

Inquiry settings actively involve the learner in knowledge construction by engaging them in various epistemic activities such as making predictions, experimenting, evaluating evidence, explaining, revising predictions, discussing, and critiquing (Fischer et al., 2014; Linn & Eylon, 2011). Scientific models are suited to test predictions, to be evaluated, and revised (Schwarz et al., 2009). Due to technological affordances, scientific models can be implemented in inquiry settings fairly easily, as well as dynamically depict aspects of scientific phenomena that are otherwise not directly observable, allow experimentation that would not be possible in a classroom, and better represent the complexity of scientific phenomena. Thus, they show an advantage over static images in fostering coherent science understanding (McElhaney, Chang, Chiu, & Linn, 2015).

Key to inquiry learning is learner guidance (Lazonder & Harmsen, 2016). Designers of scaffolds, however, are challenged with the aptly named “assistance dilemma” (Koedinger & Aleven, 2007): The fine line between providing too much or insufficient support. To be most effective, scaffolds ought to operate at what Vygotsky (1978) called the learner’s zone of proximal development (Tabak & Kyza, 2018). If a scaffold provides too much information, a learner has no room for autonomous inquiry or improvement. If a scaffold provides too little information, a learner might be overwhelmed with the task.

Research determining effective scaffolds usually investigates scaffolding independent of the social mode of learning. As known from worked example research, involving learners in problem solving before they processed domain concepts and problem structures, often results in the use of ineffective strategies. Learners should first learn with a worked example, from which domain principles and problem structures as well as solution strategies can be inferred, before engaging in less structured activities (Renkl, 2014). In example-based learning, “the apprentice observes the master demonstrating how to do different parts of the task” (Collins, Brown, & Holum, 1991, p. 2 online version). In other words, what usually happens “within” a problem-solver is externalized for observing learners. It seems, that properties of example-based scaffolds might be more suited for individual and less for collaborative learning settings.

Collaboration is a typical and critical feature of inquiry-based learning (Linn & Eylon, 2011). The effectiveness of collaboration depends on “the extent to which groups actually engage in productive interactions” (Dillenbourg, Järvelä, & Fischer, 2009, p. 6). For this reason, collaboration scaffolds have been designed to support learners' productive interaction (Kollar, Fischer, & Slotta, 2007). These scaffolds, called collaboration scripts, are most effective when they prompt learners to build on each other's ideas (Vogel, Wecker, Kollar, & Fischer, 2017). Designing content scaffolds for collaborative settings should thus be effective, when they give learners opportunities to externalize their ideas, and build on each other's ideas. In general, properties of scaffolds for collaborative settings should promote learners to generate instead of process information.

Notably, the "generative" property of scaffolds that has been identified as ineffective for individual learning, might be the essential property in collaborative settings because it elicits questions which constitutes the basis for debating meaning, argumentation, consensus building, or other interactive activities that foster successful collaboration (Weinberger & Fischer, 2006). Building on each other's ideas or constructing ideas beyond the learning materials are at the top of the ICAP framework's hierarchy of deep cognitive involvement (Chi & Wylie, 2014), which aligns with the assumed mechanism. In individual learning however, it seems that active engagement, although lower on the ICAP's hierarchy, is essential for learners' success. Whereas individual learners might feel discouraged through constructive scaffolds and give up or skip over the understanding part, in collaboration settings understanding happens through constructing knowledge in interaction. In other words, collaborative learners would not benefit from the typical advantages of collaboration when using example-based scaffolds, as it might elicit less interaction.

Research question and hypothesis

Learners creating a model, such as drawing a diagram, externalize crucial features and how features are linked, as well as underlying mechanisms, or relations (Schauble, 2018). A diagram activity thus scaffolds learning from a dynamic visualization. In the present study learners used dynamic visualizations to understand climate change in an online inquiry unit which they either completed collaboratively or individually. We compared two different scaffolds alongside the dynamic visualization and hypothesized:

> The constructive scaffold fosters understanding climate change more effectively than the example-based scaffold when learners collaborate but the opposite is the case when learners study individually.

Method

Sample, design, and materials

German university students were recruited via advertisements to participate in the study, received a participation certificate, and were entered into a lottery to win one of eight 50€-Amazon gift cards. A priori power was calculated with G*Power version 3.1 and the target sample size for detecting a medium sized effect (lower end of medium effect size according to Cohen $f = .2$) with 80% power and a 5% alpha error probability is $N = 199$. Preliminary results reported in this paper refer to $N = 71$ participants (44 females, 26 males, 1 other) with a mean age of 25.30 years ($SD = 5.85$). Participants were randomly allocated to one of the four experimental conditions of the 2X2 between-subjects design. The two manipulated factors were scaffold (constructive vs. example-based) and study mode (collaborative vs. individual).

Participants learned about different types of energy, energy flow and transformation, how energy interacts with greenhouse gases and the ozone layer, and how this contributes to global warming in an online inquiry-learning unit with dynamic visualizations. Dynamic visualizations (NetLogo simulations) portray the entire process from solar energy entering the Earth's atmosphere, being absorbed by the Earth's surface, transforming into heat energy within the Earth's surface, being released as infrared radiation back into the Earth's atmosphere, and either exiting the Earth's atmosphere or being held back by greenhouse gases. In addition, dynamic visualizations address the role of the ozone layer, which is commonly but erroneously assumed to affect the rise of global temperatures (Andersson & Wallin, 2000).

Scaffolds and study mode

Learners in the constructive scaffold condition created an energy-flow diagram (a type of concept map). Learners begin with an empty workspace and drag and drop icons that represent the physical system (e.g., the Earth) and choose from several types of energy when linking the icons (e.g., solar energy). Linking the icons shows the energy type and flow direction. Learners receive automated guidance which prompts them to further investigate the dynamic visualization if ideas are inaccurately represented. Learners in the example-based scaffold condition observed a modeling video, in which a peer learner creates the diagram, receives guidance and revises the diagram until energy flow is accurately represented.

In the individual condition, participants did not see each other's monitor display and worked alone. In the collaboration condition, participants saw each other's monitor and collaborated throughout the learning unit.

Procedure

Participants first completed a pretest including multiple choice, open response items and a diagram (20 minutes). After a quick explanation of how to navigate in the unit, they worked in the inquiry environment for 1.5 hours. Immediately after the unit, participants completed the same test as before and an additional transfer item.

Understanding of global climate change

In this paper, we only report the outcome of the multiple choice test, consisting of 10 items with four answer options each. An example item is: "How do greenhouse gases influence global temperature?". The following answer options include the correct answer (a): a) Greenhouse gases contribute to an increase in global temperature as they absorb infrared radiation and send it back to the Earth's surface, b) Greenhouse gases contribute to an increase in global temperature as they absorb infrared radiation and send it back to the Earth's surface as heat energy, c) Greenhouse gases contribute to an increase in global temperature in a different way, d) Greenhouse gases do not interact with other types of energy and thus do not affect global temperature. All ten items were shown to participants in random order, as were the four answer options of each item. Each item included one correct answer, each correct answer was coded with 1 point resulting in a maximum of 10 points. Items were designed by a group of researchers and refined through cognitive interviews and feedback from subject matter experts. Reliability of both tests was low: $r_{tt} = .28$ (acceptable) for pre- and $r_{tt} = .60$ (acceptable) for posttest.

Statistical analysis

The alpha level was set to 5% in all analyses. Statistical software used was SPSS24. Data from the collaborative condition was considered as hierarchical as individual learners were nested in dyads. To eliminate potential effects of particular learning partners on each other, we calculated the ICC for the collaborative condition. The ICC was close to 0 and statistically not significant which indicates that units in the same dyad did not resemble each other more than they resembled units from other dyads with respect to individual scores in the multiple choice test. Using individuals as unit of analysis is appropriate in this case. We tested differences in prior knowledge between all four conditions with a two-factorial ANOVA. Results showed that there were no systematic differences in prior knowledge before the study; no statistically significant difference between the scaffold conditions $F(1, 67) = 0.02$, $p = .894$, $\eta_p^2 < .01$, between the study mode conditions $F(1, 67) = 0.2$, $p = .655$, $\eta_p^2 < .01$, and no statistically significant interaction $F(1, 67) = 0.17$, $p = .668$, $\eta_p^2 < .01$ (descriptive statistics in Table 1). It is therefore appropriate to not control for prior knowledge (Senn, 2013). Also, because the prior knowledge measure cannot be considered reliable.

Results

A 2X2 ANOVA with factor 1 scaffold (constructive vs. example-based), factor 2 study mode (collaborative vs. individual), and knowledge about climate change as dependent variable showed that neither of the two scaffolds was more effective ($F(1, 67) = 0.35$, $p = .558$, $\eta_p^2 = .01$), and neither study mode was more effective than the other ($F(1, 67) = 0.8$, $p = .374$, $\eta_p^2 = .01$). In contrast, the interaction effect of scaffold and study mode was statistically significant, $F(1, 67) = 4.22$, $p = .044$, $\eta_p^2 = .06$. Descriptive statistics (Table 1) show that collaborative learners understood more with the constructive scaffold than with the example-based scaffold but that individual learners understood more with the example-based than with the constructive scaffold.

Discussion and conclusion

Without a peer to discuss, individual learners might have resorted to weak strategies when trying to learn with the constructive scaffold. They might not have recognized crucial aspects of the dynamic visualizations by themselves. It was more beneficial to observe the modeling video (i.e., the example-based scaffold) because the demonstration of constructing a simplified model of energy flow and transformation that explicitly includes inaccurate ideas and their revision helped individual learners to recognize crucial aspects of the dynamic visualization and consequently understand domain principles (Renkl, 2014). Learners who have a peer to consult might (a) more easily master technical aspects of the modeling task (how to link icons) and (b) overcome challenging aspects by asking questions, verifying understanding, or debating meaning (Weinberger & Fischer, 2006). We assume that the constructive scaffold elicited high task engagement which reflects that learners were deeply cognitively engaged (Chi & Wylie, 2014). However, with the example-based scaffold the potential of collaboration might have been underutilized, as it elicited less questions and thus less interaction followed.

Conclusions are limited because results are based on a preliminary set of participants. Further, so far only multiple choice items were used to measure understanding of climate change and a more valid picture of learners' understanding and the effects of the scaffolds will be obtained when open items and diagrams are included in the analyses. We will follow up on the idea that the constructive scaffold elicited more interaction than the example-based in the collaborative condition by analyzing video data of collaboration sessions.

Table 1: Descriptive statistics for multiple choice test across all four conditions at pre- and posttest

	Individual				Collaboration			
	M_{pre}	SD_{pre}	M_{post}	SD_{post}	M_{pre}	SD_{pre}	M_{post}	SD_{post}
Constructive Scaffold	4.64	1.14	7.64	1.87	4.64	1.28	8.79	1.12
Example-based Scaffold	4.52	1.4	8.67	1.46	4.86	2.41	8.21	1.76

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