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Sequencing and Fading Worked Examples and Collaboration Scripts to Foster Mathematical Argumentation – Working Memory Capacity Matters for Fading

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Abstract: This study investigated the effects of the sequence of introducing two scaffolds (heuristic worked examples first vs. collaboration scripts first) and the fading of the primarily introduced scaffold (fading vs. no fading) on the acquisition of mathematical argumentations skills of university freshmen. Concerning dialectic mathematical argumentation skills, the scaffolds were most effective for learners with low working memory capacity when the collaboration script was primarily introduced, but then faded out.

Theoretical background

High-level mathematical argumentation requires knowledge and skills regarding social-discursive aspects of mathematical argumentation skills (MAS) in addition to domain-specific skills (e.g., Yackel & Cobb, 1998). Within social-discursive argumentation, two different types of activities can be distinguished, namely *dialogic activities* that are characterized by a joint conversation on the same arguments, and *dialectic activities* that comprise exchanging counterarguments (e.g., challenges to arguments) and the integration of different arguments to come to a joined solution (Wegerif, 2008).

Dialogic as well as dialectic activities are assumed to be beneficial for learning, but dialectic activities seem to be more beneficial than dialogic activities (e.g., Asterhan & Schwarz, 2009). Yet, learners rarely engage in such activities spontaneously (e.g., Sadler, 2004). Two promising scaffolds to foster social-discursive MAS are heuristic worked examples and collaboration scripts. *Heuristic worked examples* not only include solutions for particular problems in an exemplifying domain (e.g. elementary number theory), but also principles of a specific learning domain (e.g., how to formulate and prove a conjecture), and strategies to solve similar problems (Renkl, Hilbert, & Schworm, 2009). *Collaboration scripts* support learners with respect to specific discursive processes while being engaged in a collaborative task. Studies have shown that learning with collaboration scripts can foster the acquisition of argumentation skills because they can prompt learners to provide arguments, counterarguments and to integrate different arguments of learning partners (e.g., Kollar, Fischer, & Slotta, 2007).

A straightforward idea would be to provide learners with both kinds of scaffolds to foster social-discursive MAS. Yet, it is not clear which scaffold should be presented first because the temporal sequence by which scaffolds are presented may substantially influence learning outcomes (Renkl & Atkinson, 2007). It is also unclear what should be done with the primarily introduced scaffold when the second one comes into play. The demand on working memory should be reduced by the fading out of scaffolds which might also play an important role for their effectiveness (e.g., Collins & Brown, & Holum, 1991).

Research questions

RQ1: What is the effect of the sequence of the presentation of the scaffolds (heuristic worked examples first vs. collaboration scripts first), the fading of the primarily presented scaffold (fading vs. no fading) and their combination on learners' acquisition of dialogic MAS (RQ1a) and dialectic MAS (RQ1b) during collaborative learning with mathematical proof tasks?

RQ2: To what extent does working memory capacity moderate the effect of the sequence of presenting the scaffolds (heuristic worked examples first, vs. collaboration script first) and the fading of the primarily introduced scaffold (fading vs. no fading) on learners' acquisition of dialogic and dialectic MAS (RQ2)?

Method

One hundred and eight prospective mathematics students (M_{age} = 18.99, SD_{age} = 1.89); 45 female learners) were randomly assigned to one of four experimental conditions of a 2x2 factorial design with the independent variables *sequence of introducing two scaffolds* (heuristic worked examples first vs. collaboration scripts first) and *fading of the primarily introduced scaffold* (fading vs. no fading). *Dialogic* and *dialectic* MAS were measured at pre- and posttest. Dialogic activities included agreements or extensions of arguments, while dialectic activities comprised objections, counterarguments or integrations of arguments and counterarguments. Dialogic and dialectic activities were coded by two trained coders. (Cohen's κ for dialogic MAS: M = .71, range = .68-.75; Cohen's κ for dialectic MAS: M = .74, range: .67-.83). Working memory capacity was measured with the automated operation span task (Unsworth, Heitz, Schrock, & Engle, 2005).

Results

There was no significant main effect of the sequence of the scaffolds on (RQ1a) the dialogic MAS (F(1,103) = 1.81, p = .18, partial η^2 = .02) and (RQ1b) the dialectic MAS (F(1, 103) = 1.92, p = .17, partial η^2 = .02). Fading of the primarily introduced scaffold had a significant positive effect on the dialogic MAS (RQ1a), F(1, 103) = 6.63, p = .01, partial η^2 = .06, but not on the dialectic MAS (RQ1b), F(1, 103) = 0.77, p = .38, partial η^2 = .01. For learners who were at first presented with the collaboration script, the fading of the script had a significant effect on dialectic MAS dependent on working memory capacity, b = 9.32, 95% CI [5.29, 13.35], p < .001, increase in R^2 due to interaction = .23 (RQ2). Learners with low working memory capacity benefitted most from fading of the collaboration script.

Discussion

Both scaffolds may have fostered dialectic activities of MAS to a similar extent and therefore the sequence of introducing them might not have played a significant role. Because both scaffolds predominantly addressed dialectic activities, removing the primarily introduced scaffold might have reduced the amount of irrelevant information for acquiring dialogic MAS. In addition, heuristic worked examples and the collaboration script may have fostered dialogic MAS to a similar extent when they were introduced as first scaffold. Therefore, introducing the second scaffold might have been redundant with respect to dialogic MAS. When introducing heuristic worked examples and simultaneously fading the collaboration script, particularly learners with low working memory capacity may have benefitted from a reduction of the interacting elements (i.e., components of the script; e.g., Sweller, 2010) in working memory. Future studies should investigate the effectiveness of combining heuristic worked examples and collaboration scripts in other heuristic domains including learners with other levels of learning prerequisites.

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Embodied Activities as Entry Points for Science Data Literacy

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Abstract: 'InfoX' curricula focus on computer supported technology and data analysis to encourage student production of publishable science news infographics. As a primer to this, students participate in a series of embodied activities as entry points for science data literacy.

Major issues

Students of the twenty-first century are able to readily access unprecedented, and seemingly infinite amounts of data. Electronic repositories, open source information, and the ease of online search engines allow any curious person to view a vast corpus of social and scientific information almost instantaneously. This publically available data is exponentially growing and frequently available at no charge. Yet, in an age of big data and an overwhelming amount of information, young people are often inept at conceptually grasping the underlying meanings of massive numeric data sets (Hammerman, 2005). Next Generation and Twenty-First Century competencies demand that definitions of 'literacy' are expanded beyond the written text to include various forms of new media, including scientific and quantitative data sources (Livingston, Couvering, & Thoumin, 2008). This requires an education that prepares students to engage various modalities of information, different forms of representation, and interactive socio-technical systems (Yore & Hand, 2010). In response to these challenges, the "Infographic Expression"' (InfoX) project seeks to foster high school students' scientific and data literacy through the collaborative critique and construction of science based infographics. InfoX curricula are designed to engage students in scientific research, data exploration, technologically mediated communication, and ultimately the computer-supported production of knowledge artifacts by way of science news infographics.

Like many other researchers and practitioners, we observe that often students are overwhelmed by, and disinterested in, large quantitative data files. For students, and perhaps the public at large, tables, spreadsheets, formulas, and other quantitative inscriptional forms may seem cognitively inaccessible. These abstract symbols and the concepts they represent may appear disconnected from real world meaning or lived experience (Anderson, 2003). While our goal is to ultimately have students engage with a suite of online and computer supported programs that allow them to research a topic, analyze data, and communicate their findings with various representational forms; we believe that prior to introducing these technological systems, students benefit from a more grounded entry. To help ease students towards interacting with and understanding these forms of data our team has developed a series of physical activities that draw on students' real time, embodied experiences to illustrate how they may use their own bodies to represent and communicate ideas drawn from science data. Here, we showcase two data focused embodied activities that can be presented in a variety of contexts to students at the beginning of a data literacy, research methods, statistics or other STEM courses to introduce the importance of multi-modal data representations. These curricula do rely on computer supported technology and data analysis, but begin with students using their own bodies as an invitation to the discipline.

Theoretical framework

Educational scholarship has moved away from a strict cognitivist framework that holds meaning making and knowledge are processes that happen only in the head, but instead are phenomenon mediated through social interaction, practical activity, cultural norms, lived experience, and bodily engagement with the physical world (Anderson, 2003; Lakoff & Johnson, 1999). Mental representations of physical experiences are called upon as individuals attempt to understand conceptual content. As Anderson (2003) explains by example, "Chair is not a concept definable in terms of a set of objective features, but denotes a certain kind of thing for sitting"(p. 101). In this example, the concept chair is directly related to the lived experience of sitting; the idea is rooted in an embodied activity. Still, some hold that certain kinds of concepts, notably mathematics, are disembodied, totally abstract and not extended in the world (Abrahamson & Lindgren, 2014). This suggests that one cannot point to, experience, or touch complex mathematical proofs in the physical world. Yet a growing body of scholastic research on embodied cognition strongly makes the case that all knowledge, including mathematics and STEM topics more broadly, are not ground in ethereal sign systems or inscriptional forms but rather, "in the situated, spatial–dynamical, and somatic phenomenology of the person who is engaging in activity" (*ibid, p. 1).* Abrahamson and Lindgren (2014) claim conceptual understanding of *any* given content, no matter how abstract, is ground in and derives from physical engagement in the world. They explain that everyday unmediated intuitive experience must be combined with disciplinary mediated analytic reasoning to grasp complex science ideas. "In order to understand STEM content students must reconcile their unmediated perceptions and actions with the mediated structures of disciplinary practice" (p. 2-3). An essential component of STEM education and data literacy is that students can navigate between their intuitive lived experiences and a conceptual, analytic disciplinary framework. To extend the implications and practice of this conceptual approach, we are currently working to develop physical activities and protocols that draw on embodied life experiences as entry points or primers to data science and technological systems.

Methods and design

We have found that a progression of data focused initiatives involving students manipulating the physical world serves as a functional 'ice breaker' and introduction into the discipline of data science. Here, we showcase two.

Bodily Data Sorting: Physical sorting activities likely occur near the beginning of a unit. Participants may not know each other well or have had limited experience with data analysis. Participants first introduce themselves by vocally responding to series of set questions (*e.g.,* grade level, date of birth, color of their bicycle, etc.). Facilitators assign colored index cards corresponding to bins of data. For example, a student might have a green card to represent West High School and a white card to represent the color of her bicycle. Participants are then prompted to sort themselves based on a variety of conditions, using the position of their own bodies as 'data points'. One progression might ask students to first line up based on birth date (x-axis). Students might then take incremental steps forward or backwards based on their height (y-axis). Here, we note that students have created a two-dimensional graph representing birth date as a function of height and solicit any observations. The colored index cards are then introduced to provide a third and forth dimension to the human chart. Do students of certain high schools have trends related to height, bicycle color, age, etc.? This activity introduces students to ideas related to sample size, multi-dimensional data representation, correlation vs. causation, variable relationship, scale, and the effectiveness of visual representation drawing on the 'data' of their own lives.

Physical Infographics: A second embodied activity involves students creating three-dimensional physical infographics to tell a data driven science news story. Students are presented with a dense quantitative table or spreadsheet (e.g., longitudinal, demographic health trends). In small groups they are asked to examine the data, consider what kind of narrative story the information could tell, and collectively decide how they would like to physically represent this story. Students are provided with crafting materials and assorted objects and tasked to create a 3-D representation of an argument derived from their data. Through structured conversation and feedback students collaboratively discuss the process of data selection, representational forms and conventions, principles of design, and how quantitative information can support a social-scientific claim.

Significance and implications

This poster will showcase two embodied activities that are utilized as entry points into the discipline of data science and visual literacy. These physical interactions show promise at promoting conceptual reasoning. Students use the somatic experience of moving their bodies to bridge the intuitive experience toward a deeper conceptual understanding of statistics. Students create physical artifacts that serve as mediators for abstract concepts and science narratives. This work supports the notion that embodied activities may serve as entry points for conceptual, abstract, disciplined STEM practices.

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Touch | Don't Touch
Exploring the Role of Interactive Displays in Natural History Museums to Help Visitors Appreciate Objects Behind Glass

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Abstract: How can we use interactive displays in museums to help visitors appreciate authentic objects and artifacts that they can't otherwise touch or interact with? This poster shares ongoing design-based research on the use of interactive displays to help visitors learn about themes and artifacts in a cultural exhibit on Chinese history and culture.

Keywords: Interactive displays, museums, collaborative learning

A persistent question facing modern natural history museums is how to understand the role of interactive digital technology in the visitor experience. Can interactive technology be used to foster visitor curiosity and engagement around the authentic artifacts that make up museum collections? Or does it lead to a digital disconnect in which visitors focus more on screens than the objects in front of them? Can technology help enrich conversation and social interaction? Or does it lead to situations in which people are isolated from one another in galleries? Coming to grips with these questions will be critical to the continued relevance of collections-based informal science institutions.

This poster will share work from a design-based research project involving a team of university-based learning scientists and computer scientists collaborating with curators and exhibit developers from a large natural history museum. In June 2015, the museum opened a 7,500 sq/ft exhibit showcasing 350 artifacts from prehistoric times to present-day China. The exhibit is divided into five themed galleries and represents a significant addition to the museum's coverage of the world cultures. The exhibit also offers a unique opportunity for computer supported collaborative learning research as it includes over 45 interactive touchscreen displays spread throughout the exhibit (see Figure 1 for a screenshot from one of these displays). The central design tension with these displays is to harness the power and engagement of interactive digital media in a way that enhances (rather than detract from) visitor appreciation and understanding of the authentic artifacts on display.

Figure 1. An existing display sharing information about artifacts highlighting Bronze Age innovations.

Recent research suggests that digital technology can create engaging opportunities for learning in museums (e.g. Block et al., 2015; Louw & Crowley, 2013; Roberts et al., 2014). In particular, large interactive displays have become increasingly popular in museums and other public spaces. However, almost all of the extant research on interactive displays in museums has focused on the displays themselves—the display *is* the exhibit. But, this misses out on a common use case—the display is a way to help visitors appreciate the exhibit, often an authentic object or artifact that they cannot otherwise touch or interact with directly.

To help address this shortcoming, we are observing and analyzing visitor interaction and conversation at focal display cases. Our research treats the depth of visitor conversation about the objects and themes of the gallery as the primary indicator of learning (see Leinhardt, Crowley, & Knutson, 2002). To capture visitor conversations, we have set up a camera and microphone at one of the most interesting but least frequently visited display case addressing the theme of Bronze Age innovations. A sign posted near the display case informs visitors that they are being audio and video recorded for research purposes. Our discourse analysis identifies conversational features such as directing joint attention, naming or describing objects, asking questions, making inferences, and reading display labels out loud. We are also building on Loewenstein's (1994) concept of curiosity as a powerful motivator for engagement and learning. This theory suggests that by highlighting unknown but knowable ideas, we can cultivate curiosity and learner desire to seek out new information. Within this theoretical and analytic framework, we are using design-based research to explore the impact of design variations on the depth of visitor conversation.

Figure 2. Our first redesign highlights "big questions" as a way to stimulate visitor curiosity.

Our first round of designs focused on inducing curiosity by prominently highlighting *big questions* related to the themes of the display case. Figure 2 shows a screenshot from this iteration. Our analysis found that this while this redesign increased engagement along simplistic measures like holding time and capture rate, visitor conversation remained infrequent and shallow. We noticed, however, that the richest conversations tended to occur as visitors explored media content buried in sub-screens in the initial designs.

This led to our next design in which we brought this media content to the foreground and made it more interactive (Figure 3). The idea is to engage visitors with interactive content *first* and then give the opportunity to read and learn more if they are interested. This follows research on instruction design (preparation for future learning) that demonstrates the importance of letting learners explore on their own before giving them formal instruction on a topic (Schwartz et al, 2004). This poster shares findings comparing these three designs.

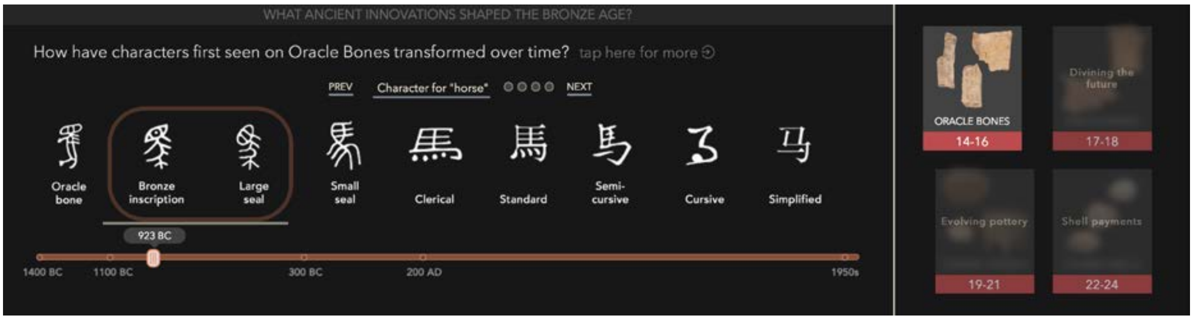

Figure 3. Our second redesign highlights interactive content first.

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