Disciplinary Task Models for Designing Classroom Orchestration: The Case of Data Visualization for Historical Inquiry

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Abstract: Incorporating data visualizations into college classrooms can enhance disciplinary learning, when accompanied by associated meaning-making practices. However, tools not specifically designed for CSCL may lack supports for collaboration and disciplinary reasoning. Therefore, it is necessary to design supports into classroom orchestration. In this paper we examine the design of such orchestration to scaffold historical reasoning with geospatial data visualizations. The orchestration of a sequence of small-group tasks scaffolded progressively more complex reasoning about historical waves of immigration, which the instructor leveraged to support students' reasoning at multiple levels in whole-class discussion. Our analyses point to these kinds of orchestrated scaffolds as a valuable direction for CSCL research and design.

In proposing productive research directions for CSCL (Ludvigsen, Cress, Law, Rosé, & Stahl, 2016; Wise & Schwarz, 2017), a number of scholars converge on broadening the purview to tools beyond the products of CSCL design research. Specifically, Reimann (in Ludvigsen et al., 2016), foresees greater attention to sophisticated representational systems used for everyday and professional goals. Ludvigsen (2016) further calls for research to identify practices for arriving at shared meanings through interactions with these representational systems, and studies that highlight when and why collaboration might be useful (Wise & Schwarz, 2017).

In this paper we explore ways to incorporate such systems and their accompanying knowledge-building practices into the post-secondary classroom. College classrooms are environments in which learners can be introduced to disciplinary inquiry for the first time. This includes being exposed to a discipline's *professional vision* (Goodwin, 1994) – being apprenticed by an instructor to see information (texts, data) through a particular lens that enables discipline-relevant insights and reasoning. This is a process that often proves challenging for college instructors (PCAST, 2012). Merely using representational tools in instruction does not guarantee that learners will see data through the eyes of the profession, especially when the tools lack support for collaboration and disciplinary meaning making (e.g., Fischer et al., 2013; Raes, Schellens, De Wever, & Vanderhoven, 2012). Incorporating these tools poses a number of design challenges: how to create coherence between existing curricula and the forms of thought introduced by the tools; how to help learners see and interpret representations through disciplinary eyes; and how to manage the complexity inherent to these tools. Meeting these challenges requires design work *around* these tools themselves.

We propose that integrating disciplinary models with *classroom orchestration* is a productive way to incorporate existing representational systems into instructional settings. We examine this in a college history education class using a data visualization tool. The study addresses the questions: How can data visualization tools be incorporated into the college classroom to support historical inquiry? How can classroom orchestration facilitate learners' ability to engage in geo-spatial reasoning for historical inquiry?

Theoretical framework

Classroom orchestration and distributed scaffolding

Research in CSCL and the Learning Sciences often argues that the meanings, purposes, and learning value of tools are mediated by the activity structures in which those tools are used. *Classroom orchestration* (Dillenbourg, Prieto, & Olsen, 2018) is a process by which teachers or other instructional designers plan, deploy and regulate multiple resources in the classroom to facilitate learning and achieve a productive workflow (Prieto, Holenko Dlab, Gutiérrez, Abdulwahed, & Balid, 2011). A central role for teachers in classroom orchestration is to assess progress and achievement, and make changes and adaptations on the fly to better align interactions with learning goals (Kaendler, Wiedmann, Rummel, & Spada, 2015). This alignment of multiple resources and interactions to support learning has been described as *distributed scaffolding* (Puntambekar & Kolodner, 2005; Tabak, 2004).

Classroom orchestration and distributed scaffolding can support learners in specific reasoning processes, such as learning to interpret data through a particular disciplinary lens, or *professional vision* (Goodwin, 1994). Members of a professional community are likely to converge on similar interpretations, while members of different communities may focus on different aspects and arrive at different meanings, even when observing the same representation (Bowen, Roth, & McGinn, 1999). Learners may be able to approach novel representational systems and derive meaning from them, but they may struggle to produce the types of explanations that typify a particular field or discipline. Therefore, a pivotal role for distributed scaffolding and orchestration is in helping learners to focus on particular attributes, and to interpret representations in particular ways, such as by teachers interpreting representations in disciplinary terms alongside learners (Tabak, 2004; Tabak & Reiser, 2008).

Moderating discussion through levels of visualization

Classroom orchestration can also involve regulating classroom discourse. Discussions around modeling or visualization tools can occur at three levels (Radinsky, Milz, Zellner, Pudlock, Witek, Hoch & Lyons, 2017). At the *interface level*, discussion centers on how to manipulate the tool and extract information and visualizations. At the *modeling level*, discussion centers on the signs, symbols, images and quantities that are represented in the tool and their relationship to the phenomena being represented. Discussions at this level can be about relationships among variables and the interpretation of patterns. At the *represented-world level*, discussion centers on the phenomena in the world that are modeled through the visualization. Discussions at the represented-world level arise from the representations, but speak in the language of the modeled phenomena rather than the images, symbols or quantities that are displayed. The goal is to push discussion beyond the interface level, to concentrate on the modeling level to ensure that new understandings are constructed, and then to the represented-world level so that the knowledge that is constructed is about the phenomena of interest. Although the instructional aim is to move from the language of representation to the language of historical phenomena, it is critical that classroom guidance regulate the connection between discussion at both levels, so that the reasoning stays anchored in data.

Data visualizations and historical reasoning

Historical reasoning involves the construction of narratives of the past that are grounded in observations from historical records (Seixas, 2017). This requires skills such as chronological reasoning, contextualizing historical data, corroborating observations across multiple sources of information, and reasoning about texts as sources (Seixas, 2017). Using a data visualization tool for historical inquiry involves more than extracting and interpreting information; it requires viewing the data as historical records of people whose experiences can be only partially and imperfectly inferred from observations of these data. Geographic information systems (GIS) are a class of visualization tools that has been part of a fundamental spatial shift in many of the social and natural sciences, but has held a more problematic place in the discipline of history. Though some historians find an ontological or epistemological mismatch between the quantified and spatialized representations of GIS and the tentative and contingent nature of historians' professional vision (Owens, 2007), there is a small but growing group of historians who embrace GIS tools because of their affordances for observing phenomena at spatial and temporal scales beyond what many traditional historical sources allow (Knowles, 2008). The present study explores a design for apprenticing students in historical reasoning that takes advantage of commonly-available GIS tools.

Using disciplinary task models to design orchestration with a "webmap"

The visualization tool used in this study, *Immigration Explorer*, is what Baker (2005) describes as "webmaps": online, public-use GIS providing access to geospatial historical data with minimal functionality for manipulating the representation, instead emphasizing ease of access and simplicity of use. This was a free resource available on a public-access URL created in 2009 by the *New York Times* for browsing historical census data for the years 1880-2000. The webmap displayed the total population of each county in each census decade; the number of people who were identified as foreign-born; and the number of foreign-born people from each of 23 countries-of-origin. The data were visualized as spheres of varying size, representing the number of county residents born in each country-of-origin. Figure 1 shows an example map of the census count of people born in Mexico living in each U. S. county in 1970, 1980 and 1990.

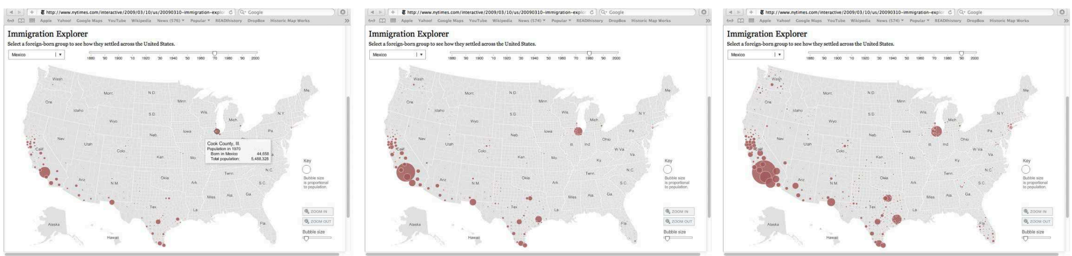

Figure 1. *Immigration Explorer* maps showing Mexican-born population by U. S. county, 1970-1990.

The design: Orchestration of sequential collaborative data interpretation activities

The simplicity and accessibility of this tool allowed for ease of integration into the classroom but required any distributed scaffolding for historical reasoning to be designed into the orchestration of the classroom activity, since no such supports were built into the tool. The design of these "wrap-around" classroom supports, to foster reasoning that is both historical and geo-spatial, is the focus of the present analysis.

Learners required considerable support in order to engage in meaningful historical inquiry while developing nascent models of multiple population patterns shifting over time. Therefore, the tacit conceptual moves involved in this reasoning process were mapped onto group activity structures to design classroom orchestration. This provided learners with a series of manageable tasks that combined to form richer, more complex interpretations of historical data. The final products of the group work could subsequently be used by the instructor in a whole class discussion to piece together, through a series of prompts, queries, and restatements, the initial building blocks of an historical account. This laid the conceptual groundwork for their subsequent interpretation of a series of historical case studies of migration (beyond the scope of the present analysis).

Five phases of activity with different group configurations guided students toward using the webmap to construct historical narratives about patterns of migration from different countries-of-origin (hereafter, CoO):

1. **Whole-class introduction of the mapping tool**: whole-class discussion showing how to use *Immigration Explorer* (interface level), introducing historical census data as a resource for historical reasoning (modeling and represented-world levels).
2. **Small-group investigation of one CoO in one region**: in groups of three, students select one CoO group and make observations of that group's changing population pattern in one region over time. For example, they might examine the changing Chinese-born population in northern California from 1880 to 1930.
3. **Same-group comparing changing patterns for the same CoO in different regions**: in the same groups of three, students compare the patterns of population change of the same CoO in one region with another region, e.g., comparing Chinese-born population patterns in northern California to the very different patterns of Chinese immigration in the Midwest, around Chicago.
4. **New "jigsaw" groups compare "waves of migration" for different CoO**: students form new groups of three that each include an "expert" on a different CoO population. In these "jigsaw" groups (Johnson & Johnson, 1982), students take turns teaching the patterns they observed for their population, and then consider similarities and differences across these CoO's patterns of migration.
5. **Whole-class sharing and discussion of group findings**: groups present their findings and with the instructor's help articulate connections and interpretations towards constructing historical narratives. Instructor scaffolds bridge from modeling level to represented-world reasoning.

At each of the small-group phases (see Figure 2) there are challenges for reasoning at all three levels (interface, modeling, and represented-world). Phase 2 allows a group to focus on only one region and one CoO as they practice with the tools, attempting to describe change over time. Phase 3 adds the challenge of doing this for two regions of the USA, but with the same CoO map. Phase 4 requires the use of three different CoO maps, and pushes them to reason about different spatio-temporal patterns for different immigrant groups, potentially over centuries.

Whole-class discussion led by the instructor (Phase 1) provides modeling of the language of careful and specific observations (e.g., "the population of people born in Mexico grew quickly in this area from 1970 to 1990"), prior to students practicing these kinds of observations in small groups (Phase 2), and prior to repeating this same skill while attending to multiple regions of the map (Phase 3). The decade slider provides support for noticing population changes without having to change maps, and both regions they are comparing are visible in the same map. Students then take responsibility for sharing those observations with a new group, and making similar comparisons across different maps displaying different CoO's (Phase 4). Finally, the instructor-mediated whole-class discussion (Phase 5) allows for a more formal sharing of the cross-group observations and comparisons, allowing communal scrutiny of their findings. This affords scaffolding, modeling, and shaping of students' language by the instructor, referring back to the worked example from Phase 1.

Though fairly straightforward as a "jigsaw" lesson, the rationale for this sequence embodies a set of propositions about learning that have value for CSCL researchers. As Vogel, Wecker, Kollar and Fischer (2017) note, "CSCL scripts are particularly effective for domain-specific learning when they prompt transactive activities (i.e., activities in which a learner's reasoning builds on the contribution of a learning partner) and when they are combined with additional content-specific scaffolding (worked examples, concept maps, etc.)" (p. 477). The phases of activity reflect the conceptual steps that a historian might take in constructing an inquiry comparing waves of migration for different populations. For a single learner, conducting these steps would be taxing. By reducing the complexity of the task within the original group (comparing patterns within a single map display) and then pooling resources by forming new comparison groupings, students are able to consider multiple, multi-level comparisons, without having to produce such complex comparisons from scratch. The whole-class, teacher-mediated sharing affords joint attention to reasoning across multiple regions, populations, and decades, modeling data not simply as numbers, but as representations of historical movements of people through space and time.

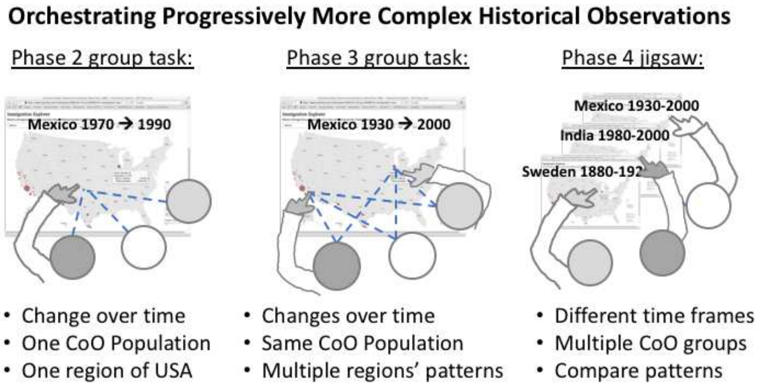

Figure 2. Orchestration "jigsaw" design constructs multiple, multi-level comparisons of historical migrations.

Methods

Participants and setting

Participants were 15 Masters students (12 female, 3 male) in a teaching licensure program. The lesson was conducted in a course taught by the first author, as an action research project, documented by a research assistant, and following IRB-approved procedures for consenting, data gathering and analysis. The course was a pre-service methods class for history and social studies teachers, and the focal lesson was part of a module on historical inquiry and migration. The larger instructional unit built conceptual understandings of migration, including specific cases of migration drawn from students' families and a variety of texts, leading to an analysis of case studies from a historical text (not described here). The focus of this lesson was on different geographic and temporal patterns of immigration to the United States.

Data collection and analysis

We report on a subset of the data collected for the larger research project: a video recording of the focal lesson (65 minutes). The classroom video was transcribed for speech and gesture by one research assistant, second-passed by another. All student names are pseudonyms. In addition, a pre-instruction reflection interview with the instructor (first author) was documented, articulating the logic of the sequence of group activities in the lesson. This was used to articulate the design rationale and intended trajectory of classroom talk.

The transcript of the final presentations and discussions was coded for descriptive and comparative discursive moves at the *interface, modeling,* and *represented-world* levels, following conventions described in (Radinsky et al, 2017), and a grounded-theory open-coding approach was used to identify the range of historical and geospatial descriptions, comparisons and explanations that emerged. This produced a set of 35 distinct codes, which are being developed into a coding scheme for ongoing analysis of project data. For the analysis presented here, qualitative descriptions of the unfolding spatial and historical observations, comparisons, and explanations were used to examine the ways the orchestration design supported instructional opportunities to scaffold disciplinary learning with the *Immigration Explorer* webmap.

Findings

Due to space limitation, we present only details from the discussions that occurred in the whole-class segment following the jigsaw activity (Phase 5). We report on interactive presentations from two jigsaw groups: Lisa, Penny and Maritza, who studied immigrations from Vietnam, Sweden and Mexico, respectively; and Tina, Nancy and Cory, who studied immigrations from Sweden, Mexico and India, respectively.

Lisa's group: Comparing quantities and rates (*modeling* level)

Lisa, Penny and Maritza presented each CoO group's pattern in order, starting with Vietnam. Lisa described how "we noticed the biggest county in 1980 was Orange County … we looked at Orange County and Chicago for comparisons." Using these two counties in different regions of the country to construct their comparison, they noticed a pattern of the Vietnamese-born population doubling: "So from 1980 to 1990 it doubled in Orange County [California] and Cook County [Illinois, where Chicago is located]. And then from 1990 to 2000 it doubled also. Umm that was pretty much all from Vietnam."

When they moved on to present the data for Sweden, Penny followed Lisa's lead at the *modeling level* in presenting data for a single county (Douglas County, Minnesota), and then constructing a rate of change for that population in that county: "we went back to 1880 and we found um, a population of over 2,000 people … And every 20, every 20 years … every 20 years it decreased." Penny moves from naming quantities to giving a qualitative description of the changing map representation as she changes the time: "1940, we only have a little over 800, um, people in Douglas County and 20 years after by 1960 its in the 300s. And the bubble just continues to disappear and I don't find it, by the time we get to 2000, I don't find it. I don't find it anymore." Lisa then connected the patterns for the two groups: "So as you're – as the Swedish population in Minnesota was decreasing by half every 20 years the Vietnamese population was doubling every 10 years. So that was a cool comparison we thought of in our group."

Maritza's presentation of the pattern for people born in Mexico picks up on a different part of Lisa's initial description: the absence of data for some decades. She narrates their inquiry process as a series of discoveries of the limitations of the data, then shifts to add their observations about Hawaii: "we looked it up in Wikipedia that Hawaii didn't become a state until 1959. So that explains why there's no data here."

Three things are notable here: (1) their construction of the task of *making observations* as reporting single-county data values (rather than qualitative descriptions of regional patterns); (2) their use of data values to construct and compare rates of population change over time (doubling each decade, halving every 20 years); and (3) the emphasis on incomplete data. The instructor engages the exploration of some of these opportunities during the presentation, grounding the conversation in the *modeling level* (comparing quantitative patterns) that the group has highlighted. For example, when Maritza says "Once again, it [the data] disappears from Texas," the instructor adds: "And from the whole South. You see that? The whole South disappears," gesturing to the map to highlight the missing data Maritza has mentioned. This move takes up Maritza's language ("disappears"), adds to the observation in a way that better reflects the scale of the pattern ("the whole South"), and invites intersubjective attention to the data ("You see that?", gesturing).

A more active engagement occurs when Lisa presents the group's "cool comparison" of rates of change (doubling versus halving). The instructor endorses their positive self-evaluation ("Very cool"), and then asks the rest of the class to re-represent that comparison of rates-of-change:

Instr: Very cool. Imagine of what ways we can visualize that, other ways we can show that change. Can anybody show that with your hands? What Lisa just said? Like if you were going to describe that change what would it look like?

Penny: [points up with one hand and down with the other]

Instr: So Penny went like this. [mimics Penny's hand motion, eliciting general laughter] What does this mean? [repeats gesture]

Edita: Increase, decrease.

Instr: Edita what are you going to show us again?

Edita: [two flat hands, raising one and lowering the other] One decreased –

Instr: Anyone got another one?

Erica: Like this? [opens one hand and closes the other, eliciting general laughter]

Instr: This is great. A way to visualize these numbers changing helps everybody.

This collaboratively-constructed sequence of re-representations of the group's reported data patterns (doubling versus halving) is explicitly endorsed as something that is "great" and "helps everybody." This presents an opportunity to reflect on multiple ways to communicate these phenomena, encouraging students to think beyond direct quantitative comparisons, in ways that support reflection on the phenomena they are modeling, and their own ability to model it in different ways.

Tina’s group: generating migration concepts (*represented-world* level)

Tina begins with a concise statement that bundles together a number of historical observations:

Tina: Our group we have Mexico, India and Sweden - Sweden. And then we said that - that Mexico has the most um, population compare to India and Sweden. And then in Sweden people actually stayed in the middle first but then um, India they come from California and New York, those port| areas first.

In contrast to the previous group, this statement foregoes a process of recounting each CoO’s data separately and avoids reading out specific numbers for individual counties. Instead, it presents summary comparisons that include multiple populations: Mexico had more population than either India or Sweden; Swedish and Indian immigrants came to different geographic areas “first” (“the middle” for Sweden, versus “those ||port|| areas” for India). This begins to bridge the modeling level with the represented-world level – using the patterns to begin to imagine the experiences of actual people in historical places. The instructor, sensing that there are multiple moves worth highlighting here, invites careful attention to Tina’s observations:

Instr: I want everyone to get what Tina is saying. I want everyone to get this. Can someone repeat what she said? [no one volunteers immediately] [to Tina] OK, will you come up please and show us? I want everyone to get it. I don't want to let her off the hook until we all understand. She is comparing patterns now and she is not just using the numbers. So listen to how she describes it. So I've got Sweden right here. You want to do this? [motioning her to come up to the projecting computer]

Tina: [coming to computer] Alright, OK. So Sweden [selects Sweden, 1880] I think in the beginning is all in the middle [circles data pattern on display with mouse] but then if we compare to India [changes menu to India] there's no data over here until 1970 [changes year to 1970]. And then they all in the coastal areas - is that how you say it? Like New York [circling northeast data pattern] and California [circling southwest data pattern] compared to uh, Sweden again [selects Sweden, changes year back to 1880].

Tina: In the middle, in the middle [circling data pattern in central Midwest]

Instr: And you said “at the beginning”

Tina: Yes

Instr: So you compare when they *start* to show up, even though that’s in different years.

Having brought Tina’s group’s complex spatial observations into the shared space of the projected display, the instructor again invites other students to re-represent it:

Instr: Can someone please restate what was the comparison that Tina made … - the immigration patterns from people from Sweden, India and Mexico. How did she compare them? …

Nate: So she compared them by uh, genesis point I guess. So when their populations first started to show up on the map, the sort of concentrations.

Instr: Can someone explain what Nate means by genesis point? He just gave us an awesome phrase that we can use. What is a genesis point for immigration? He's going to copyright it quickly so let's make sure we know. What does he mean by genesis point? Do you guys get this? If not please ask Nate to explain himself.

Beth: Like where they moved? Where they moved to? Entry point

Instr: Beth, say that again

Beth: Their entry point

Instr: Their entry point. Anyone else have another way of saying it?

Marie: The beginning of the census for uh, that specific region group um, on the map

Instr: The beginning of that census group on the map. You guys got it? Ok, so now … so you said they each had a different genesis point.

Nate: Yeah, even though that was separated by years their uh, they had starting populations in areas and then spread out from there.

Several classmates are encouraged here to develop multiple ways of describing the phenomenon Tina's group introduced. The instructor's moves push the students beyond simply describing the patterns as midwestern and coastal, which locate more within the modeling context. By emphasizing her words "at the beginning," he brings out an important concept for historical reasoning about migrations: "So you compare when they *start* to show up, even though that's in different years." This moves the discussion from the modeling level to the represented-world level by pushing the comparison toward language that is relevant to phenomena of migration, leading to the development and uptake of Nate's concept of "genesis point" for an immigrant population, which is what enables Tina's group to make a geospatial comparison of the Swedish and Indian immigration patterns, despite their being separated in time by a century. Nate explains, "even though that was separated by years … they had starting populations in areas and then spread out from there." As the class continues to examine this idea, Erica shifts to the represented world, connecting these patterns and her prior knowledge to a possible, partial explanation: "It seems like India's might be connected to hub airports because you have like Chicago, and is that Detroit?"

Discussion

The learning opportunities created in this lesson proceed from the seeding of historical and spatial reasoning practices embedded in the progression of small-group activities. Like any CSCL design, the space of learning opportunities is mediated by the real-time decisions of the teacher, but the design of the learning environment provides distributed scaffolds and other resources that shape opportunities for disciplinary learning.

Scaffolding multi-level disciplinary reasoning in group activity structures

All groups were able to bring back to the whole-class discussion descriptions of different CoO groups' changing population patterns. As the analysis demonstrates, there were notable differences between the two focal groups' representational practices in their presentations. Lisa's group remained mostly at the *modeling* level of reporting numbers and comparing quantitative changes for individual counties – valuable visualization practices that were taken up by the instructor and used to scaffold multiple representational moves in the classroom. Tina's group's comparisons of data patterns moved from the *modeling* level to the *represented-world*, enabling the instructor to engage the class in generating concepts for comparing regional migration patterns, even at different points in time.

Neither of these learning opportunities would have been likely in a lesson using this kind of webmap without the progression of distributed scaffolds orchestrated in the lesson. Although not all groups were able to provide descriptions that could be readily used to construct a historical narrative, enough groups were able to do so in order to provide the instructor with fodder to demonstrate how to use their observations in taking this next step. The instructor drew on the building blocks generated by the jigsaw groups to reposition their observations from discussions at the modeling level to discussions at the represented-world level. The progression from group presentations to the seeds of historical narratives in the culminating discussion suggests that the orchestration design, mapping multiple, multi-level comparisons into a sequence of group tasks, was effective in managing complexity and enabling novices to co-construct historical interpretations of complex visual data.

Re-representation of patterns for disciplinary reasoning beyond the tool

Our analysis points to a promising strategy for fostering deep learning when using visualization tools. The aim of teaching with visualization tools is to move beyond the language of numbers, shapes or colors, to narrate the real-world phenomena they are meant to represent, so that learners develop knowledge about the phenomenon that endures even in the absence of the visualization tool. The interactive discussion here built on the jigsaw activity to encourage students to re-represent not only the data, but the patterns and phenomena they were co-constructing to compare migrations, both verbally and gesturally. Asking learners to re-represent patterns and concepts prompted co-construction of the ideas being discussed, free of the complexity of the data interface, while providing opportunities for formative assessment to guide the ongoing lesson. The outcomes of this strategy seen here suggest the value of further examining its potential for supporting deep learning and transfer.

Conclusion

Following recent calls by leaders in CSCL (Ludvigsen et al., 2016; Wise & Schwarz, 2017) we examined how the design of classroom orchestration could reap the educational potential of sophisticated representational systems, which are used in professional and everyday contexts, in the college classroom. We propose that disciplinary task models can serve as a guide for making orchestration design decisions. We demonstrated how mapping configurations of group work to the conceptual reasoning moves that professionals make in using these tools could lead to disciplinary learning goals while using everyday tools like webmaps that were not designed as learning environments. Understanding how to orchestrate the classroom to cultivate students' disciplinary thinking with tools that may not have built-in collaboration and reasoning scaffolds holds promise as a valuable area to explore in future CSCL work. Focusing on such tools may offer advantages beyond the support of disciplinary learning. Various visualization tools are becoming prevalent in daily life in online news, social networking, and other sites, making competency in interpreting these visualizations an important skill for civic participation. Using such tools in their everyday form in the classroom may lead to better transfer to everyday settings. In addition, as Roschelle et al have argued (2008), an alternative strategy for assuring the products of CSCL research have impact at scale is that rather than "scale up," CSCL innovations be integrated into materials and tools that are already used at scale. Using disciplinary models to design orchestration around tools that are already widely available may be a way to achieve advances in college disciplinary learning at scale.

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