CSCL for the era of climate change: A squib proposal

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Abstract

The world changed significantly about 70 years ago. Some scientists name the new age starting then the "Anthropocene" (human-influenced) epoch. The atomic bomb, population explosion, exponential growth of fossil-fuel usage and CO_2 emissions, urban/suburban sprawl and numerous other socio-economic transformations led to a dangerous increase in the influence of human behavior on worldwide natural systems. Our public knowledge routines now have to catch up so we can comprehend and moderate the new and potentially catastrophic processes. The learning sciences should urgently develop appropriate approaches to understanding and teaching about this new world of climate change, in which natural, technological and societal processes are inexorably entangled. This will require transformed conceptualizations of knowledge and new methods of education.

This squib – a statement to provoke discourse on topics of theoretical importance – reports on a research project that indicates a direction for designing education in and about the Anthropocene. By reviewing the project's empirical results, it suggests a new direction for the future of computer-supported collaborative learning (CSCL). As an illustrative case study of educating for the Anthropocene, it proposes that dynamic geometry as taught in the project can provide student collaborative knowledge building with a model of dependencies in interconnected systems, preparing groups of students to understand the interactions among human, technical and natural systems in the present age.

Review of this research project elaborates a theory of "group cognition" – learning by means of social and semantic interaction within technically mediated group discourse, rather than within individual minds. The recommended approach to cognition centered on technologically supported small-group interaction aligns CSCL with the multidisciplinary nature of science in the Anthropocene, and indicates how CSCL can contribute appropriately to learning in this problematic epoch of climate change.

Keywords: Anthropocene epoch, climate science, dependency relations, dynamic geometry, group cognition, group practices, shared understanding, virtual math teams

The challenge of learning climate science

Learning in the future will require new ways of understanding interactions among countless actors: human, animal, mineral, technological, computational and Earth-system agents. Referring to the present geological epoch as the "Anthropocene" denotes the essential influence of human behavior, industry and consumption upon major systems of the biosphere: the land, oceans, vegetation, animals, sea life, insects, viruses and climate (Crutzen & Stoermer, 2000; Steffen et al., 2015; Thomas, Williams & Zalasiewicz, 2020).

The current coupling and interpenetration of cultural and natural evolution (Donald, 1991; Donges et al., 2017; Latour, 2017) requires more than simple mechanistic laws and equations like Galileo's and Newton's to comprehend, anticipate and influence; it involves thinking in terms of probabilistic formulations of subtle interdependencies (Kolbert, 2014; Krauss, 2021; Thomas et al., 2020; Wiener, 1950). Teaching and learning mathematics in our age should provide cognitive tools and perspectives for humanity to survive in this complex setting of global climate change and possible species extinction (Coles, 2017; Gomby, 2022). This poses an urgent and potentially consequential challenge for CSCL.

In response to a major shift in reality, we need to re-conceptualize scientific analysis, including its mathematical and cognitive underpinnings (Cole, 2024; Griscom et al., 2017; Steffen & Morgan, 2021). New approaches to teaching and learning mathematics are required here as much as in particle physics (Boylan & Coles, 2017; Mikulan & Sinclair, 2017; Yoon et al., 2016). Physics has had to consider stochastic, relativistic and quantum calculations, feedback and observer influences, field and gauge theories or conceptualizations like entropy, strings, entanglement, dark energy and alternative universes. Now our understanding of the world at the everyday scale needs to incorporate how systems are intertwined in surprising ways with exponential change, non-linear chaos, feedback loops and tipping points (Kemp et al., 2022; Lenton, Held, Kriegler & Schellnhuber, 2008; Steffen et al., 2018).

This squib reports on a research project to develop a paradigmatic CSCL approach to teaching dynamic geometry as a way of conceptualizing *dependencies* among objects and for comprehending causal interconnections. This may suggest an approach to computer-supported collaborative learning in the future: to support group exploration of core concepts of climate science. Just as Roschelle's (1992) early CSCL experiment modeled acceleration as a fundamental concept of Newtonian mechanics, the project reviewed here models dependency as a central notion of Euclidean geometry. Similarly, Anthropocene science relies on many relationships that lend themselves to computer modeling of core relationships that could be incorporated in contexts of educational collaboration software (Boylan & Coles, 2017; Hashem & Mioduser, 2011; Yoon, Goh & Park, 2018).

Previous squibs and proposals for CSCL have concentrated on CSCL methodologies (e.g., Rummel, 2018; Wise & Schwarz, 2017) and on CSCL theories such as group understanding (Stahl, 2017; unknown_author1 & unknown_author2, 2024). In this squib, the focus is on subject matter (geometry, climate science) and associated conceptualizations (dependency relations). It is proposed that the dual use of collaboration (group inquiry) and computer support (dynamic modeling) could allow CSCL approaches to help students prepare for the challenges of the current era.

Dynamic geometry for modeling the Anthropocene

The research reviewed here suggests that teaching and learning mathematical thinking relevant to the Anthropocene may be furthered through carefully designed student exploration of dynamic geometry. Dynamic geometry is an interactive computer application that allows students to investigate the structure and interrelationships of well-defined geometric elements and constructions. This can provide a primer and conceptual foundation for understanding dependencies in the intertwined Anthropocene world.

Dynamic geometry is grounded on Euclidean geometry and implemented in popular applications such as GeoGebra and Geometer's Sketchpad (Hohenwarter & Lavicza, 2009; Sinclair, 2008). As an example, Figure 1 shows an equilateral triangle constructed in dynamic geometry with side lengths dependent upon circles with equal radii, as specified in Euclid's first proposition. Then an interior equilateral triangle was constructed with vertices equal distances from the vertices of the exterior triangle. Dragging around points of each triangle suggests that the two triangles both remain equilateral regardless of the positions of their specified points.

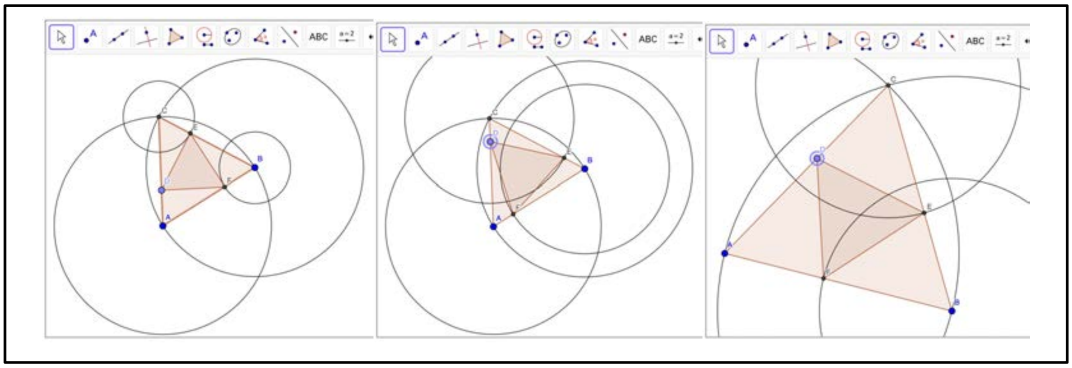

Figure 1. Inscribed equilateral triangles constructed in GeoGebra and dragged to different positions.

Dynamic geometry visualizes the generalization implicit in Euclidean geometry and the dependencies that underlie it by allowing points, lines and figures to be interactively dragged to alternative possible locations. Dependencies that persist despite such dragging suggest which relationships still hold when locations are generalized from arbitrary initial positions of points to other possible positions (Netz, 1999). An understanding of dynamic geometry in terms of the design of dependencies provides insight into the design of geometric figures – insight that is not always fostered by a traditional presentation of deductive proof.

Students exploring dynamic geometry can learn to think about systems of interdependent elements, some of which are completely restricted by the positions of others, some are constrained (e.g., to move only in a fixed circle around another point) and some are simply free to move anywhere (Hölzl, Healy, Hoyles & Noss, 1994; Jones, 1996). Such systems thinking can later be applied to evolutionary models of nature, like an interactive representation of animal populations dependent upon climate, vegetation and interactions among species.

Educating students for the Anthropocene involves helping them to think and talk about systems of abstract (non-visible, underlying, theoretical) interdependencies. While science in the Anthropocene is more complicated and multidisciplinary than geometry, it is still based on understanding dependencies, even if they are harder to compute (Krauss, 2021; Zhai et al., 2021). Since the beginning of Western science, Euclidean geometry has been used to teach students how to think rigorously about dependencies. Today, dependency is a foundational concept in both dynamic geometry and environmental science.

Global climate change is a high-level result of interactions at the molecular level. The CO_2 greenhouse effect raises average temperatures, melts arctic ice, modifies weather patterns, increases sea-level rise. These, in turn, alter the conditions for flora and fauna, potentially leading to species extinction. All these natural systems interact with each other and with human social and technical systems to feed back on each other, eventually passing tipping points.

Climate science involves a new conception of causation. Agency can no longer be considered a simple effect of individual mental thinking determining physical action – for many reasons.

1. Cognition increasingly takes place within tools, such as sheets of paper, charts, calculators, computer models, spreadsheet analyses. Ideas are posed, worked out, communicated and preserved in these shared-meaning physical media in ways they could not be in pure thought (Donald, 2001). They are also discussed, shared, critiqued, developed and negotiated in small groups. CSCL approaches can support the resulting synthesis of technology mediation and collaborative communication.
2. Consequences of individual human intentions and actions are not simple direct results of individual cognition. Latour (2014, p.7) points out that the central military outcome in Tolstoy's detailed presentation of *War and Peace* was not simply due to the commander's agency, but was influenced by

innumerable peripheral actors and unanticipated circumstances. Latour develops a new conceptualization of causation involving potentially huge networks of actors, both human and non-human. Technological artifacts, for instance, can embody inferred human intentionality of both designers and users (Latour, 1988; Rabardel & Beguin, 2005; Simondon, Mellamphy & Hart, 1980).

3. Especially in the Anthropocene, human actions involve and affect natural phenomena. The causal relationships involved are complex and only partially understood by the actors. They may involve huge numbers of objects and intricate patterns of interaction, which are not precisely predictable. It is often not possible for people to know the ultimate consequences of their actions based on simple causal relationships; broader dependencies may have to be taken into account.

Dynamic geometry could provide workspaces for exploring systems of interdependent objects, where students can design dependencies into constructions of multiple objects and then observe the consequences of the dependencies through manipulation of the objects. This can offer an exploratory playground for groups of students to learn about mathematical relationships important for understanding the contemporary world.

An illustrative CSCL research project on understanding dependency

Hosting education on computer devices not only allows the use of apps like dynamic geometry, but supports collaborative learning beyond face-to-face settings. It permits many forms of automated support: online information sources, AI commentary and archiving of activity transcripts. Furthermore, it opens new dimensions of social interaction and collective inquiry.

Unfortunately, most commercial collaboration software and popular social media are primarily designed to support the expression of narrowly directed individual thinking and hierarchical management. They reinforce individual opinions rather than stimulating collaborative thinking. CSCL environments are designed to enhance individual and group cognition by students, furthering their collaborative learning and social knowledge building.

The design of computer software to support online collaborative learning to build shared knowledge was explored through experiments with a number of prototype CSCL systems described in *Group Cognition* (Stahl, 2006). One major finding from that research was that mechanisms of “meaning making” or “negotiation of meaning” needed to be better understood than it had been in previous CSCL theory. Most earlier analyses of shared understanding were based on theories of individual cognition, perhaps coordinated by efforts of “common grounding” (Clark & Brennan, 1991). The studies collected in this volumebegan to provide alternative analyses of small groups adopting shared meanings of charts or mathematical problems through discourse, explicit agreement and subsequent tacit usage.

The need for much more detailed analysis of meaning making and negotiation in collaborative learning led to a decade-long research effort: the Virtual Math Teams Project (VMT). This project involved designing and iteratively improving an online environment for small groups to explore and discuss mathematics together. Functionality was provided for both textual dialog (chat) and diagrams (whiteboard). Teams of students were recruited through teachers and were provided with challenging mathematical problems, mainly of middle-school combinatorics and geometry curriculum.

The VMT Project experimented with systems of flexible computational support for collaborative interaction, negotiation of meaning, intersubjective consensus building. *Studying Virtual Math Teams* (Stahl, 2009) includes reports of this research by about 40 academics from several countries. It motivates the project, analyzes the data of student interactions and draws implications for the science of CSCL.

The VMT effort began to define a science of group cognition and to identify the characteristics and mechanisms of small-group-level cognitive phenomena, which can, for instance, contribute to the teaching and learning of mathematics. The computer technology involved in the project not only supports interaction and exploration by student groups, but also facilitates experimentation and analysis by the project researchers, software developers and curriculum developers.

The VMT Project included a systematic attempt to "translate" classical Euclidean geometry for the Anthropocene by reactivating its meanings in settings of collaborative learning and by emphasizing the functioning of dependencies. A comprehensive description of this research in *Translating Euclid* (Stahl, 2013) includes chapters detailing interdisciplinary aspects of this effort, including: the project vision, history of geometry, guiding project philosophy, covered mathematics, developed technology, approach to collaboration, educational research, social theory, curricular pedagogy, analysis of practice and design-based-research methodology.

At this point, the VMT Project developed a unique multiuser version of the open-source GeoGebra app and integrated it into an online collaboration environment, so that groups could view and work on shared dynamic-geometric constructions collaboratively in real time. It also iteratively tested curricula that scaffolded student groups to explore the basic concepts, propositions and dependencies of Euclidean geometry. Researchers analyzed the transcripts of group cognition in which meanings were negotiated, sedimented and tacitly reactivated in their group language and understanding. Analysis included consideration of social, psychological, mathematical, technological, semantic and pedagogical factors. Within this multi-dimensional consideration, focus centered on tracking the increasing student comprehension of dependency, as a central phenomenon of geometry and potentially of Anthropocene science.

Group cognition for building knowledge in the Anthropocene

According to CSCL theory, cognition is not a matter of isolated mental functions that individuals develop internally, but a consequence of interaction with the social and physical world, including other people, physical artifacts and spoken language. This is a step toward a conceptualization appropriate to the Anthropocene, in which phenomena are defined by their interactions with other agencies. To stress the social basis of learning and cognition, the concept of "group cognition" is used as an alternative to the traditional focus on individual cognition and as a core foundational phenomenon for CSCL.

The VMT Project was designed to study empirically how group cognition takes place in a CSCL setting. *Constructing Dynamic Triangles Together* (Stahl, 2016) analyzes every chat posting by a particular small group of students who engaged in eight hour-long online sessions in the VMT Project using the collaborative version of dynamic geometry. It documents step-by-step and chat posting-by-posting how the group increased its understanding of dependency. The group adopted numerous practices that markedly increased its ability to identify, construct, manipulate and reason with geometric dependencies. In Log 1 (Stahl, 2016, p.206), for instance, the group begins to adopt the vocabulary of dependence, negotiating the distinction between "restricted" and "constrained."

Log 1. A restricted point in Polygon 5.

145	54:52.3	cornflakes	point t is restricted
146	55:13.9	fruitloops	agreed because off the color
147	55:33.5	fruitloops	so t only moves when you move the other points
148	55:46.7	cheerios	yea thats one way to prove that is constrained
149	56:09.6	fruitloops	i thought it was restricted
150	56:09.9	cornflakes	and when you move point r all the points move around point q
151	56:29.9	cornflakes	yeah its restricted dude

Through the close interaction analysis of chat discourse and geometric manipulations, it becomes clear that the group was collaboratively negotiating shared meanings and adopting these as group practices. About 60 distinct group practices are highlighted in the analysis. Each of these is explicitly discussed in the group discourse and analyzed in the book. The variety of practices reviewed covers many needs of collaborative learning, dynamic geometry, computer support, design of dependencies and online interaction.

Because group cognition involves a mix of tacit understanding and explicit interpretation, it is perhaps best to conceive it in terms of "practices" rather than mental representations. In particular, collaborative learning can be analyzed as the adoption of group practices by the small group (Stahl, 2017). These practices may be derived from pre-existing society-wide cultural practices, and they may be subsequently personalized as individual practices, but to be effective they must first be adopted by the small group and integrated into its activity and discourse.

For each practice, the group went through a process of (a) confronting a problem, (b) discussing action options, (c) agreeing on a path for going forward and then (d) proceeding with putting the practice into action. While this response to a problem initially required explicit discussion and group agreement, subsequently the group could tacitly proceed with the adopted solution without any discussion. The practice was adopted by the group and integrated into its behavior. Stahl (1993) had previously analyzed the interplay of explicit and tacit understanding in computer-mediated knowledge building, following this general process.

When a group of students collaborates on a dynamic-geometry problem in a system like VMT, its group cognition resides primarily in the shared software interface, which displays the group work, including both chat discourse and constructed figures as a kind of joint problem space (Teasley & Roschelle, 1993). Group knowledge building is mediated by and stored in physical knowledge artifacts (Damsa, 2014). The learning of mathematics can be studied by analysis of the development of mathematical group cognition, such as occurred by teams of students using VMT.

Group cognition is itself an Anthropocene conceptualization. Sciences and theories of the Anthropocene no longer support notions of independent organisms in environments, such as methodological individualism (Gibson, 1979; Winograd & Flores, 1986). They conceptualize agents as defined by intricate links, interactions and interdependencies. CSCL analyses of group cognition do not consider the isolated thinker, but look at interactions among multiple agents embedded in rich worlds, especially socio-technical systems. The analysis of group cognition is a multidisciplinary undertaking; it often involves forms of conversation analysis, statistical analysis, educational psychology, semantics, video analysis, communication theory and software design.

Theoretical Investigations (Stahl, 2021) brings together two dozen papers on various aspects of the philosophy of computer-supported collaborative learning. Starting with a meso-level analysis of software design that looks beyond a single app to its whole technological, digital infrastructure, the book goes on to consider technology in terms of its interaction with and adoption by students. This begins to shift CSCL to the kind of science appropriate to the Anthropocene, where minds and technologies increasingly work together. Other papers from the *International Journal of CSCL* reprinted in the first half of the volume consider semantic, visual, sequential, temporal and interactional dimensions.

The second half of the book presents microanalyses of VMT interaction data from small groups learning mathematics. It includes a wealth of examples of specific aspects of how group cognition unfolds. This includes detailed illustrations of groups constituting themselves as intersubjective understanding, negotiating meaning, building knowledge, solving problems, adopting practices, crafting knowledge objects, refining terminology and learning mathematics. These investigations of VMT data explicate core concepts of group cognition, such as: intersubjectivity, knowledge building, shared meaning making, negotiation of meaning, adoption of group practices, cognitive evolution, knowledge objects, referential resources, instrumental genesis and the co-experienced world. The volume points toward a multidisciplinary science appropriate for the Anthropocene, which considers educational issues within a complex environment of interdependencies.

An example CSCL curriculum for the Anthropocene

The VMT Project pursued a vision of students around the world learning mathematics collaboratively by communicating and exploring problems online within virtual math teams. It provided a CSCL model for fostering group cognition of geometry. The curriculum was designed to scaffold the adoption of group practices for exploring dependencies, a concept that seems pivotal to comprehending both Euclidean geometry and Anthropocene science.

In 2020, the Covid Pandemic provoked rushed efforts around the world to provide educational resources for online pods of students in place of shuttered classrooms. Unfortunately, this rarely took advantage of recent research in the learning sciences or in computer-supported collaborative learning like VMT, instead using business software, social media apps and non-collaborative pedagogy.

To suggest how to fill the glaring educational gap during the pandemic, the final version of the curriculum for the VMT Project was made publicly available on the GeoGebra website and as a free e-book: *Dynamic Geometry Game for Pods* (Stahl, 2020). It includes a sequence of 50 dynamic-geometry challenges at increasing levels of expertise. Each level is demanding enough to benefit from collaboration.

The Game for Pods and the VMT Project leading up to it provide a concrete, detailed, tested example of a CSCL approach to fostering an understanding of dependencies in dynamic geometry. The underlying research involved a multidisciplinary consideration of interrelations among various cognitive units, technological media, mathematical systems, semantic structures, interpersonal interactions and social practices. This can provide a model for learning and teaching mathematics in the Anthropocene. As we have already seen with the impact of the Pandemic on schooling and the influence of climate denial on public acceptance of science, the need for and the urgency of appropriate innovations are rising rapidly.

The VMT research project was a design-based research approach to exploring CSCL in realistic educational settings. It confirmed that a CSCL approach could successfully be developed for collaborative learning of mathematics, including an understanding of dependency. Now it is time to see if CSCL can be effectively used more generally to prepare students with the analytic skills necessary for understanding the world they face – the Anthropocene. Accordingly, this squib suggests the following set of hypotheses for future CSCL research:

- Understanding the current world involves comprehending multidisciplinary complex systems, in which natural and social phenomena interact on many scales.
- A key concept for appropriate understandings in contemporary physical, social and environmental sciences is “dependency.”
- Studying digital geometry can provide a foundation for understanding, designing and manipulating dependencies.
- The concept of dependency in digital geometry can be adapted to help understand dependencies in the multidisciplinary sciences of the Anthropocene.
- CSCL technology, curriculum and pedagogy can be developed to support online collaborative learning of many foundational relationships in climate science. The VMT Project can be taken as a forerunner for the kind of research to accomplish this.

CSCL has the potential to provide unique and effective approaches to the challenge of preparing students for knowledgeable life in the Anthropocene. With its dual focus on collaborative learning and on computer support, CSCL unites social and technological educational design concerns. Using a design-based research approach, it can develop pedagogical units that have been iteratively tested in realistic educational conditions. It can thereby become a multi-faceted science of learning appropriate to the intricate nature of the Anthropocene. Future CSCL research should pursue this potential to prepare students to understand the dependency relationships definitive of the era of climate change.

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