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Peer Explanation Networks in Conceptually Difficult Courses

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Abstract

Conceptually difficult university courses present a distinctive instructional problem because students may successfully reproduce procedures while retaining incomplete or incorrect mental models of the underlying concepts. Physics, mathematics, chemistry, statistics, engineering, economics, and other concept-intensive fields frequently contain threshold ideas whose mastery requires learners to distinguish superficially similar cases, revise prior intuitions, coordinate multiple representations, and justify relationships rather than memorize definitions. Peer explanation provides one mechanism for making these reasoning processes explicit. In a classic undergraduate science study, Smith and colleagues demonstrated that peer discussion could improve conceptual understanding even when no member of a discussion group initially selected the correct answer, suggesting that discussion can generate new reasoning rather than merely transmit the answer from a knowledgeable student. More recent evidence continues to support the value of peer interaction: Tullis and Goldstone found consistent improvements in accuracy following peer discussion across six university classes, while Gjerde and Hagane's 2020 physics research emphasized the cognitive processes through which explanation can address misconceptions and develop conceptual language.

This paper proposes a Peer Explanation Network Model (PENM) for conceptually difficult courses. Rather than treating peer instruction as a sequence of isolated pair discussions, the model conceptualizes a class as a dynamic explanation network in which students alternately act as explainers, challengers, listeners, questioners, and revisers. The framework combines conceptually diagnostic questions, individual commitment, explanation exchange, counter-reasoning, network rotation, second-response assessment, and instructor synthesis. Social-network analysis provides a methodological basis for examining whether explanation opportunities are concentrated among a few highly connected students or distributed more broadly across the class. Previous research has shown relationships between collaboration-network position and academic performance, while a 2026 multi-institutional Nature Physics study involving active-learning courses found that conceptual learning varied substantially across instructional approaches even when peer-network development was broadly similar, indicating that network existence alone is insufficient without productive classroom activity.

Keywords: peer explanation, peer instruction, conceptual learning, learning networks, social network analysis, conceptual change, difficult courses, STEM education, collaborative learning, higher education

1. Introduction

Conceptually difficult courses are often challenging for reasons that cannot be reduced to the volume of content or the mathematical complexity of assessment. Students may enter a course with intuitive models that work reasonably well in everyday settings but conflict with disciplinary explanations. They may memorize equations without understanding the conditions under which those equations apply, recognize familiar examples without transferring reasoning to novel cases, or reproduce procedures while remaining unable to explain why a solution is valid. Such difficulties are especially prominent in introductory physics, mathematics, chemistry, statistics, engineering, and other courses in which later learning depends strongly on a small number of foundational concepts. Active-learning research has consistently shown that replacing exclusively transmissive instruction with structured student engagement can improve performance across science, engineering, and mathematics, while recent comparative physics research continues to show measurable conceptual gains across several established active-learning methods.

Peer explanation is valuable in this context because explanation externalizes reasoning. When students must defend an answer to another learner, they can no longer rely entirely on familiarity or unexamined intuition. They must identify relevant principles, connect those principles to the problem, respond to questions, and reconcile inconsistencies. Smith and colleagues' influential study demonstrated that peer discussion improved responses to subsequent conceptually similar questions even when none of the students in a group initially possessed the correct answer. Tullis and Goldstone later examined 208 undergraduates across six classes and 86 questions and found that students became both more accurate and more confident after discussion. Their analysis characterized the improvement as a group process gain rather than simple answer copying. These findings are important because they suggest that explanatory interaction can create conceptual understanding through comparison, elaboration, and reconstruction.

Yet the educational value of peer explanation should not be understood solely at the level of one pair. Students in real courses form networks. Some learners regularly explain ideas to many classmates, others interact repeatedly with the same small group, and some remain peripheral. Grunspan, Wiggins, and Goodreau demonstrated how social-network analysis can reveal classroom interaction structures relevant to learning, pedagogy, and equity. Vargas and colleagues subsequently examined collaboration networks in three upper-division physics courses and reported significant relationships between several network-centrality measures and homework performance, with students who collaborated broadly and frequently tending to achieve stronger homework outcomes. These studies suggest that conceptual learning may depend not only on the presence of collaborative activities but also on how explanatory opportunities circulate through the classroom.

Network structure, however, cannot be treated as a substitute for instructional quality. Sundstrom and colleagues' 2026 multi-institutional Nature Physics study compared Peer Instruction, ISLE, Tutorials, and SCALE-UP across introductory physics and astronomy courses. All four approaches produced measurable conceptual learning gains, but SCALE-UP produced significantly larger gains than Peer Instruction and ISLE in the reported comparison. Importantly, peer-network development was broadly similar across the approaches, whereas the amount and type of student-centered classroom activity differed considerably. This result cautions against a simplistic assumption that more network connections automatically produce more learning. What students do within those relationships—explain, challenge, justify, test, revise, or merely exchange answers—matters substantially.

2. Objectives of the Study

2.1 To Develop a Structured Peer Explanation Network Model

The first objective is to convert peer discussion from a collection of occasional pair conversations into a deliberately designed learning network. The proposed model requires students to commit to an individual interpretation, explain that reasoning, encounter a contrasting explanation, challenge or defend claims, revise their response, and periodically interact with different peers.

The objective is not to maximize interaction volume. It is to increase the number of productive explanatory ties through which students exchange reasoning rather than final answers.Tullis and Goldstone's work provides support for this distinction because peer-instruction gains were associated with discussion processes that generated better collective performance than predicted from individual performance alone.

2.2 To Examine Network Participation as a Dimension of Conceptual Learning

The second objective is to operationalize classroom peer interaction using learning-network concepts such as degree, reach, reciprocity, diversity of explanation partners, and persistence of peripheral participation.

Social-network analysis is particularly useful because it permits researchers to distinguish a class in which almost every learner exchanges explanations with several peers from one in which the same small number of students dominate intellectual interaction. Grunspan and colleagues identified social-network analysis as a useful framework for questions concerning pedagogy, learning, and social equity in undergraduate classrooms.

2.3 To Design Equitable Peer Explanation in Difficult Courses

The third objective is to prevent peer-learning structures from reproducing participation inequalities. Active learning can improve achievement broadly, but participation within active-learning environments is not necessarily equally distributed. Aguillon and colleagues documented gender differences in participation within an active-learning biology classroom, demonstrating that participation structure itself deserves explicit instructional attention.

The proposed model therefore includes individual response protection, rotating explanation partners, written reasoning before discussion, structured speaker/listener roles, anonymous whole-class polling, and instructor monitoring of network peripheries.

3. Review of Literature

3.1 Peer Explanation and Conceptual Reconstruction

Peer Instruction is commonly organized around a challenging conceptual question, an individual response, discussion with a peer, and a second response. Tullis and Goldstone describe this sequence as a widely used evidence-based strategy and found consistent gains after peer interaction across their semester-long study. The learning mechanism appears more sophisticated than copying a confident peer because students can construct new understanding during discussion.

Smith and colleagues provided particularly influential evidence for this mechanism. In their undergraduate genetics study, peer discussion improved performance on conceptually similar follow-up questions even when neither student originally knew the correct answer. Such results indicate that explanation may operate through distributed sense-making. One student may contribute a relevant principle, another may notice an inconsistency, and the interaction may produce an interpretation that neither participant had articulated independently.

Gjerde and Hagane's 2020 study in *Physical Review Physics Education Research* revisited the cognitive processes involved in physics peer instruction. Their work emphasizes that students gain practice using the abstract language and models of physics and that conceptual questions can activate processes through which misconceptions are confronted and reasoning is refined. This is particularly relevant in difficult courses because expert disciplinary language often compresses relationships that remain invisible to novices.

Peer explanation also has a metacognitive function. Tullis and Goldstone found that students' confidence influenced answer revision but did not fully account for the learning gains, suggesting that explanation quality and knowledge construction contributed beyond simple confidence matching. Students are required to compare not only answers but the coherence of competing explanations. In a well-designed activity, the cognitively important question becomes not “Who sounds more certain?” but “Which explanation accounts for the evidence more completely?”

3.2 Classroom Networks and Distributed Learning Opportunity

Peer-learning research has often concentrated on the immediate interaction between two students, but classroom relationships accumulate across time. Social-network analysis allows researchers to represent students as nodes and their learning interactions as ties, enabling examination of network density, centrality, reciprocity, clustering, and isolation. Grunspan and colleagues introduced this approach to education researchers as a way of examining how classroom relationships influence learning and other outcomes.

Vargas and colleagues applied network analysis to student collaboration in upper-division physics and found that several measures of network centrality correlated significantly with homework scores across three courses. Students who interacted meaningfully with a wider set of peers tended to perform more strongly on homework, although relationships with examinations were less consistent. The result should not be interpreted as proof that centrality causes achievement; higher-performing students may become more central because others seek them out. Nevertheless, the study shows that the organization of peer relationships is educationally relevant.

Network analysis is especially valuable for identifying students who remain peripheral. A class average may indicate substantial participation even when a subgroup of students experiences almost no explanatory interaction. Such students lose opportunities to articulate reasoning, obtain formative feedback, and observe alternative conceptual models. In difficult courses, repeated peripheral positioning may compound academic disadvantage because conceptual errors remain private until formal assessment.

The most recent comparative evidence adds an important qualification. Sundstrom and colleagues' 2020 Nature Physics study found similar peer-network development across four active-learning methods despite meaningful differences in conceptual gains. Network connection therefore appears to be a necessary but insufficient condition. The pedagogical content of interaction, the proportion of class time allocated to student-centered work, and the tasks around which networks form remain essential.

A Peer Explanation Network Model should therefore measure both network structure and interaction quality. A highly connected class can still be conceptually weak if students exchange answers without explanation, while a smaller but intellectually intensive network may generate deeper learning.

3.3 Participation Equity and Instructor Orchestration

Active learning does not automatically produce equitable participation. Aguillon and colleagues found gender differences across several forms of participation in an active-learning biology course, with men participating more than expected from class composition in multiple categories. Such findings demonstrate that open invitations to discuss or volunteer answers can reproduce confidence hierarchies rather than equalize learning opportunity.

Theobald and colleagues' meta-analysis provides a complementary perspective by showing that high-intensity active learning can narrow achievement gaps for students from groups historically underrepresented in STEM. The implication is not that any active-learning structure is automatically equitable but that well-designed student-centered instruction can improve outcomes when participation and learning opportunities are deliberately structured.

Instructor orchestration is therefore central to peer-explanation networks. The instructor determines the conceptual question, timing, group composition, explanation prompt, criteria for productive disagreement, and moment of whole-class synthesis. A weak question generates little reasoning even in a dense network. A strong question can reveal misconceptions, but if students interact only with friends who share the same misconception, the network may stabilize incorrect reasoning.

Recent Nature Physics evidence reinforces the importance of what instructors do with class time. Sundstrom and colleagues found that courses using Tutorials and SCALE-UP devoted more time to student-centered activities than many observed Peer Instruction and ISLE classes, and these differences were associated with variation in conceptual gains. Peer explanation should consequently be treated as an instructional ecology rather than a brief discussion inserted between long lecture segments.

4. Research Methodology

4.1 Research Design

The present study employs a conceptual-methodological research design with simulation-based learning-network analysis. No actual students were recruited, no classroom interactions were recorded, and no institutional learning-management-system data were collected.

The methodological framework was developed by synthesizing evidence from peer instruction, conceptual learning, active learning, social-network analysis, and classroom participation research. Particular weight was given to studies that distinguish genuine conceptual gains from simple answer convergence and to research examining learning relationships as networks rather than isolated interactions. The simulation described below is designed only to demonstrate how a future empirical study could analyze network participation against conceptual-learning outcomes.

4.2 Peer Explanation Network Model

The proposed model contains seven instructional components.

Table 1: Proposed Peer Explanation Network Model for Conceptually Difficult Courses

Network Component	Instructional Purpose	Student Activity	Evidence Generated
Concept Diagnostic	Identify competing mental models	Answer a conceptually discriminating question individually	Initial conceptual state
Reason Commitment	Prevent immediate peer conformity	Record brief justification before discussion	Individual reasoning trace
Explanation Exchange	Externalize conceptual relationships	Explain answer to assigned peer using evidence, principle, or representation	Explanatory tie
Counter-Reasoning	Test explanatory coherence	Ask one challenge question or identify inconsistency	Critical interaction
Network Rotation	Broaden explanatory exposure	Interact with different peers across repeated cycles	Partner-diversity measure
Reasoned Revision	Capture conceptual change	Re-answer and state why the position changed or remained	Post-dialogue reasoning
Instructor Synthesis	Stabilize disciplinary understanding	Compare representative explanations and address persistent misconceptions	Expert feedback and conceptual closure

4.3 Network and Conceptual-Learning Metrics

A Peer-Explanation Network Participation Index (PENPI) is proposed:

$PENPI=0.25D+0.20R+0.20P+0.20Q+0.15C$

where:

D = diversity of explanation partners R = reciprocal explanation rate P = participation frequency Q = assessed explanation quality C = conceptual challenge participation

All components are normalized to a 0–100 scale.

Conceptual learning is assessed separately using matched pre/post concept questions or validated concept inventories rather than ordinary course grades alone.

A conceptual mastery gain score is represented as:

CMG=100−PrePost−Pre×100

where appropriate for normalized-gain applications. Researchers may instead use raw change scores, item-response models, or multilevel approaches depending upon the assessment instrument.

The proposed design explicitly separates network participation from conceptual performance so that strong interaction is not automatically interpreted as successful learning.

5. Analysis

5.1 Simulated Peer-Explanation Network Conditions

Four conceptual network conditions are used to illustrate how explanation networks may differ even when the number of enrolled students is identical.

Table 2: Simulated Characteristics of Alternative Peer-Explanation Network Conditions

Network Condition	Partner Diversity	Explanation Reciprocity	Conceptual Challenge	Instructor Monitoring	Simulated Conceptual-Learning Potential
Fixed-Pair Network	Low	Moderate	Low–Moderate	Moderate	Limited by repeated exposure to the same reasoning
Centralized Expert Network	Moderate	Low	Moderate	Moderate	Vulnerable to dependence on a few confident/high-performing students
Random-Rotation Network	High	Moderate	Moderate	Moderate	Broad exposure but variable explanation quality
Structured Reciprocal Explanation Network	High	High	High	High	Strongest balance of distributed participation and explanation quality

Note: The classifications are conceptual and not observations from real courses.

The fixed-pair condition may produce useful dialogue but risks conceptual redundancy. If both students share the same misconception, repeated discussion may reinforce rather than destabilize it.

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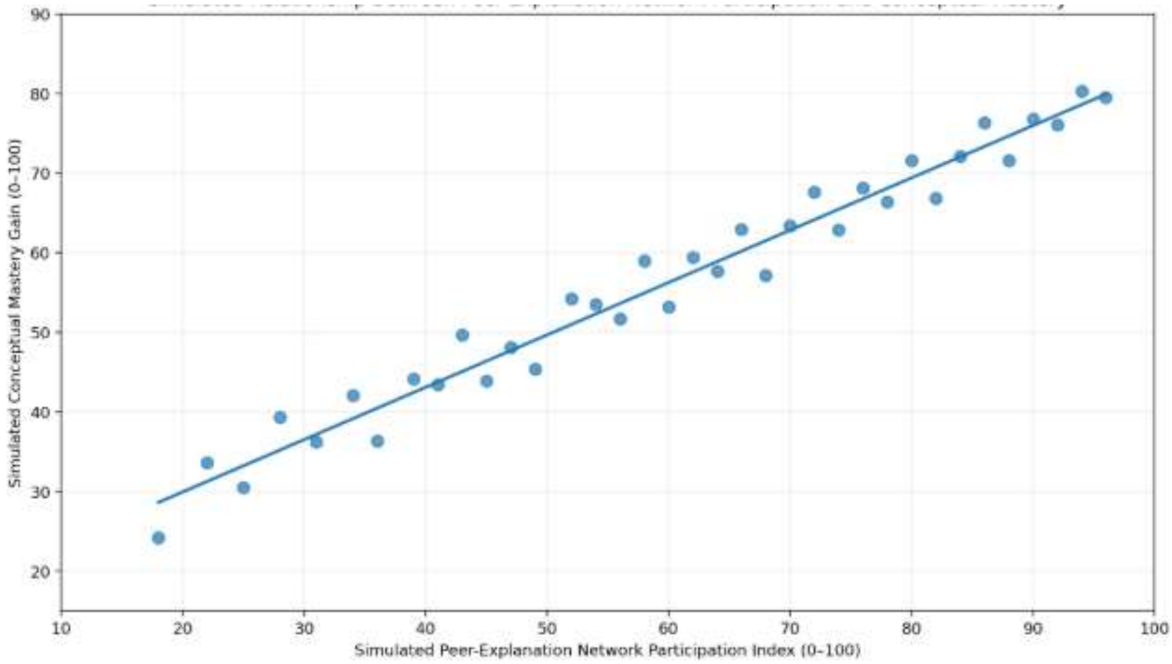
The centralized expert network can improve answer accuracy when highly knowledgeable students distribute correct reasoning, but it creates an unequal explanatory economy in which a small number of students consistently teach while others remain primarily recipients.

The random-rotation network improves exposure to different perspectives but can generate superficial exchanges when students lack structured prompts.The structured reciprocal network therefore introduces rotating partners together with explicit explanation and challenge responsibilities. The goal is distributed intellectual agency rather than simply maximum connectivity.

5.2 Scatter-Plot Analysis of Network Participation and Conceptual Mastery

Graph 1: Simulated Relationship Between Peer-Explanation Network Participation and Conceptual Mastery Gain



The simulated data show a strong positive relationship between Peer-Explanation Network Participation and conceptual mastery gain. The correlation within the illustrative dataset is approximately r = 0.983. This unusually strong relationship was deliberately generated to make the analytical logic visible and should not be interpreted as an empirical estimate of the relationship expected in real classrooms.

The graph illustrates how a future study could test whether students who participate in broader, more reciprocal, and more conceptually substantive explanation networks exhibit stronger conceptual gains.The relationship should be tested carefully because network participation and achievement can influence one another. Strong students may become central because peers seek their explanations, while centrality may also expose students to more reasoning opportunities. Vargas and colleagues' physics research reported significant relationships between several collaboration-network centrality measures and homework performance but did not establish simple causal direction.

The 2020 multi-institutional physics results provide an additional caution: peer networks were broadly similar across instructional methods despite differences in conceptual learning. Empirical analysis should therefore include explanation quality and instructional activity rather than treating network degree as an adequate learning metric by itself.

5.3 Conceptual-Difficulty Responsive Network Design

The strongest use of the network model is diagnostic rather than generic. Different conceptual difficulties require different explanation prompts.

Where students confuse correlation with causation, partners can be required to identify which evidence would distinguish the two interpretations. In physics, learners can be required to reconcile verbal, graphical, and mathematical representations of the same phenomenon. In mathematics, students can compare a procedurally correct solution with a conceptually invalid proof. In chemistry, students can explain particle-level mechanisms underlying symbolic equations.

Gjerde and Hagane's 2024 research is relevant because it emphasizes the importance of peer explanation for practicing abstract physics language and working through misconceptions. The explanation network should consequently be driven by disciplinary misconceptions rather than generic "discuss with your partner" instructions.

A practical cycle may use one diagnostic question every fifteen to twenty minutes during conceptually dense instruction. Students first answer privately, then explain to a peer, rotate when appropriate, reconsider the response, and finally encounter instructor synthesis.

Network data need not be collected continuously in routine teaching. Simple periodic questions such as "Whom did you explain your reasoning to?" can reveal whether particular students remain repeatedly isolated. Full social-network analysis can be reserved for research or systematic course evaluation.

6. Discussion

6.1 Peer Explanation Works Through Reasoning Reconstruction Rather Than Answer Transmission

The central interpretation of the literature and simulation is that peer explanation should be understood as a process of reasoning reconstruction. If the mechanism were simply the transmission of correct answers from stronger students to weaker students, learning should depend heavily on the initial presence of a knowledgeable peer. Smith and colleagues demonstrated that improvement can occur even when nobody in the original discussion group initially knows the correct answer. Tullis and Goldstone similarly characterize peer-instruction improvement as a process gain in which discussion creates performance beyond what would be expected from individual answers alone.

This interpretation changes how instructors should design peer activities. Pairing a high-performing student with a lower-performing student is not necessarily the ideal universal model. Heterogeneous explanation can be useful, but students with incomplete reasoning can also learn by identifying contradictions together. The educational target is not simply correct-answer transfer; it is a conversational environment in which conceptual models become explicit enough to be evaluated.

Explanation quality is therefore more important than explanation length. A student repeating the textbook definition contributes less conceptual value than a student who identifies a governing principle, applies it to the current case, contrasts it with a plausible misconception, and explains why the alternative fails.

For this reason, peer explanation should include challenge. A partner who only listens politely provides fewer learning opportunities than one who asks for evidence, requests clarification, or introduces a counterexample. The network becomes educationally powerful when explanation and critique circulate together.

6.2 Network Breadth Should Be Balanced with Interaction Quality and Equity

The second implication concerns network structure. Social-network research demonstrates that learning relationships are not distributed uniformly through classrooms, and collaboration centrality can correlate with academic outcomes. This makes it tempting to treat greater centrality as the instructional objective. Such an interpretation would be incomplete.

A student can possess many low-quality ties. Frequent one-sentence answer exchanges may produce high interaction counts while generating little conceptual reasoning. Conversely, a smaller number of reciprocal explanatory relationships can be highly productive.

The 2020 Nature Physics comparison is particularly instructive because peer-network development was similar across active-learning methods despite meaningful differences in conceptual gains. The result suggests that interaction topology alone does not explain learning; classroom activity and cognitive work within those interactions matter.

Equity presents a further reason to avoid unstructured network formation. Confident students can become central hubs while quieter, less-connected, language-minoritized, or socially marginalized students remain peripheral. Participation research in active-learning biology demonstrates that unequal participation can persist even when the classroom is formally interactive.

The proposed rotating-network model therefore seeks minimum distributed participation rather than maximizing individual centrality. Every learner should repeatedly explain, question, listen, and revise. Academic success should not depend upon having independently formed a socially advantageous peer network before entering the course.

6.3 The Instructor Remains the Architect of the Explanation Network

Peer explanation does not reduce the importance of disciplinary expertise. It redistributes when and how that expertise enters the learning process.

The instructor remains responsible for selecting conceptual questions capable of revealing important mental models, defining what counts as a satisfactory explanation, deciding when disagreement is pedagogically useful, observing common misconceptions, and providing disciplinary closure.

This role becomes particularly important because peer interaction can stabilize incorrect explanations. When several students share the same intuitive misconception, social agreement may increase confidence without increasing validity. The instructor therefore needs access to second-response patterns, sampled explanations, or brief written justifications.

Peer Instruction research consistently emphasizes the role of conceptual questions and instructor explanation rather than treating peer discussion as a self-sufficient method. Recent Nature Physics evidence similarly suggests that the overall allocation of class time and the intensity of student-centered activity influence conceptual outcomes.

In conceptually difficult courses, the instructor's role can therefore be described as network architect and epistemic regulator. The instructor creates the conditions under which students become resources for one another while retaining responsibility for the quality of the disciplinary knowledge that ultimately emerges.

7. Conclusion

Peer explanation networks provide a promising framework for strengthening conceptual learning in university courses where students commonly memorize procedures without fully reorganizing the mental models required for disciplinary understanding. Existing peer-instruction research demonstrates that explanation can improve understanding beyond simple answer transfer, and classroom-network research shows that learning relationships form structured patterns that can influence who receives opportunities to explain, challenge, and receive feedback. These two traditions become especially valuable when combined.

The Peer Explanation Network Model proposed in this study treats the classroom as a dynamic network of explanatory relationships rather than a set of fixed pairs. Students move through cycles of individual commitment, explanation, challenge, rotation, revision, and instructor synthesis. Such a structure is designed to prevent the intellectual labor of explanation from becoming concentrated among a small number of confident or high-performing students. Every learner is expected to function repeatedly as both a source and recipient of reasoning.

The simulated analysis shows how future empirical work could examine relationships between network participation and conceptual mastery. Although the hypothetical dataset produces a strong positive correlation, the value is intentionally illustrative and should not be interpreted as empirical evidence. Real research should measure network diversity, reciprocity, explanation quality, prior achievement, participation equity, and conceptual gains longitudinally. The most recent multi-institutional physics evidence demonstrates why this richer approach is necessary: peer networks can appear similar even when instructional methods produce different conceptual-learning outcomes.

The broader conclusion is that peer learning becomes educationally powerful when explanation responsibility is distributed but epistemic standards remain rigorous. The objective should not be to make students talk more frequently. It should be to create networks in which conceptual reasoning is repeatedly articulated, challenged, reconstructed, and transferred. Future empirical research should test the proposed model in mathematics, physics, chemistry, engineering, statistics, economics, and other conceptually difficult courses; compare fixed and rotating networks; examine the role of explanation quality; and investigate whether deliberately structured network participation can reduce persistent achievement and participation inequalities. A well-designed explanation network can transform classmates from a passive social background into an active intellectual infrastructure for conceptual learning.

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