

Peer Discourse in Process-Based Physics Tasks: Discursive Moves and Meaning-Making in Asynchronous Learning

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ABSTRACT

This study examines the nature of peer discourse in an asynchronous introductory physics course that was intentionally redesigned from traditional discussion formats to process-based tasks requiring students to externalize their thinking through handwritten work, diagrams, concept maps, tables, and structured explanations. Drawing on qualitative content analysis, 64 peer responses generated by 18 students across four discussion modules in mechanics were analyzed. Rather than applying predefined instructional categories or assigning a single dominant code, responses were coded inductively to identify all discursive moves present within each contribution, allowing multiple overlapping forms of engagement to be captured within individual responses. The analysis revealed that peer discourse was strongly characterized by active engagement, including probing reasoning, interpreting representations, negotiating conceptual understanding, co-constructing explanations, and extending ideas. Conceptual negotiation and probing reasoning were particularly prominent, indicating sustained attention to underlying physics concepts and solution processes, while surface-level responses constituted a relatively small portion of the dataset. Qualitative examination of full student responses further demonstrated that individual contributions frequently integrated multiple discursive moves, highlighting the layered and dynamic nature of peer interaction. These findings suggest that peer discourse occurring within process-based tasks can be characterized by sustained engagement with reasoning, representations, and conceptual ideas. While the present study does not establish causal effects of instructional design, the findings indicate that process-based tasks may provide opportunities for these forms of peer engagement. In the context of increasing reliance on artificial intelligence (AI) tools, these findings may have implications for the design of learning activities that emphasize reasoning, representations, and visible thinking. Future research could examine how such approaches relate to AI-supported learning environments. The study contributes to understanding the characteristics of peer interaction observed within a process-based instructional context and highlights the potential of structured, process-oriented discourse as a site for engagement and meaning-making in asynchronous environments.

KEY WORDS: Asynchronous learning, discursive moves, peer discourse, physics education, process-based tasks, qualitative content analysis

INTRODUCTION

Persistent challenges in learning introductory physics have long been attributed to students' deeply held misconceptions, particularly in foundational areas such as motion and Newton's laws. These misconceptions often arise from everyday experiences and intuitive reasoning and frequently conflict with scientifically accepted models, making them resistant to traditional forms of instruction (Driver et al., 1994; McDermott, 1991; Viennot, 1979). Instructional approaches that emphasize correct answers without explicitly addressing underlying reasoning have been shown to be insufficient for promoting meaningful conceptual understanding (Hestenes et al., 1992; Posner et al., 1982). As a result, physics education research has increasingly shifted toward instructional designs that foreground reasoning, representation, and conceptual explanation as central components of learning.

One important direction in this shift involves the use of process-based tasks, which require students to make their

thinking visible through diagrams, graphs, written explanations, and structured problem-solving steps. Research has shown that such approaches can significantly enhance conceptual understanding and problem-solving ability, particularly when students engage with multiple representations that connect abstract concepts with visual and mathematical forms (Ainsworth, 2006; Kozma and Russell, 1997; Van Heuvelen, 1991). These representations play a critical role in helping students interpret relationships between physical quantities and construct coherent conceptual models. However, while the impact of process-based tasks on student performance and artifacts has been well documented, less attention has been given to how these tasks influence student interaction, especially in the context of peer interactions.

This gap becomes particularly prominent in asynchronous online learning environments, where interaction is mediated through written communication rather than real-time discussion. Asynchronous online learning discussion forums provide opportunities for reflection and elaboration, but their

effectiveness depends heavily on task design and the extent to which students meaningfully engage with each other's ideas (Garrison et al., 2000; Hrastinski, 2008). In such contexts, peer feedback represents a key site of interaction, where students encounter alternative perspectives, respond to reasoning, and potentially revise their own understanding. Prior research suggests that peer discussion can enhance conceptual learning when students engage in explanation and argumentation rather than simply comparing answers (Mazur, 1997; Smith et al., 2009). However, the nature of this discourse is closely tied to the kinds of artifacts students which are asked to produce.

Despite these insights, relatively little is known about what students actually say when interacting with process-based work, and whether such discourse reflects deeper engagement with reasoning, representations, and conceptual understanding. Much of the existing literature has focused either on task design or on student outcomes, with limited attention to the discourse that emerges between students in response to process-oriented artifacts. Understanding this discourse is critical, as it may reveal the ways in which peer interaction functions beyond simple feedback, including opportunities for reflection, meaning-making, and engagement with alternative perspectives.

The present study addresses this gap by examining the nature of peer discourse in an asynchronous introductory physics course in which all tasks were designed to be process-based. Rather than analyzing student artifacts themselves, this study focuses on student responses to those artifacts, exploring what students attend to, question, and critique in their interactions. Specifically, the study investigates whether peer discourse reflects engagement with reasoning processes, representations, and conceptual understanding, and whether such interaction suggests opportunities for learning beyond the completion of individual tasks.

THEORETICAL FRAMEWORK

This study is grounded in social constructivist perspectives, which conceptualize learning as socially mediated through interaction and dialogue (Vygotsky, 1978; Wertsch, 1991). From this perspective, knowledge is constructed as learners engage with one another's ideas, interpret alternative viewpoints, and negotiate meaning through language. In science education, this process is particularly important, as students must reconcile everyday intuitions with formal disciplinary concepts (Driver et al., 1994).

Within this framework, learning is not only supported by interaction but also by the use of external representations as mediating tools. In physics, representations such as diagrams, graphs, and equations play a central role in structuring reasoning and making abstract concepts visible (Kozma and Russell, 1997; Van Heuvelen, 1991). When shared in a learning environment, these representations function as cognitive artifacts that allow students to interpret, critique, and build on each other's thinking.

From a discursive perspective, peer interaction can be understood as a form of meaning-making through language, where students use talk, or in asynchronous settings, written responses, to engage with and transform understanding (Sfard, 2008). Discourse in this sense is not merely communication, but a process through which knowledge is constructed, negotiated, and refined. When students respond to peers' representations and explanations, they are participating in a form of process-oriented discourse, in which reasoning, assumptions, and conceptual relationships become the focus of interaction.

Importantly, engaging with peer-generated artifacts creates opportunities for students to move beyond their initial thinking. Research on peer discussion suggests that interaction can stimulate explanation, comparison, and conceptual refinement, particularly when students engage with underlying reasoning rather than simply evaluating answers (Chi, 2009; Smith et al., 2009). In this way, discourse becomes a site where learning is distributed across individuals and representations, and where understanding emerges through collective engagement with visible thinking.

Building on these perspectives, the present study examines peer feedback as a form of process-oriented discourse, focusing on how students engage with reasoning, representations, and conceptual ideas in response to process-based tasks. Rather than conducting a formal discourse analysis of language structure, this study analyzes patterns in what students attend to and how they engage with one another's thinking, to understand the nature of interaction and its potential role in supporting learning.

LITERATURE REVIEW

There have been ongoing challenges in supporting conceptual understanding in asynchronous science classrooms. For example, Nigon et al. (2024) found that students in face-to-face settings demonstrated significantly higher conceptual understanding than those in asynchronous online environments. Related work suggests that these differences may be linked to the nature of participation in asynchronous discussions. Widiastih et al. (2025) observed that participation in such contexts often remains limited and surface-level, with relatively few students contributing and many posts focused on superficial engagement. However, they also found that students who engaged more deeply with the content in their contributions tended to achieve higher levels of conceptual understanding. Taken together, these findings highlight the importance of designing asynchronous learning environments that promote meaningful engagement rather than surface-level interaction.

Teaching for conceptual understanding is crucial because research in physics education has consistently demonstrated that students enter introductory courses with deeply rooted alternative conceptions that conflict with scientific understandings, particularly in mechanics and Newtonian

physics (Driver et al., 1994; McDermott, 1991; Viennot, 1979). These misconceptions have been shown to persist even after instruction, raising concerns about the effectiveness of traditional lecture-based approaches (Hake, 1998).

As a result, a substantial body of research has explored instructional approaches that emphasize conceptual understanding and reasoning processes rather than procedural problem solving alone. Research on active engagement in physics has traditionally emphasized structured peer interaction in synchronous, face-to-face settings (Mazur, 1997; Smith et al., 2009). More recent work has begun to examine the potential of fully asynchronous instruction, raising questions about how meaningful interaction can be sustained in such contexts (Massey-Noel, 2026). This shift highlights the need for instructional designs that deliberately translate principles of active engagement into asynchronous environments by fostering meaningful peer interaction and engagement with reasoning.

One major direction in this research has been the development of process-based and interactive instructional methods, including modeling instruction and peer instruction. Studies of peer instruction have shown that engaging students in discussion around conceptual questions can improve conceptual gains compared to traditional teaching, particularly when students are required to articulate and defend their reasoning (Mazur, 1997; Smith et al., 2009). For example, Smith et al. (2009) demonstrated that peer discussion can lead to improved accuracy even when no group member initially holds the correct answer, suggesting that interaction itself contributes to conceptual refinement. However, while such studies highlight the importance of interaction, they often focus on learning outcomes rather than examining the nature of the discourse that produces those outcomes.

Related work has emphasized the role of diagrams, graphs, and equations as central tools for reasoning in asynchronous physics classrooms. Multiple representation frameworks argue that understanding is strengthened when students can coordinate between different representational forms (Ainsworth, 2006; Kozma and Russell, 1997; Van Heuvelen, 1991). Empirical studies have shown that engaging with diagrams and graphical representations can support conceptual understanding and problem solving, as representations make abstract relationships more visible and manipulable (Kozma and Russell, 1997; Van Heuvelen, 1991). At the same time, other studies have pointed out that students often struggle to interpret or construct representations effectively, limiting their benefits unless explicitly taught (Kohl and Finkelstein, 2006). This tension suggests that while representations are powerful, their effectiveness depends not only on their use but also on how students engage with and interpret them.

Research on peer feedback and interaction further complicates this picture. In educational contexts, feedback has been identified as one of the most influential factors affecting learning, particularly when it focuses on processes rather than

outcomes (Hattie and Timperley, 2007). However, studies have also shown that student-generated feedback often remains superficial, emphasizing correctness, praise, or procedural comments rather than deeper engagement with reasoning (Nicol et al., 2014). In contrast, studies on collaborative learning suggest that when students engage in explanation, questioning, and critiquing, their interaction can promote deeper learning and conceptual change (Chi, 2009). This divergence highlights a key issue: Peer interaction has the potential to support learning, but its effectiveness depends on the quality and focus of discourse.

In physics education specifically, research on peer discussion has demonstrated that meaningful learning is associated with discourse that emphasizes conceptual reasoning and explanation. For instance, studies have shown that students who engage in explanatory talk during collaboration outperform those who focus primarily on answers (Mazur, 1997; Smith et al., 2009). However, much of this work has been conducted in synchronous classroom settings, where interaction is immediate and often instructor mediated. Less is known about how such dynamics operate in asynchronous environments, where communication is delayed and entirely text-based.

Asynchronous discussion forums have been widely adopted in online and blended learning, offering opportunities for reflection and extended engagement. Research suggests that such environments can support deeper thinking when tasks require elaboration and explanation, as students have more time to construct responses (Garrison et al., 2000; Hrastinski, 2008). However, studies also indicate that without careful task design, participation can remain limited or focus on surface-level interaction, such as agreement or minimal feedback (Hew and Cheung, 2010). This raises questions about how instructional design, particularly the use of process-based tasks, might shape the nature of discourse in asynchronous settings.

Despite extensive research on misconceptions, representations, and peer interaction, there remains a notable gap in understanding how these elements intersect. Much of the existing literature has examined student artifacts (such as diagrams, problem solutions, or conceptual test scores) or has focused on learning gains resulting from instructional interventions. In parallel, a substantial body of work has analyzed asynchronous discussion forums, often emphasizing participation patterns, cognitive presence, or levels of knowledge construction (Garrison et al., 2000; Hew and Cheung, 2010). Other studies have explored peer feedback in online environments or the use of multimedia artifacts such as video-based discussions and peer-reviewed presentations to support engagement and interaction (Moffat et al., 2021; Lowenthal et al., 2022). While these studies provide valuable insight into the role of interaction in online learning, they typically rely on predefined coding frameworks, aggregate indicators, or participation measures. Far fewer studies have examined peer interaction itself as the primary unit of analysis in a fine-grained way, particularly in contexts where students

are responding to process-oriented work that makes reasoning and representations visible. In other words, although prior research demonstrates that both process-based tasks and asynchronous interaction can support learning, relatively little is known about what students actually do discursively when engaging with such tasks, especially when multiple forms of engagement co-occur within individual responses.

The present study addresses this gap by focusing explicitly on peer discourse as a form of engagement with peers' representations, reasoning, and conceptual explanations in an asynchronous, process-based context. By analyzing what students attend to, question, and extend in their responses, the study seeks to provide insight into the nature of interaction that emerges from process-based instructional design, and whether such interaction reflects opportunities for learning beyond individual task completion.

METHODOLOGY

This study employed a qualitative content analysis approach to examine the nature of peer discourse in an asynchronous introductory physics course. Qualitative content analysis is particularly suited for systematically interpreting textual data through the identification of patterns, categories, and underlying meanings (Krippendorff, 2018). It enables researchers to move beyond surface-level descriptions of text to develop conceptual insights into how participants construct and communicate meaning. In this study, the method was used to analyze how students engaged with one another's work, with particular attention to the discursive actions through which students interpreted, questioned, and extended peer ideas.

The study was conducted in a fully asynchronous introductory Principles of Physics course for non-science majors at a public community college in the United States during the Spring 2026 semester. The course spanned 14 weeks and included multiple discussion activities designed to support engagement with course content. Although 24 students were enrolled in the course, 18 students consented to participate in the study and their responses were included in the dataset. The dataset consisted of 64 individual peer feedback responses generated by these 18 students across four discussion modules covering key topics in mechanics: Newton's First Law, Linear Motion, Newton's Second Law, and Newton's Third Law. The four discussion modules analyzed in this study represented a subset of discussion activities implemented during the semester. These modules were selected because they focused on foundational mechanics concepts and generated substantial peer interaction involving representations, explanations, and problem-solving processes. The mechanics modules also provided a conceptually coherent dataset for examining how students engaged with one another's reasoning in response to process-based tasks. Because students often contributed multiple comments and addressed more than one peer within a single discussion, the unit of analysis was the individual response rather than the student. This approach aligns with qualitative research practices that emphasize analyzing meaning units

within texts rather than aggregating data at the participant level (Creswell, 2013).

All discussion prompts were associated with tasks intentionally designed as process-based, requiring students to externalize their thinking through diagrams, graphical representations, handwritten solutions, tables, and written explanations of reasoning. These tasks were developed through the redesign of traditional discussion activities and emphasized the construction and communication of reasoning rather than the presentation of final answers alone. Such an approach aligns with modeling-oriented perspectives in physics instruction, which emphasize making reasoning visible through representations (Hestenes, 1987). These tasks emphasized the construction of solutions rather than the correctness of final answers, thereby generating rich artifacts for peer interpretation and feedback. Across all modules, students were required to respond to a classmate's submission by either asking a probing or clarifying question about the work presented or describing an alternative approach to the same problem. Peer responses were evaluated using a discussion rubric that emphasized substantive engagement with classmates' reasoning, representations, and explanations.

Because the present study focuses on peer responses to process-based artifacts, it is important to characterize the nature of the tasks that generated those artifacts. Table 1 provides representative examples drawn from the four mechanics modules included in the analysis, together with the corresponding task types. Students were provided with multiple process-based activity options within each module and completed a subset of the available tasks.

Following submission of their work, students were required to engage with a classmate's contribution by providing a peer response. Students were instructed to either ask a probing or clarifying question about a peer's work or describe an alternative approach to the same problem. Peer responses were evaluated using a discussion rubric that emphasized substantive engagement with classmates' ideas rather than simple agreement or praise. Within educational research, such peer interactions are recognized as important opportunities for learning, as feedback can provide clarification, alternative reasoning strategies, and opportunities for reflection (Hattie and Timperley, 2007).

Through iterative comparison across responses, related codes were refined, consolidated, and differentiated. For example, responses such as "*Why did you decide to use that formula instead of the other one we learned?*" were categorized as probing reasoning because they focused on understanding how a peer arrived at a solution. In contrast, responses such as "*Does net force = 0 mean the object stops, or can it still keep moving?*" were categorized as conceptual negotiation because they centered on examining or reconciling an underlying physics concept. Similarly, responses such as "*I agree with your explanation, and I think it also relates to Newton's Second Law because of $F = ma$* " were categorized as co-construction of understanding because they explicitly built on a peer's idea,

Table 1: Representative process-based task prompts from the four mechanics modules

Module	Representative task prompt	Task type
Newton's First Law	Tossed coin on a train; motion sketch ✓ Draw two panels on paper: ✓ Panel A: Train moving at constant speed when the coin is tossed straight up. Show the coin and train at launch and landing, from a passenger's viewpoint and from a ground observer's viewpoint (you can use two small subsketches). ✓ Panel B: Train slowing down while the coin is in the air. Show where the coin lands relative to the passenger. ✓ Upload your sketches. ✓ In 5–7 sentences, use your drawings to explain: Where the coin lands in each case. ✓ How inertia and relative motion explain the difference between uniform motion and slowing down.	Representation-Based Reasoning Task
Linear Motion	Coin in a well, annotated solution ✓ Mr. Wolf drops a coin into a well; it hits the water after 5 s. ✓ On paper: Draw a simple diagram of the well and the coin's motion (including an arrow for the direction of motion). ✓ Under your diagram, use kinematic equations by hand to: Find the coin's striking speed after 5 s, compute the average speed during the fall, and determine the depth of the water surface. ✓ Clearly box or underline each final result. ✓ Upload your page. ✓ In 5–7 sentences, explain how your diagram and calculations show the role of acceleration due to gravity and how average speed differs from instantaneous speed.	Procedural and Analytical Reasoning Task
Newton's Second Law	PhET "Forces and Motion," screenshot plus sketch ✓ Open the PhET "Forces and Motion" simulation (or watch the instructor's demo video if you cannot run it). ✓ Choose one scenario from the simulation (for example, pushing a box with friction). ✓ On paper, sketch what you saw: the object, applied forces, friction, and resulting motion, labeling all forces. ✓ Upload your sketch (you may also add a screenshot if allowed, but your sketch is required). ✓ In 5–7 sentences, describe what you changed in the simulation (force, mass, and friction) and how it affected the acceleration, using your drawing and Newton's Second Law to explain.	Multi-Representational Reasoning Task
Newton's Third Law	Two masses on frictionless surface, action–reaction diagram ✓ Draw Object A (2 kg) and Object B (1 kg) on a frictionless surface, with Object A pushing Object B to the right. ✓ Draw and label: The 10 N force of A on B to the right, the force of B on A to the left. ✓ Under the drawing, write the Third Law pair explicitly and then use $F_{net}=ma$ to compute the acceleration of each object. ✓ Upload your work. ✓ In 4–6 sentences, explain how your diagram and calculations show that the forces between A and B are equal and opposite, but their accelerations differ because of their different masses.	Modeling and Conceptual Reasoning Task

whereas responses such as “*What would happen if there was no friction in this situation?*” were categorized as extension of ideas because they introduced a hypothetical scenario beyond the original task.

To further enhance transparency and consistency in category assignment, operational definitions were developed for each discursive category and are summarized in Table 2.

Rather than assigning a single dominant code to each response, the analysis identified all discursive moves present within each contribution. This non-mutually exclusive coding approach allowed a response to be associated with multiple categories when it exhibited more than one form of engagement. This decision was made to more accurately capture the layered nature of peer discourse, where students frequently integrate questioning, interpretation, conceptual reasoning, and evaluation within a single interaction. As a result, coding focused on the presence of discursive features across responses rather than forcing each contribution into a single category.

To enhance the credibility of the analysis, the coding process involved collaborative review and negotiated agreement. One author conducted the initial coding of all responses and organized the coded data into preliminary categories. The second

Table 2: Operational definitions of discursive categories

Category	Operational Definition
Probing Reasoning	Questions or comments aimed at understanding how a peer arrived at a solution or conclusion.
Interpreting Representations	Engagement with diagrams, graphs, arrows, tables, equations, or other representations produced by a peer.
Conceptual Negotiation	Discussion that examines, questions, clarifies, or reconciles underlying physics concepts or principles.
Co-construction of Understanding	Explicitly building upon a peer's idea by adding reasoning, connections, or elaborations.
Evaluative Feedback	Suggestions, critiques, or recommendations intended to improve clarity, accuracy, or communication.
Extension of Ideas	Introduction of hypothetical situations, alternative conditions, or applications beyond the original task.
Surface-Level Response	Minimal engagement consisting primarily of praise, agreement, or acknowledgement without substantive discussion.

author then reviewed the resulting coding framework, category definitions, representative coded examples, and the consistency of category interpretation across the dataset. Questions regarding category boundaries and category assignments were discussed through iterative dialogue, particularly for conceptually related categories such as probing reasoning,

conceptual negotiation, co-construction of understanding, and extension of ideas. Through this process, consensus was reached regarding the final coding framework and application of the categories. Consistent with this negotiated qualitative approach, no statistical inter-rater reliability coefficient was calculated. Instead, trustworthiness was supported through collaborative review, reflexive discussion, and consensus-building regarding category definitions and interpretations (Creswell, 2013; Mayring, 2014).

To support transparency and trustworthiness, representative exemplar quotes were selected from the dataset to illustrate each discursive category. Quotations presented in the Results section and Appendix A are drawn from student responses and are reported verbatim except for minor corrections to spelling, punctuation, and capitalization made to improve readability where necessary. These excerpts were chosen to reflect recurring patterns in the dataset rather than isolated or exceptional cases. In addition, a subset of complete student responses was included in the Results section to provide a fuller representation of the discourse and to demonstrate how multiple discursive moves co-occur within individual interactions. Further examples of full responses are provided in Appendix A to illustrate the range and variability of peer engagement.

While frequency counts were used to provide an overview of the distribution of discursive features, the primary aim of the analysis was to examine the qualitative nature of peer interaction. The focus was therefore on how students engaged with, interpreted, and built on each other's thinking. Although this study does not constitute a formal linguistic discourse analysis, it draws on a discursive perspective by treating peer feedback as a site of meaning-making through interaction.

Several limitations should be acknowledged. Participation varied across discussion modules, and not all students contributed equally, resulting in uneven representation in the dataset. In addition, the study does not include a comparison with traditional, product-focused tasks and therefore does not claim that the observed patterns are unique to process-based instruction. Finally, as with all qualitative research, the analysis involved interpretive judgment; however, the use of iterative coding, clearly defined categories, and collaborative review was intended to enhance the consistency and credibility of the findings.

RESULTS

To better understand the nature of peer interaction, responses were analyzed in terms of the discursive actions students performed when engaging with their peers' work. Rather than categorizing responses according to predefined instructional features or assigning each response to a single category, all discursive moves within each contribution were identified. This approach allowed individual responses to be associated with multiple categories when they exhibited more than one form of engagement. Accordingly, the categories were not

treated as mutually exclusive; instead, the analysis focused on the frequency of discursive features across responses rather than on discrete response types. This method captures the overlapping and multi-layered nature of peer discourse, in which multiple forms of engagement frequently co-occur within a single response.

As shown in Table 3, the distribution of discursive moves highlights the range of ways in which students participated in meaning-making, including probing reasoning, interpreting representations, negotiating conceptual ideas, and collaboratively refining understanding.

The distribution of discursive features across peer responses is shown in Table 3. Responses were analyzed by identifying all discursive moves present within each contribution, allowing a single response to be coded into multiple categories when it exhibited more than one form of engagement. As such, the coding scheme was non-mutually exclusive, and the reported counts represent the frequency of discursive features rather than discrete responses. Because the coding scheme was non-mutually exclusive, category frequencies represent that the number of times a discursive feature was identified within the dataset rather than the number of responses or students exhibiting that feature. Percentages are therefore reported relative to the total number of coded features ($n = 141$) and are intended as descriptive characteristics of the qualitative dataset. These percentages reflect the relative frequency of each discursive move within the overall discourse. Because individual responses could include multiple discursive moves, a single response may contribute to more than one category. As a result, the percentages do not sum to 100%, but instead reflect the overlapping nature of discursive features within the dataset.

Across the coded features, peer discourse was strongly characterized by active engagement with reasoning, representations, and conceptual understanding. Conceptual negotiation was the most frequently identified discursive feature, accounting for 22% of all coded features within the corpus. Probing reasoning (20% of coded features) and interpretation of representations (16% of coded features) were also prominent within the dataset, indicating sustained attention to understanding how solutions were constructed and how representations conveyed meaning. Co-constructive contributions (13% of codes) further demonstrate that students frequently built on and extended one another's ideas, while extension of ideas (12% of codes) and evaluative feedback (11% of codes) show that students moved beyond immediate tasks and engaged in refining peer work. In contrast, surface-level responses were relatively limited (6% of codes), suggesting that most interactions involved substantive engagement. Taken together, the convergence of these measures highlights the depth and complexity of peer discourse, with responses often integrating multiple forms of meaning-making within a single contribution.

Table 4 presents representative excerpts from student responses illustrating each discursive move.

Table 3: Distribution of discursive moves identified in the peer response corpus (n=141 coded features)

Category	What student is doing	Example phrase	Count	% of codes
Probing Reasoning	Trying to understand how/why the solution works	“Why did you use that?”	28	20
Interpreting Representations	Talking about diagrams, arrows, graphs	“Why is this arrow that long?”	22	16
Conceptual Negotiation	Thinking about the physics idea itself	“Does net force=0 mean stop?”	31	22
Co-construction	Building on peer idea (agree+extend)	“I agree, but also...”	19	13
Evaluative Feedback	Suggesting improvements	“You could label this better”	15	11
Extension of Ideas	Going beyond the problem (“what if”)	“What if there was no friction?”	17	12
Surface Response	Minimal response (praise only)	“Good job!”	9	6

Table 4: Discursive moves and exemplar student quote

Discursive Move	Representative Student Quote
Probing Reasoning	“Why did you decide to use that formula instead of the other one we learned?”
Interpreting Representations	“How did you decide how long each arrow should be in your diagram?”
Conceptual Negotiation	“Does net force=0 mean the object stops, or can it still keep moving?”
Co-construction of Understanding	“I agree with your explanation, and I think it also relates to Newton’s Second Law because of $F=ma$.”
Evaluative/Formative Feedback	“Adding the equation could make your explanation clearer and stronger.”
Extension of Ideas	“What would happen if there was no friction in this situation?”
Surface Response	“Great job, your explanation is really clear.”

Quotations are drawn from student responses in the analyzed dataset and are presented as examples of the discursive categories identified in the analysis. Individual responses often contained multiple overlapping forms of engagement

Illustrative Full Responses with Commentary

While Table 4 presents concise excerpts, individual student responses often contained multiple layers of engagement within a single interaction. The examples below are presented in full to illustrate how discursive moves unfolded in context. Each example is accompanied by brief commentary to highlight how students engaged with peers’ ideas and how multiple forms of meaning-making co-occur within a single response.

Example 1

“I agree with your answer, but I was wondering why you chose that formula instead of the other one we used before. Also, for the diagram, how did you decide the length of the arrows? I think labeling them might make it clearer. I didn’t think about breaking the forces into components until I saw your approach.”

This response illustrates a combination of discursive moves within a single contribution. The student begins with agreement but quickly transitions into probing reasoning by questioning the choice of formula. This is followed by interpretation of representations through questions about the diagram’s construction. The suggestion to label the arrows reflects evaluative feedback, while the final statement may indicate reflection on the student’s own understanding or engagement with an alternative approach. Together, these elements

highlight how interpretation, evaluation, and conceptual reflection can operate simultaneously within peer interaction.

Example 2

“Your explanation makes sense, but I’m a little confused about the net force being zero. Does that mean the object stops, or can it still move? I always thought it meant stopping, but now I’m not sure. Also, what would happen if there was no friction in this case?”

In this response, the student engages in conceptual negotiation by explicitly expressing uncertainty about the meaning of net force. The questions posed reflect an effort to reconcile prior understanding with the peer’s explanation. The statement “I always thought...” signals conceptual tension, while the follow-up introduces an extension of ideas through a hypothetical scenario. This example demonstrates how peer discourse can prompt both reflection on existing beliefs and exploration beyond the immediate task.

Example 3

“I like how you showed the diagram, it helped me understand the direction of the forces. I agree with your answer, and I think it also relates to Newton’s Second Law because of $F = ma$. Maybe adding the equation would make your explanation stronger.”

This response reflects co-construction of understanding, as the student builds on the peer’s explanation and connects it to a broader principle. The reference to Newton’s Second Law extends the original reasoning, while the suggestion to include the equation represents evaluative feedback. The initial comment also shows interpretation of representations, illustrating how visual elements support meaning-making. Overall, the response integrates interpretation, extension, and refinement within a single contribution.

Example 4

“I noticed that your graph shows the velocity increasing steadily, but I was wondering how that connects to acceleration. Would the slope of the graph represent that? I think if you added that explanation, it might make it clearer to someone reading it.”

This response combines probing reasoning and interpretation of representations. The student engages directly with a graphical representation and seeks to understand the relationship between velocity and acceleration. The reference to slope demonstrates

emerging conceptual reasoning tied to the representation, while the suggestion to clarify this point reflects evaluative feedback. This example highlights how students use representations as a basis for deeper conceptual inquiry.

Example 5

“I like your explanation about friction, especially how you connected it to real life. I was thinking, what would happen if the surface was completely smooth, like ice? Would the object keep moving without slowing down? That part helped me think differently about how motion works.”

This response illustrates extension of ideas and conceptual negotiation. The student builds from the peer’s explanation by introducing a new hypothetical scenario, prompting consideration of motion in the absence of friction. At the same time, the statement about ‘thinking differently’ suggests engagement with an alternative conceptual interpretation and may indicate conceptual reflection. Although the response begins with positive feedback, its primary function lies in extending and reinterpreting the underlying concept.

Example 6

“Great job! Your diagrams are really clear and easy to understand.”

This response represents a surface-level form of engagement, as it is limited to general praise without further elaboration. While the student acknowledges the clarity of the diagrams, the response does not include questioning, interpretation, or attempts to engage with the underlying reasoning or concepts. There is no effort to extend the idea, suggest improvements, or connect it to broader principles. As such, the interaction remains at a minimal level, serving primarily a supportive or social function rather than contributing to deeper meaning-making.

Additional examples of full peer responses illustrating the range of discursive features observed are provided in Appendix A.

DISCUSSION

The findings of this study provide insight into the nature of peer discourse in a context where tasks were explicitly designed to foreground reasoning, representation, and conceptual understanding through process-based artifacts such as handwritten work, diagrams, and structured explanations. Rather than functioning primarily as evaluative feedback, student responses were characterized by a range of discursive actions through which participants engaged with one another’s thinking. Across the dataset, students consistently asked questions, interpreted representations, negotiated conceptual ideas, and built on peer contributions, suggesting that peer interaction extended beyond verification of answers and became a site for meaning-making.

A central pattern in the data was the prevalence of responses that oriented toward understanding how solutions were

constructed. Probing reasoning emerged as one of the most prominent features, indicating that students frequently approached peer work as something to be interpreted and unpacked rather than simply assessed. This stands in contrast to prior research on peer feedback, which often finds that student comments remain focused on correctness or general evaluation (Hattie and Timperley, 2007; Nicol et al., 2014). In the present context, however, students repeatedly engaged with the logic underlying solutions, asking why particular approaches were used and how steps were justified. This suggests that when tasks require learners to externalize their thinking, the resulting artifacts invite interpretive engagement, shifting interaction toward reasoning rather than judgment.

A related pattern was the sustained attention to representations, particularly diagrams and graphical elements. Students did not treat these as secondary to the solution, but as central objects of meaning. Responses frequently involved questioning how diagrams were constructed, evaluating their clarity, and suggesting refinements. This aligns with research emphasizing the importance of representations as tools for reasoning in physics (Kozma and Russell, 1997; Van Heuvelen, 1991), but extends it by showing how such representations also function as shared resources for interaction. When made visible, representations become accessible to peers, allowing them to engage directly with another student’s thinking. In this sense, representations operate not only as cognitive tools for individuals but also as interactional tools that support collective interpretation and discussion.

The data also revealed frequent instances of conceptual negotiation, where students articulated uncertainty, questioned assumptions, and attempted to reconcile conflicting ideas. These moments are particularly significant given the well-documented persistence of misconceptions in physics learning (Driver et al., 1994; McDermott, 1991). In several cases, students explicitly reflected on their thinking, suggesting that engagement with peer explanations may create opportunities for reconsidering prior ideas. Such exchanges are consistent with models of conceptual change, in which learning involves confronting and reorganizing existing knowledge structures (Posner et al., 1982). Although the present study did not directly measure conceptual change, the findings suggest that peer discourse may provide opportunities for students to engage with alternative perspectives and examine existing ideas. Another notable feature of the discourse was the presence of extension moves, in which students introduced hypothetical scenarios or variations that went beyond the original task. These responses indicate that students were not limited to completing assigned problems but were actively exploring how concepts might apply under different conditions. This form of engagement may reflect attempts to apply ideas beyond the immediate context of the original task. Importantly, these extensions were not always prompted directly by the task itself but often emerged through interaction, indicating that peer discourse can stimulate additional cognitive engagement beyond immediate task requirements.

Also notable is the presence of co-constructive responses, where students built on and refined one another's ideas. Rather than simply agreeing or disagreeing, students frequently added new elements, clarified reasoning, or connected explanations to broader principles. These interactions are consistent with collaborative knowledge-construction processes, in which participants build on and elaborate one another's ideas. This is consistent with social constructivist perspectives that emphasize the role of interaction in learning (Vygotsky, 1978; Wertsch, 1991), as well as research showing that peer discussion can enhance conceptual understanding when students engage in explanation and elaboration (Smith et al., 2009).

In this context, peer discourse functioned not simply as feedback but as a space in which ideas were discussed, elaborated, and refined.

Importantly, the analysis revealed that these forms of engagement did not occur in isolation. Individual responses frequently combined multiple discursive moves, such as questioning, interpretation, conceptual reasoning, and evaluation within a single contribution. This layered structure of interaction suggests that peer discourse operates as a dynamic and multifaceted space for meaning-making, rather than a set of discrete or independent communicative functions.

Taken together, these findings describe the nature of peer interaction observed within this process-based instructional context. While the study was not designed to establish causal effects of instructional design, the findings suggest that process-based tasks may provide opportunities for discourse centered on reasoning, representations, and conceptual ideas. By requiring students to externalize their thinking, process-based tasks generate artifacts that make reasoning visible and available for critique and interpretation. These artifacts provide a shared basis for interaction, enabling students to engage with one another's ideas in ways that extend beyond correctness and answer comparison. In the context of increasing access to AI tools capable of generating complete solutions, the present findings may have implications for the design of learning activities that emphasize processes, representations, and reasoning. Future research could examine whether these forms of task design influence the nature of student engagement in AI-supported learning environments.

A number of limitations should be noted. Participation varied across modules, resulting in uneven representation in the dataset. In addition, the analysis is based on peer feedback rather than the original student artifacts, so interpretations of task types are indirect. The identification of discursive features involved interpretive judgment, particularly given the overlapping nature of categories. Future research could analyze student artifacts alongside peer feedback or compare discourse patterns across different instructional formats. Overall, the findings highlight the forms of peer discourse observed in response to process-based tasks, particularly the attention students devoted to representations, reasoning, and conceptual ideas. Although AI use was not examined in the present study,

the observed emphasis on visible reasoning, representations, and process-oriented explanations aligns conceptually with current discussions of AI-resilient assessment design, which increasingly emphasize documenting how solutions are constructed rather than evaluating final answers alone.

CONCLUSION

This study examined peer discourse generated in response to process-based physics tasks in an asynchronous introductory physics course. Analysis of 64 peer responses revealed that students frequently engaged in probing reasoning, interpreting representations, negotiating conceptual ideas, co-constructing explanations, and extending discussions beyond the immediate requirements of a task. The findings highlight the diverse and often overlapping forms of engagement that characterized peer interaction in this instructional context.

The primary contribution of the study is its characterization of peer discourse through a non-mutually exclusive coding approach that captures multiple discursive moves within individual responses. Rather than focusing exclusively on participation rates or predefined interaction categories, the analysis illustrates how students engaged with peers' representations, reasoning processes, and conceptual explanations. These findings suggest that process-based tasks may provide opportunities for substantive peer engagement in asynchronous learning environments.

At the same time, the study does not establish causal effects of process-based task design, nor does it provide direct evidence of conceptual learning outcomes. Future research should examine how discourse patterns compare across different instructional formats, explore relationships between discourse and student learning, and investigate how process-oriented designs function in evolving online learning environments.

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APPENDIX

Appendix A. Additional examples of full peer responses across discursive categories

Example	Full Student Response	Discursive Features Observed
A1	"Hi, I really liked how you explained that the force diagram helped you understand how applied force, gravity, and the normal force act on an object. I was also wondering, how do you calculate the acceleration when the forces are acting at different angles?"	Probing Reasoning; Conceptual Negotiation
A2	"I like how you explained the difference between distance and displacement using the sketch. One thing I was thinking about is if the object takes a curved path instead of a straight line, would the displacement still be the same?"	Conceptual Negotiation; Extension of Ideas
A3	"Your diagrams are really clear and helped me understand the forces better. One suggestion is to label each force so it's easier to follow what is happening."	Evaluative Feedback; Interpreting Representations
A4	"I agree with your explanation, especially how you showed that the acceleration depends on mass. I think this also connects to Newton's Second Law because of $F=ma$."	Co-construction; Conceptual Negotiation
A5	"For the graph you made, I was a bit confused about why the line is straight. Does that mean the acceleration is constant? I think explaining that part could make it clearer."	Probing Reasoning; Interpreting Representations; Evaluative Feedback
A6	"I noticed that both bricks fall at the same rate even though one is heavier. I always thought the heavier one would fall faster, so this made me rethink that idea."	Conceptual Negotiation; Conceptual Reflection
A7	"What would happen if there was no friction acting on the object? Would it keep moving forever or eventually stop?"	Extension of Ideas; Conceptual Negotiation
A8	"I like how you broke the forces into x and y components. I didn't think about it that way before, and it helped me understand how to solve the problem."	Co-construction; Conceptual Reflection
A9	"Your explanation makes sense, but I'm not sure why the arrows are different lengths. Shouldn't they be the same if the forces are equal?"	Interpreting Representations; Probing Reasoning
A10	"Great job, everything is very clear and well explained."	Surface Response
A11	"I was looking at your elevator example and noticed that the normal force is greater than gravity. Is that why the acceleration is upward?"	Probing Reasoning; Conceptual Negotiation
A12	"The way you explained the tug-of-war example really helped me understand how friction works. I was also wondering if the outcome would change if both sides had the same shoes."	Co-construction; Extension of Ideas
A13	"Your velocity-time graph looks good, but I think showing the starting velocity more clearly would help."	Evaluative Feedback; Interpreting Representations
A14	"I agree with your answer, but I think you could also explain why the forces don't cancel if they act on different objects."	Co-construction; Conceptual Negotiation
A15	"If the mass increases but the force stays the same, then the acceleration decreases, right? That's how I understood it from your explanation."	Conceptual Negotiation; Probing Reasoning
A16	"Nice work!"	Surface Response

Responses are presented in full to preserve the integrity of student discourse. Labels A1-A16 are anonymized identifiers assigned to individual responses. Coding reflects all discursive features identified within each response, and multiple categories may apply