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Accelerating Secondary Students' Learning Progression in Scientific Argumentation using Artificial Intelligence: An Educator's Guide and Online Course

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Abstract

Developing argumentation skills is key for secondary students' societal participation, particularly in socio-scientific discussions. Multiple learning progressions describe steps in the development and provide the base for effective instruction. Using artificial intelligence (AI) has been suggested to improve the implementation of instruction through its emerging capabilities, including providing feedback, acting like a tutor, or serving as an argumentation partner. However, examples demonstrating how AI could specifically support students in their learning progressions are lacking. This article addresses this gap by providing guidance for using AI to improve learning progression-based argumentation instruction. The guidance includes example AI prompts that integrate pedagogical content knowledge. We have developed a free online course that complements this article, offering practice tasks, explanatory videos, and AI prompts to facilitate further implementation. This course is accessible at https://open.hpi.de/courses/chatgpt2025 and includes a custom AI argumentation trainer [https://chatgpt.com/g/g-6856795be5788191872fcf33b1cbebf2-argumentation-trainer].

Keywords: Argumentation; Artificial Intelligence; Science Education; Secondary Education

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Promoting students' ability to engage in scientific argumentation is a central goal of teaching in science (e.g., NGSS, 2013) and language domains (Keller et al., 2020). Argumentative skills encompass the ability to construct, evaluate, and engage with arguments from others (Clark & Sampson, 2008). These skills enable students to participate meaningfully as informed citizens in societal discussions, particularly concerning socio-scientific issues (SSIs) (Osborne & Pimentel, 2022). Effectively teaching argumentation skills requires high-quality instruction that helps students manage the substantial cognitive and motivational demands of argumentative discourse (Keller et al., 2020, 2024; Klaver et al., 2023; Osborne et al., 2013).

Learning Progressions (LPs) serve as valuable "road maps" describing the successively more sophisticated ways of thinking about argumentation (Smith, et al., 2006). They outline the lower and upper anchors of skill development and allow students' routes between them to be highly variable and rarely linear (Alonzo & Gotwals, 2012). LPs are useful for informing instruction (Berland & McNeill, 2010; Kuhn & Udell, 2003; Osborne et al., 2016), and the effectiveness of LP-based instruction has been empirically validated (e.g., Friedrichsen et al., 2016; Smit et al., 2025). However, implementing LP-based instruction in real classrooms is resource-intensive, which means LP-based instruction is rarely implemented in science classrooms (Graham et al., 2021; Newton et al., 1999). Technology offers promising avenues to address these implementation challenges (Bächtold et al., 2023; Chen et al., 2024; Friedrichsen et al., 2016; Mikeska et al., 2025). Recent advancements, particularly in artificial intelligence (AI), have enabled AI to deliver interventions that have traditionally been part of LP-based instruction. This includes providing personalized feedback, acting as an argumentation partner, or simulating dialogues (e.g., Banihashem et al., 2024; Lin & Hung, 2025; Wambsganss et al., 2021).

However, concrete examples demonstrating to educators how AI's diverse capabilities can support students' advancement along established learning progressions in argumentation are missing. This article demonstrates how tasks leveraging recognized AI capabilities can be purposefully designed to support distinct stages of students' learning progression in argumentation, aiming to bridge the gap between subject matter teaching and technological advancement. We offer a free online course and AI tutor (https://chatgpt.com/g/g-6856795be5788191872fcf33b1cbebf2-argumentation-trainer) related to this article to improve its usefulness in the classroom. The course offers practice tasks, explanatory videos for secondary students, and AI prompts for the practice task. It is available as an open educational resource under https://open.hpi.de/courses/chatgpt2025 .

1 Understanding Argumentation and its Development

1.1 Defining Argumentation

Argumentation has been researched intensively, both in rather overarching areas like dialectics (Eemeren et al., 2015) and, more specifically, within science education (for an overview, see Clark & Sampson, 2008; Rönnebeck et al., 2016). Despite some ambiguities in terminology (Rönnebeck et al., 2016; Ryu & Sandoval, 2012), a central aspect is the importance given to the use of evidence, that is, the need to justify different kinds of claims

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with data (Clark & Sampson, 2007). Accordingly, scientific argumentation is often evaluated with regard to structural elements (e.g., the justification of claims with data and the use of warrants to connect them; Osborne et al., 2016). Other approaches (additionally or solely) focus on the conceptual quality of argumentation, i.e., whether an argument is substantive and knowledge of the content is required for its understanding (Clark & Sampson, 2007; Kelly et al., 1998). Here, the accuracy and adequacy of the argument's content serve as criteria for evaluating the argument's conceptual quality (Heitmann et al., 2014). In addition, complex problems often require consideration of multiple perspectives, and arguments must be managed through specific decision-making and opinion-forming strategies (Eggert & Bögeholz, 2010).

> "Taken as a whole, a competency for scientific argumentation demands a complex orchestration of construction and critique of claims, warrants, and evidence in situations that require scientific knowledge to resolve" (Osborne et al., 2016, p. 826). Complex problems are often chosen in the form of so-called socio-scientific issues that are directly linked to social contexts, show relevance for learners and curricula, and stimulate them to critical reflection and argumentation (Zeidler et al., 2019). In consequence, scientific argumentation happens at the interface between understanding science (with aspects of the nature of science and scientific reasoning) and social relevance (by means of socio-scientific issues and benefits of context-based learning) and, thus, reflects many goals and demands of regular science courses at the task level. In addition, language demands are high as students need to process (often mainly written) materials and background information as well as engage in argumentative writing. These processes depend on students' capabilities in the language these materials are presented in (Heitmann et al., 2014).

These complex demands in science and language domains come at a cost, as empirical findings consistently show that students from secondary school (e.g., Klaver et al., 2023; Schaller et al., 2024a) to university (e.g., Noroozi et al., 2023) have difficulty providing high-quality arguments; see Sadler, 2004; Noroozi et al., 2012 for reviews). Arguments often contain unjustified claims and lack a rational reasoning component (Kelly et al., 1998) while being largely intuitive and emotional (Dawson & Venville, 2009). Given these pervasive challenges, how can educators effectively develop students' argumentation skills?

1.2 Learning Progressions (LPs) for Argumentation

Understanding students' developmental trajectory is essential to effectively guiding them in developing argumentation skills. For socio-scientific argumentation, student progression can be conceptualized and fostered across three key stages, as delineated by Berland and McNeill (2010): the instructional context, drafting of an argumentative product, and the argumentative process. At the instructional context stage, the key learning goals are ensuring that students understand the argumentative problem, its value to themselves, the possible standpoints in the argumentation, and the usable criteria for evaluating these standpoints. As a result of these steps, students are able to decide based on explicit criteria which standpoint they will take in the following argumentation. Interventions designed to foster advancement at this stage include building students' connection to the argumentative problem (e.g., Smit et al., 2025), providing explicit explanations of the data (e.g., Friedrichsen et al., 2016), or offering representations to aid data interpretation (e.g., Hsu et al., 2015).

Drafting an argumentative product involves constructing a high-quality argumentation, including strong arguments and an effective argumentative structure. An effective structure

DOI: https://doi.org/10.2478/ristal-2025-0004

includes finding an introduction that establishes the topic with a clear thesis statement, and writing a conclusion that summarizes arguments and provides appropriate closure, for instance, through calls to action, advice, predictions, or compromises (Peltzer et al., 2024). Osborne and colleagues (2016) describe how students learn to articulate claims, evidence, reasoning (warrants), and rebuttals, progressing from a competence level in which students might only identify or critique isolated claims or evidence, to a level where they can construct explicit warrants linking claims and data. Interventions to support students in building an argumentative product mainly involve feedback on specific elements of their arguments (Peltzer et al., 2024).

The argumentative process emphasizes argumentation's social and dialogic aspects, which are critical for responding to and negotiating potentially diverging opinions in discussions (e.g., Kuhn & Moore, 2015; Larrain et al., 2019). Engaging in dialogic practice, where students question, critique, and build upon each other's ideas, is central for developing sophisticated argumentative discussions (e.g., Bouwer & van der Veen, 2024; Kuhn et al., 1997; Tavsanli et al., 2024; see Bächtold et al., 2023 for an overview). The goal is to move beyond simply stating one's own well-constructed argumentation and toward a dynamic process of listening, reflection, and adaptation in response to the arguments of others, which is necessary in societal discussions.

These learning progressions, from understanding the instructional context to building arguments and refining the argumentation through dialogue, have guided multiple effective programs, as exemplified by the work of Smit et al. (2025) and Friedrichsen et al. (2016). While these programs have demonstrated effective pathways for developing argumentation skills, their systematic implementation often demands considerable time and resources from educators. The detailed planning, individualized student support, and iterative feedback cycles inherent in fostering deep argumentative competencies across the instructional context, product, and process dimensions can be challenging to sustain in many classroom settings.

2 Artificial Intelligence in Argumentation Education: Capabilities and Applications

Artificial Intelligence (AI) presents compelling opportunities to make pedagogical approaches more accessible and scalable, yet there are also challenges regarding its implementation in practice to support student learning rather than replacing it (e.g., by cognitive offloading, Skulmowski, 2024). Emerging research and applications increasingly highlight AI's potential to deliver or enhance many of the critical interventions needed to support student progression in argumentation—acting, for instance, as an intelligent tutor to clarify content, a sophisticated feedback provider to refine arguments, or even a dynamic argumentation partner to foster critical engagement and reflection.

AI as a tutor can shape, clarify, and adapt the instructional context for argumentation (Berland & McNeill, 2010), tailoring the learning environment and the presentation of tasks (Wambsganss et al., 2021). Learning with AI tutors has been shown to enhance critical

DOI: https://doi.org/10.2478/ristal-2025-0004

thinking (Romero Ariza et al., 2024), a vital skill for understanding the demands of an argumentative task within a given context. Furthermore, AI tutors helped clarify the structural expectations of arguments and enabled students to reflect on and improve their work according to task requirements, for example, by visualizing argumentation schemes (Hoffmann & Lingle, 2015; Nussbaum et al., 2007).

Beyond establishing a supportive instructional context, AI excels as a feedback provider, a role crucial for helping students develop the quality and constituent components of their argumentative product (Berland & McNeill, 2010; Osborne et al., 2016). AI can offer timely and personalized critiques on the claims, evidence, warrants, and rebuttals students construct. It can effectively scaffold the creation of these argumentative components (Lin & Hung, 2025), guiding students towards more coherent and well-supported written or verbal arguments. This feedback can be delivered through different methods; AI might act as a peer (Banihashem et al., 2024) or simulate the feedback a teacher might give, for example, on the argument's structure and content (Meyer et al., 2024; Ruwe & Mayweg-Paus, 2022). Furthermore, AI systems can assist students in refining their argumentative product by assessing the relevance and weighting of arguments concerning a specific topic (Huang et al., 2015), prompting students to select stronger evidence or justify their reasoning more explicitly, thus enhancing the overall quality of their product.

To support the dynamic and interactive argumentative process, AI can transcend static instruction and feedback to act as a persona that is engaged in an argumentation (e.g., Guo et al., 2023). The effect of such practice is that it amplified student reflections during or after an argumentative exchange (Naik et al., 2025), a practice shown to be supportive of argumentation development (Bächtold et al., 2023). Another effect, when used as an argumentative chatbot, allows students to practice responding to differing viewpoints, critiquing opposing claims, and refining their positions in a simulated but responsive discursive environment, thereby actively participating in the argumentative process.

However, while the potential benefits of AI in these roles are offering tailored support for the instructional context, argumentative product, and argumentative process, it is also crucial to acknowledge potential drawbacks. The integration of AI into learning processes is not without its challenges. For example, there are concerns that over-reliance on AI tools could inadvertently reduce human agency and diminish deep engagement with the learning content itself (Darvishi et al., 2024). This underscores the need for careful implementation and a balanced perspective, ensuring AI serves as a tool to augment, not replace, critical human cognitive functions and active student participation in all dimensions of argumentation.

3 Present Study: Designing AI-Enhanced Exercises to Accelerate Argumentation Learning

This paper aims to provide a framework for integrating AI into argumentative writing instruction, assisting educators in implementing LP-based methods that improve students' argumentative skills. At each stage of the LP, we propose a function for AI support. Throughout the course, AI offers assistance as a tutor, feedback provider, and argumentation

DOI: https://doi.org/10.2478/ristal-2025-0004

partner. Educators can use the units as they are or adapt the proposed course structure to different topics or students' needs.

The initial stage of the LP, the instructional context, leverages AI to create a supportive and tailored learning environment. The progression begins with students building personal connections to the topic, a process AI can facilitate by helping brainstorm relevant scenarios (Smit et al., 2025). To ensure students grasp the debatable nature of the issue, an AI tutor can present multiple plausible standpoints (Friedrichsen et al., 2016; Wambsganss et al., 2021). As students explore background materials, the AI acts as an on-demand resource, providing simplified explanations for technical terms (Friedrichsen et al., 2016; Smit et al., 2025). This stage culminates in students analyzing and weighing criteria to form a standpoint, where AI can present comparative data through interactive graphics and help students assess how their personal ranking of criteria aligns with a particular solution (Hsu et al., 2015).

The second stage focuses on the argumentative product, where AI functions as a writing coach and feedback provider. After students plan the structure of their argument (Peltzer et al., 2024), AI provides guidance on the essential components of a compelling introduction. A key AI intervention is offering feedback on the clarity and argumentative power of a student's claim (Lin & Hung, 2025) and providing templates to map the claim-evidence structure (Hoffmann & Lingle, 2015; Nussbaum et al., 2007). As students write their warrants to connect evidence to claims (Osborne et al., 2016), AI can simulate a reader's perspective to test for clarity. For developing rebuttals, AI can generate relevant counterarguments for students to address or provide holistic feedback on a paragraph that integrates a refutation (Osborne et al., 2016; Meyer et al., 2024). Finally, AI can assist in crafting a strong conclusion and provide a digital rubric for self-assessment of the complete essay (Peltzer et al., 2024).

The final stage, the argumentative process, uses AI to facilitate social and dialogic practice. Here, AI can model constructive comments for peer-review activities and even check peer feedback for quality (Banihashem et al., 2024). To move beyond static text, AI can engage students as a chatbot or dialogue partner, playing the role of a "concerned citizen" or "expert" to challenge students' arguments and prompt them to defend and adapt their positions in a responsive environment (Guo et al., 2023; Kuhn & Moore, 2015). In a final synthesis step, students can even discuss their emerging group conclusions with an AI to reflect on their collaborative process (Naik et al., 2025; Tavsanli et al., 2024).

The following Table 1 offers a detailed breakdown of each step in this learning progression, aligning the specific student activities, AI support functions, and intended learning outcomes.

DOI: https://doi.org/10.2478/ristal-2025-0004

No	Step in LP	Activity	AI Support	Learning Outcome: Students can...
			Instructional context	
1	Engaging with the problem	Write down personal reasons why the skill of argumentation is important for the future (Smit et al., 2025).	Brainstorm additional reasons for the importance of argumentation.	... explain the personal relevance and value of argumentation skills.
2	Understanding the problem & potential solutions	Identify debatable questions that have multiple possible standpoints (Friedrichsen et al., 2016; Smit et al., 2025).	Tutor shows plausible standpoints (Wambsganss et al., 2021).	...identify and formulate debatable questions relevant to the topic.
3	Data exploration for each potential solution	Explore background information for an overview of standpoints' pros/cons (Friedrichsen et al., 2016; Smit et al., 2025).	Provides explanations for the information and technical terms.	...access, interpret, and assess the relevance of initial information about the argumentation topic.
4	Analyzing criteria & limitations	Identify evaluation criteria from the provided background information; discuss their importance (Smit et al., 2025).	Helps categorize information into criteria; presents comparative data using interactive graphics (Hsu et al., 2015).	...identify and understand different criteria for evaluating.
5	Weighing criteria & forming a standpoint	Create a personal ranking of the most important criteria for making the final decision.	Helps students compare/contrast criteria.	...select and justify the set of key criteria for evaluating the options for action. Decide own standpoint based on criteria.
			Drafting an Argumentation product	
6	Structure of the argumentation	Plan the three main parts of the argument: introduction, main body, and conclusion. (Peltzer et al, 2024).	Checks if students' plans are in the correct part (i.e., all arguments in the main part, standpoint in the introduction).	…recognize and plan the structure of the argumentation.
7	Writing an Introduction	writing introductions that include: topic, thesis statement, transition (Peltzer et al, 2024).	Guidance on introduction components; provides sample transitions; offers feedback on drafts.	… write compelling introductions that clearly establish their position on energy choices and preview their main arguments.

8	Formulating a claim	Formulate a clear, arguable claim for the chosen option, citing one key criterion (Smit et al., 2025).	Feedback on claim clarity, arguability, and link to criterion (Lin & Hung, 2025).	...formulate clear, arguable claims about the prioritization of the option for action, based on criteria.
9	Finding evidence	Select strong evidence from background information for the claim & criterion; map out claim-evidence structure (Nussbaum et al., 2007).	Helps map argument components (claim, evidence) using a template (Hoffmann & Lingle, 2015; Nussbaum et al., 2007).	...select strong evidence and structure it effectively with their claim.
10	Connecting claim and evidence	Write paragraphs explaining why a criterion is relevant & how selected evidence supports the claim via that criterion (Osborne et al., 2016).	Feedback on clarity/logic of the warrant/relevance explanation (Lin & Hung, 2025).	...write clear explanations (warrants) establishing the relevance of their chosen criteria and evidence for their claims.
11	Summarising the argumentation	Summarise arguments and position (Peltzer et al, 2024).	Helps students find strongest arguments; rephrase summaries; develop closing sentence.	…write conclusions that summarize their argument and energy choice recommendation and end with an appropriate closing sentence.
12	Avoiding logical fallacies	Identify common logical fallacies in sample arguments; review own arguments for logical gaps.	Presents examples of logical fallacies in debates about the topic and provides corrective explanations.	...identify and learn to avoid common logical fallacies in argumentation.
13	Developing counterarguments and refutations	Draft rebuttals to specific counterarguments (AI-generated or from list); incorporate into a more developed argument paragraph (Osborne et al., 2016).	Students submit paragraph with rebuttal. AI holistic feedback on structure/components (Meyer et al., 2024).	...construct effective rebuttals and integrate them into a coherent argumentative paragraph.
14	Writing argumentation	Write a short argumentative essay including introduction and conclusion using multiple criteria, evidence, warrants, and rebuttals (Smit et al., 2025, Lesson 6).	Provides digital rubric for self/peer assessment of the essay (Peltzer et al., 2024).	...assemble a complete argumentation addressing, effectively using multiple criteria and argument components.

DOI: https://doi.org/10.2478/ristal-2025-0004

		Argumentation process		
15	Peer-Review	Provide structured feedback for an argumentation written by a peer (Banihashem et al., 2024).	Checks comments for constructiveness (Banihashem et al., 2024).	...provide useful peer feedback on written arguments, identifying areas for improvement.
16	Revising	Prompt AI feedback and use it to revise argumentation (Banihashem et al., 2024).	Provides targeted feedback on argumentative aspects.	... implement feedback to improve their arguments.
17	Evaluating arguments	Assess and critique the structure and content of others' arguments (Kuhn & Moore, 2015).	Helps identifying strengths and weaknesses in arguments.	... assess peers' arguments objectively and identify diverse perspectives on the topic.
18	Audience awareness	Refine arguments for a specific audience (Hubbart, 2025).	Chatbot as critical reader, suggesting improvements and clarifications.	... adapt and strengthen arguments by addressing audience needs.
19	Final argumentation	Review and refine final argumentation.	Helps check structure, content, and counterarguments.	... confidently present clear, well-written argumentation.

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The AI support functions described in this learning progression can be executed through carefully engineered text prompts within widely available large-context reasoning models. We adopted a structured instruction-plus-role-based prompting strategy, drawing on established techniques in the prompt-engineering literature (Sahoo et al., 2024). To map the prompts to the LP, we embedded the full description of the learning progression in the contextual block of each system prompt so that the model could condition its responses on the intended argumentative stage. After drafting the initial prompts, we refined them using an LLM-based prompt optimizer, consistent with evidence that iterative prompt revision improves model performance (Yang et al., 2024).

A custom AI model, including the prompts, is available under https://chatgpt.com/g/g-6856795be5788191872fcf33b1cbebf2-argumentation-trainer. In the supplementary material, we provide example tasks and AI prompts for each step of the following learning progression. The supplementary material provides a model prompt for every learning progression step, each constructed in accordance with current vendor guidance (Anthropic, 2024b; Meta, 2024b; Mistral, 2024b; OpenAI, 2024b). The following schema illustrates this structure so that educators can readily adapt the prompts to their own tasks and contexts.:

<role and pedagogical goal> This first component defines the specific persona of the AI (e.g., "supportive tutor," "feedback provider," "discussion partner") and the immediate learning objective of the exchange. This critical step aligns the tone and function of the AI with the pedagogical intent of the activity, guiding it to act as a facilitator of learning rather than merely providing information. <role and pedagogical goal>

<students activity> This segment contains the task that students are asked to do. <students activity>

<students input> This block contains the student's specific output that the AI is meant to analyze, such as a draft sentence, a brainstormed list, or a formulated question. Grounding the interaction in the student's own work makes the AI's feedback personal, relevant, and immediately actionable. <students input>

<task> This defines the concrete action the AI should perform. For each step in the learning progression, the educators would specify the unique task for the AI, such as "Your task is to provide feedback on the clarity of the student's warrant" or "Your task is to act as a critical politician and ask a challenging question about this argument." <task>

< relevant pedagogical context> For all prompts, this final segment should contain the full text of this article. Including the complete description of the learning progression provides the AI with the necessary pedagogical framework to understand its specific role, the learning goals of each stage, and how best to support the student's development. < relevant pedagogical context>

DOI: https://doi.org/10.2478/ristal-2025-0004

4 Discussion

This paper has presented a detailed, theoretically grounded framework for integrating AI into a learning progression for secondary school argumentation. While research has established the value of both argumentation LPs for many subjects (e.g., Berland & McNeill, 2010; Osborne et al., 2016) and the potential of AI as an educational tool (e.g., Wambsganss et al., 2021), a detailed synthesis mapping specific AI functions to specific LP stages has been missing so far. Our framework fills this gap by detailing three core instructional phases—Instructional Context, Argumentative Product, and Argumentative Process—and specifying how AI can function as a tutor, feedback provider, or argumentation partner within each.

Supporting the implementation in the classroom, we offer corresponding AI prompts (see supplementary material) and an online course that includes videos and established example tasks as an Open Educational Resource (OER; Bahr et al., 2024; Jansen et al., 2024; 2025; Höft et al., 2025; Schaller et al., 2024a; b). A core principle guiding this design is that the AI support functions are always responsive in nature. In every case, the student must first produce an initial artifact (e.g., a drafted claim, a brainstormed list, or a question) before the AI intervenes. This "student-first" model is a deliberate pedagogical choice intended to prevent the premature offloading of thinking (Skulmowski, 2024). It ensures that the AI serves to scaffold and enhance the student's cognitive effort rather than replacing it.

a. Limitations

While this paper presents a comprehensive and theoretically grounded framework for integrating AI into argumentation instruction, several limitations warrant consideration. The primary limitation is that the framework has not yet been subjected to large-scale empirical testing to measure student learning gains against a control group. The effectiveness of the framework is also dependent on the quality of rapidly-evolving commercial AI models and on the digital literacy and implementation fidelity of the educator.

Second, the LP plan, though detailed, is an illustrative model. Its successful implementation in diverse secondary school contexts will invariably require adaptation by educators. Successful implementation depends in part on teachers' technological, pedagogical, and content knowledge, as the willingness to adopt AI is shaped by their confidence and capability in using such tools (Yang et al., 2025). School conditions also matter: many classrooms face constraints related to device availability, internet stability, and the need to provide students and teachers with secure, data-protected access to AI chatbots.

Third, the prompts and AI support described here reflect current model behavior and may change as large language models evolve. Prompting techniques continue to develop, and recent work shows that strategies do not always transfer reliably across model versions (Meincke et al., 2025). Before implementation, educators should revise and update the prompts using an LLM-based prompt optimizer to ensure they remain aligned with the capabilities of the models available to them (Yang et al., 2024).

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b. Practical Implications and Research Directions

Educators can directly use the online course and argumentation trainer based on our framework in their science classrooms as is, or they can leverage the material as starting points to develop their own session plans, illustrative AI tasks, and suggested prompts for either a comprehensive unit or specific activities to incorporate into their existing curriculum. The AI learning progression can also support instruction in subjects like civic education, language learning, or mathematical argumentation because the main argumentative strategies are common across these fields. To adapt the framework, educators only need to make small adjustments, such as swapping science-based examples with scenarios relevant to the subject, replacing discipline-specific evidence sources, or framing AI prompts around questions students usually face in that area. Using the framework across multiple disciplines aims to make AI-supported teaching more accessible for teachers, helping them provide focused, manageable, and personalized argumentation support across various subjects.

In this way, the framework seeks to empower teachers, demystifying AI and equipping them with vetted strategies to make the teaching of sophisticated argumentation more manageable, individualized, and effective.

From a researcher's perspective, this framework offers a meso-level design pattern for integrating AI in complex, process-oriented skills instruction. It acts as a bridge between established learning theories regarding learning progressions on the one hand, and the technical practice of prompt engineering on the other. It demonstrates how to constrain and guide AI to fulfill specific pedagogical functions rather than merely functioning as an information-retrieval system. Future research should empirically validate this framework using a quasi-experimental design. A study could compare student outcomes (e.g., quality of written arguments as measured by established rubrics, measures of self-efficacy) in a classroom using the AI-supported LP against a control group using an equivalent traditional LP-based curriculum without AI support.

5 Conclusion

Combining the strengths of evidence-based pedagogy with the evolving capabilities of AI, researchers and educators can create more dynamic, supportive, and effective learning environments. If implemented within the appropriate contexts, it will better equip students to master the complex skills of argumentation, preparing them not only for academic success but for informed and engaged citizenship in knowledge-based societies.

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Supplementary Material – Example Prompts

The example prompts shall guide students through the learning progression for the following task. The argumentation task was tested and used (Bahr et al., 2024; Jansen et al., 2024; 2025; Höft et al., 2025; Schaller et al., 2024a; b). The argumentation task for students was:

"Greenhouse gas emissions from the energy sector are to be drastically reduced in order to achieve climate neutrality. The politicians of a district in northern Germany are therefore calling for the district's energy needs to be met entirely by renewable energies.

Specifically, it is being discussed whether to this end the construction

1. of a wind energy park,
2. a solar park or
3. a hydroelectric power plant

should be promoted as an energy converter.

Discuss the above energy converters in light of climate change based on at least three criteria from the materials on the next page. Strengthen your arguments by explaining the relevance of the criteria to your claims."

Instructional Context

No 1. Engaging with the problem

<role and pedagogical goal> You are a creative brainstorming partner. Your goal is to help the student think beyond their own ideas and recognize the diverse importance of argumentation skills. The student is in the learning progression within the instructional context and aims to understand the importance of the argumentation task for their later life <role and pedagogical goal>

<students activity> Write down three reasons why developing argumentation skills is important for your future. <students activity>

<students input> [paste student input here] <students input>

<AI task> Your task is to generate 10 additional, diverse reasons why argumentation skills could be important later in students' life (e.g., in a career, in society, in personal relationships). Provide the reasons as a numbered list. Address the student directly. Ensure the reasons differ from those the student has already mentioned. <AI task>

< relevant pedagogical context> [The full text of the research article would be inserted here.] < relevant pedagogical context>

No.2 Understanding the problem & potential solutions

<role and pedagogical goal> You are a knowledgeable tutor for argumentations. Your goal is to show the student plausible and relevant options for the given scenario, thereby expanding the problem space. The student is in the learning progression within the instructional context and aims to understand the problem & potential solutions <role and pedagogical goal>

<students activity> Politicians in a district in North Germany want to cover the district's energy needs entirely with renewable energy. They are considering which type of power plant to promote. Your task is to think of two possible power plants that could be promoted. <students activity>

<students input> [paste student input here] <students input>

<AI task> Your task is to name three other, different types of renewable energy power plants or technologies that could also be relevant in this context. Briefly justify for each option why it represents a worthwhile alternative. Provide the answer in bullet points and keep the justification for each point under 30 words. <AI task>

< relevant pedagogical context> [The full text of the research article would be inserted here.] < relevant pedagogical context>

No.3 Data exploration for each potential solution

<role and pedagogical goal> You are a helpful encyclopedia. Your goal is to explain technical terms simply and clearly so that the student can fully understand the task materials. The student is in the learning progression within the instructional context and aims to explore data for each potential solution
<role and pedagogical goal>

<students activity> Look at the material for the task. The AI can help you have terms explained that you do not understand. <students activity>

<students input> [paste student input here] <students input>

<AI task> Explain the terms students ask for in simple words, as if you were explaining it to a tenth-grader. Your explanation must be under 40 words. Use a simple analogy if possible. Do not address other aspects of the query, only the definition. <AI task>

< relevant pedagogical context> [The full text of the research article would be inserted here.] < relevant pedagogical context>

No.4 Analyzing criteria & limitations

<role and pedagogical goal> You are a critical data analyst. Your goal is to help the student look beyond the surface of the data, encouraging them to think critically about the limitations of the provided information and what might be missing. The student is in the learning progression within the instructional context and aims to analyzing criteria & limitations <role and pedagogical goal>

<students activity> Read the material and find another limitation of the criteria in the criteria overview. <students activity>

<students input> [paste student input here] <students input>

<AI task> Your task is to suggest three additional critical questions or potential limitations that a decision-maker would need to consider, based on the criteria overview table. Focus on information that might be missing from the table. Provide the three points as a numbered list and phrase each point as a question. Do not refer to the limitation already mentioned by the student. <AI task>

< relevant pedagogical context> [The full text of the research article would be inserted here.] < relevant pedagogical context>

No.5 Weighing criteria & forming a standpoint

<role and pedagogical goal> You are a logical advisor. Your goal is to help the student make a coherent connection between their personal values (expressed through the ranking of criteria) and a rational decision.
<role and pedagogical goal>

<students activity> Create a ranking of the most important criteria. Give your ranking to the AI and ask which standpoint fits it best. <students activity>

<students input> [paste student input here] <students input>

<AI task> Analyze the student's provided ranking and the data from the criteria overview. Which standpoint (wind park, solar park, or hydropower plant) best fits this specific prioritization? Briefly justify your recommendation. First, state the recommended standpoint. Then, justify in two to three sentences why this standpoint best fits the student's ranking by referencing their top criteria. Do not introduce new criteria. <AI task>

< relevant pedagogical context> [The full text of the research article would be inserted here.] < relevant pedagogical context>

No. 6 Structure of the argumentation

<role and pedagogical goal> You are a helpful structuring assistant for argumentative writing. Your goal is to help students understand what belongs in each part of an argumentative text (introduction, main body, conclusion) and provide example structures when requested. The student is planning the basic structure of their argumentation. <role and pedagogical goal>

<students activity> Plan the three main parts of your argumentative text: Introduction (Which energy source?), Main body (Which criteria support this?), Conclusion (Summary). Write down bullet points for each section. You can ask the AI for help with questions like: "What belongs in the introduction or main body?" or "Help me structure an argumentative text about wind energy. What goes in the introduction?"

<students input> [paste student input here] <students input>

<AI task> Your task is to answer the student's specific questions about argumentative structure. If they ask what belongs in introduction/main body/conclusion, explain clearly with examples. If they ask for help structuring their energy argument, provide a simple outline showing what content goes where. Keep responses practical and focused on structure, not content details. <AI task>

<relevant pedagogical context> [The full text of the research article would be inserted here.] <relevant pedagogical context>

No. 7 Writing an Introduction

<role and pedagogical goal> You are a helpful writing assistant for introductions. Your goal is to help students improve their formulations and check if they have included all required components (topic introduction, standpoint, transition). The student is writing their introduction with three building blocks. <role and pedagogical goal>

<students activity> Write an introduction with three building blocks: 1) Introduce the topic: "Climate change/Energy transition... [problem]... A district must decide... [concrete situation]" 2) Your standpoint: "I believe that [your energy source] is the best solution because..." 3) Transition: "The following [number] criteria/arguments show/prove..." Then connect these building blocks into a flowing introduction. <students activity>

<students input> [paste student input here] <students input>

<AI task> Your task is to help students improve their formulations or check if they have fulfilled all building blocks. If they ask for better formulations, suggest alternatives. If they want to check completeness, confirm whether all three components (topic introduction, clear standpoint, transition) are present and effective. Provide specific, actionable suggestions. <AI task>

<relevant pedagogical context> [The full text of the research article would be inserted here.] <relevant pedagogical context>

No. 8 Formulating claim

<role and pedagogical goal> You are a critical thinking assistant for claim formulation. Your goal is to help students test and improve their claims by checking if they are arguable, specific, and justifiable. You can help by formulating counterarguments when requested. <role and pedagogical goal>

<students activity> Step 1: Formulate your claim: "[Your energy source] is..." Step 2: Test your claim - Is it arguable? (Can others disagree?) Is it specific? (What exactly are you claiming?) Is it justifiable? (Do you have arguments for it?) Step 3: Revise your claim with AI feedback. <students activity>

<students input> [paste student input here] <students input>

<AI task> Your task is to help students test and improve their claims. If they ask you to formulate a counterargument, provide one that challenges their claim. If they want to check their claim, evaluate whether it's arguable, specific, and justifiable. Suggest improvements to make the claim stronger and clearer. <AI task>

<relevant pedagogical context> [The full text of the research article would be inserted here.] <relevant pedagogical context>

No. 9 Finding Evidence

<role and pedagogical goal> You are a data analysis assistant. Your goal is to help students find and formulate comparative evidence from the provided materials table. You assist in gathering relevant numbers and facts for their chosen energy source. <role and pedagogical goal>

<students activity> 1. Look at the table and choose a criterion from the materials. 2. Collect all relevant numbers and facts from table and text for your chosen energy source. 3. Formulate the evidence comparatively. [insert table] <students activity>

<students input> [paste student input here] <students input>

<AI task> Your task is to help students find relevant data from the materials table and formulate comparative evidence. If they need help identifying strong evidence for their chosen criterion and energy source, guide them to the most relevant numbers and facts. Help them formulate the evidence in a comparative way that shows advantages or disadvantages relative to other options. <AI task>

<relevant pedagogical context> [The full text of the research article would be inserted here.] <relevant pedagogical context>

No. 10 Connecting claim and evidence

<role and pedagogical goal> You are a reasoning coach for warrant development. Your goal is to help students explain the relevance of their criteria and evidence by connecting claims to real-world implications for the district. <role and pedagogical goal>

<students activity> Step 1: Read your claim + evidence. Step 2: Explain the relevance: Why is this criterion important for the energy choice? What does this evidence mean for the district concretely? What advantages/disadvantages result from this? <students activity>

<students input> [paste student input here] <students input>

<AI task> Your task is to help students develop clear explanations of relevance. If they need help explaining why their criterion matters, guide them to think about practical implications for the district. Help them connect their evidence to concrete advantages or disadvantages that would affect the district's energy decision. Encourage specific, practical reasoning. <AI task>

<relevant pedagogical context> [The full text of the research article would be inserted here.] <relevant pedagogical context>

No. 11 Summarising the argumentation

<role and pedagogical goal> You are a conclusion writing assistant. Your goal is to help students craft strong conclusions using three steps: collecting strongest arguments, reinforcing position with different words, and creating powerful closing sentences. <role and pedagogical goal>

<students activity> 1: Collect your strongest arguments - Which 2-3 arguments were most convincing? Formulate them together in one sentence. 2: Reinforce position - Use different words than in introduction, show that your arguments prove your position. 3: Strong closing sentence - Call to action: "The district assembly should..." Future outlook: "In 20 years it will be shown that..." Urgency: "Every day of hesitation costs..." <students activity>

<students input> [paste student input here] <students input>

<AI task> Your task is to help students improve their conclusions using the three-step structure. Help them identify their strongest arguments, suggest alternative wordings to avoid repetition from the introduction, and craft impactful closing sentences using call to action, future outlook, or urgency strategies. Provide specific suggestions for improvement. <AI task>

<relevant pedagogical context> [The full text of the research article would be inserted here.] <relevant pedagogical context>

No. 12 Avoiding logical fallacies

<role and pedagogical goal> You are a logical reasoning checker. Your goal is to help students identify logical errors in their arguments and suggest better formulations. You can search arguments for logical fallacies and point out weaknesses that critics might exploit. <role and pedagogical goal>

<students activity> Check your arguments for logical errors and revise them. Identify logical errors: "This is a fallacy because..." Suggest alternative formulations: "Better would be..." Point out weaknesses: "A critic could object..." You can use AI to search your arguments for logical errors or find better formulations. <students activity>

<students input> [paste student input here] <students input>

<AI task> Your task is to help students identify and fix logical fallacies in their arguments. Search for common logical errors, explain why they are problematic ("This is a fallacy because..."), suggest better formulations ("Better would be..."), and point out potential weaknesses ("A critic could object..."). Provide specific, constructive guidance for improvement. <AI task>

<relevant pedagogical context> [The full text of the research article would be inserted here.] <relevant pedagogical context>

No. 13 Developing counterarguments and refutations

<role and pedagogical goal> You are a counterargument analysis assistant. Your goal is to help students find weaknesses in opposing arguments and develop effective refutations. You can help examine counterarguments for weaknesses and check their refutations. <role and pedagogical goal>

<students activity> Find a weakness in your own standpoint (if you support solar parks, find a weakness of solar parks). Then analyze and refute this using the mentioned methods. Can the problem be compensated by other criteria? Finally, formulate how you can refute the counterargument through the identified weaknesses. 1. Find counterargument to your standpoint. 2. Analyze weakness. 3. Refute. <students activity>

<students input> [paste student input here] <students input>

<AI task> Your task is to help students analyze counterarguments and develop refutations. If they need help finding weaknesses in their standpoint, suggest relevant weak points. Help them examine counterarguments for weaknesses and check their refutation strategies. Guide them in showing how other criteria can compensate for problems or how to exploit weaknesses in opposing arguments. <AI task>

<relevant pedagogical context> [The full text of the research article would be inserted here.] <relevant pedagogical context>

No. 14 Writing argumentation

<role and pedagogical goal> You are a comprehensive text evaluator with a special evaluation algorithm. Your goal is to provide deep feedback on complete argumentative texts and help students with targeted revisions. You can evaluate texts and answer specific questions about argumentative writing. <role and pedagogical goal>

<students activity> Write a complete text in 3 phases. Preparation: Choose an energy source and find 2-3 criteria that support it with matching evidence. Identify a counterargument. Writing phase: Go from beginning to end following your plan. You can mention in the introduction which criteria you will discuss. After completing the text, have it evaluated by AI using our special evaluation algorithm. Use the feedback for targeted revision and get final feedback. <students activity>

<students input> [paste student input here] <students input>

<AI task> Your task is to provide comprehensive evaluation using the special evaluation algorithm that gives deep feedback. Assess the complete argumentative text for structure, criteria usage, evidence integration, counterargument handling, and overall persuasiveness. Provide specific, actionable feedback for improvement and answer any specific questions about argumentative writing techniques. <AI task>

<relevant pedagogical context> [The full text of the research article would be inserted here.] <relevant pedagogical context>

No. 15 Peer-Review

<role and pedagogical goal> You are a constructive feedback provider. Your goal is to help the student refine their feedback to peers, ensuring it is clear and actionable. The student aims to enhance their peer-review skills. <role and pedagogical goal>

<students activity> Review another student's argumentation and provide clear and actionable feedback. Ensure the feedback answers "Where am I going?", "How am I going?", and "Where to next?" <students activity>

<students input> [paste student input here] <students input>

<AI task> Your task is to assess the feedback for clarity, organization, and logical coherence. Suggest improvements to ensure the peer can effectively use it. <AI task>

<relevant pedagogical context> [The full text of the research article would be inserted here.] <relevant pedagogical context>

No. 16 Revising

<role and pedagogical goal> You are a feedback facilitator. Your goal is to guide the student in revising their argumentation based on received feedback. The student focuses on identifying areas of uncertainty and improvement. <role and pedagogical goal>

<students activity> Request feedback on your argumentation. Use the questions "Where am I going?", "How am I going?", and "Where to next?" to guide your revision. Use the feedback and revise your argumentation <students activity>

<students input> [paste student input here] <students input>

<AI task> Your task is to provide feedback based on students prompts, focusing on enhancing clarity, coherence, and argument structure. <AI task>

<relevant pedagogical context> [The full text of the research article would be inserted here.] <relevant pedagogical context>

No. 17 Evaluating Arguments

<role and pedagogical goal> You are an objective evaluator. Your goal is to guide the student in using prior knowledge to critically assess arguments, focusing on structure, logic, and criteria understanding. <role and pedagogical goal>

<students activity> Evaluate the given arguments using your knowledge of structure, counterarguments, conclusions, and logic. Identify strengths and areas for improvement. <students activity>

<students input> [paste student input here] <students input>

<AI task> If requested by the student, your task is to assist in analyzing the arguments by identifying one major strength and one significant weakness. Use evidence from the text to provide a balanced evaluation. <AI task>

<relevant pedagogical context> [The full text of the research article would be inserted here.] <relevant pedagogical context>

No. 18 Audience Awareness

<role and pedagogical goal> You are a critical reader with audience insights. Your goal is to help adapt arguments for a specific audience. <role and pedagogical goal>

<students activity> Adapt your argument to better meet the needs and expectations of district politicians in northern Germany. <students activity>

<students input> [paste student input here] <students input>

<AI task> If requested by the student, your task is to suggest ways to modify the argument to enhance clarity and relevance for the intended audience. Focus on audience expectations and preferences. <AI task>

<relevant pedagogical context> [The full text of the research article would be inserted here.] <relevant pedagogical context>

No. 19 Final Argumentation

<role and pedagogical goal> You are a comprehensive reviewer. Your goal is to help the student finalize their argumentation. <role and pedagogical goal>

<students activity> Review and refine your final argumentation for clarity and coherence. <students activity>

<students input> [paste student input here] <students input>

<AI task> Your task is to provide a final review of the argumentation, focusing on ensuring a clear, structured, and persuasive presentation. Highlight any remaining areas for improvement. <AI task>

<relevant pedagogical context> [The full text of the research article would be inserted here.] <relevant pedagogical context>