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Validating the Use of Epistemic Network Analysis to Describe the Nature of Learning in Practice-Based Learning Settings

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Introduction

Preparing engineering students to thrive in the workplace post-graduation has been a long withstanding challenge and discussion topic in engineering education spaces. To provide students with authentic engineering experiences, there have been shifts in engineering education curricular approaches, such as problem-based, case-based, and project-based approaches – which have had various success rates at increasing transfer, learning, and engagement [1-3]. There has also been some preliminary work exploring how practice-based and other work-based learning can prepare students for the workplace, but these learning environments offer unique challenges. As stated by Luk and Chan [4], "compared to learning in the classroom, learning in the workplace is less predictable", which overall makes it difficult to determine and map what the learning outcomes truly are for work experiences and how they connect to classroom learning. Various frameworks of learning outcomes and experiences from internship experiences have been created [4-7], but none has truly allowed for the complexity and breadth of student experiences to be mapped and expanded upon. Therefore, there is value in creating assessment and evaluation tools that illustrate the variety of work being completed while still allowing for ways to quantitatively evaluate and describe the learning that is occurring.

One potential method for illustrating the complexities of practice-based learning and other work-related learning opportunities is epistemic network analysis (ENA) – a method that uses coded data to find connections between ideas. ENA describes and measures learning by analyzing how people connect and integrate various ideas while documenting their learning, allowing for the flexibility needed when analyzing diverse learning experiences that vary from person to person and workplace to workplace. A variety of coding schemes exist for ENA, but this project will assess the validity of using the Community of Practice framework and five corresponding epistemic frame elements (Knowledge, Skills, Values, Identity, and Epistemology) introduced in [8] to code student learning during their co-op experiences. The preliminary validation will be conducted using senior capstone papers written by students at Iron Range Engineering, an engineering program that uses the practice-based learning model.

The primary outcome of this paper is to assess the validity of using the five epistemic frame elements and epistemic network analysis on senior papers written by students in the Iron Range Engineering program to describe how they integrate learning in practice-based learning settings.

Background

Practice-Based Learning

Practice-Based Learning is a pedagogical approach that situates students within an authentic and relevant context to practice engineering [9-10]. [9] presents a framework for practice-based learning that defines three characteristics of practice-based learning environments: 1) the context of authentic engineering practice, 2) supporting learners' agency in the process of becoming professionals, and 3) opportunities to work and learn simultaneously. Practice-based learning differs from many other innovative pedagogies because students are working in authentic engineering workplaces (e.g., engineering internships and co-ops) while also taking technical coursework. By connecting students to opportunities and mentors in both the workplace and the classroom, students are supported as they create their own pathway in the world of engineering.

Community of Practice Framework

The Community of Practice Framework assumes that learning is a result of the experiences and people we interact with [8, 11]. In the case of practice-based learning, these experiences and people come from both engineering workplaces and engineering classrooms – creating a unique and diverse community around each student that is learning within the model. These communities of practice can be described using five epistemic frames: Knowledge, Skills, Identity, Values, and Epistemology [8], and this framework makes the assumption that learning is best described by showing how each individual uniquely connects ideas within each of the five epistemic frame elements.

Epistemic Network Analysis (ENA)

One possible strategy for analyzing the connections between these frame elements is ENA, a method that uses coded data to find temporal connections between ideas within an individual or community. Each of these codes are represented as a node in the network, and edges between nodes represent the strength of an individual or community's connection between those two codes. For example, epistemic network analysis has been used to investigate how engineering identity emerges as students participate in a medical device company simulation [12], how students develop an epistemic frame when completing an urban planning simulation [13], and how engineering values and epistemology emerge as students participate in a four-week engineering program where they designed virtual creatures while considering biomechanics [14]. ENA allowed researchers in these projects to quantitatively analyze how components of Knowledge, Skills, Identity, Values, and Epistemology were related within the communities of practice – even in complex learning spaces. This success illustrates the potential of using ENA in practice-based learning contexts as well.

Study Context

To assess the potential for using ENA and the five epistemic frame elements to analyze practice-based learning, a preliminary study was carried out at Iron Range Engineering – an ABET-accredited upper division engineering program that implements practice-based learning. After completing lower division coursework at a community college, students at Iron Range Engineering participate in a one-semester certification program called the Bell Academy where they gain training in the areas of technical learning, design, and professionalism. In addition to completing their technical coursework, they also complete a team design project with industry clients and participate in workshops to develop as engineering professionals. For their next four semesters after the Bell Academy, they work full-time in engineering internships and co-ops around the globe while continuing their technical courses remotely.

During their senior year, students write six chapters, which result in a senior capstone paper. These papers have been used to assess student learning, as well as to measure ABET performance indicators such as applying technical learning during the execution of an engineering design project (ABET Outcome 1), critically judging design solution and/or project results effectiveness based on criteria (ABET Outcome 2), and evaluating effectiveness of one's ability to lead, manage people, and manage projects (ABET Outcome 4). Therefore, other programs may find value in using a similar paper format and assessment strategy for their own ABET assessment and evaluation of student learning during co-op experiences. This paper focuses only on these senior papers, but it should be noted that at Iron Range Engineering, students are continually delivering learning journals, class project reports, verbal exams, etc. that this (and future) coding frameworks could be applied to.

Research Questions

The goal of this study is to determine if ENA will be an appropriate and effective method for evaluating practice-based learning experiences. For this method to be appropriate and effective, the five epistemic frame elements (Knowledge, Skills, Identity, Values, and Epistemology) should appear within the senior paper excerpts, these epistemic frame elements should co-occur within the writing (i.e. two or more elements should be mentioned together), and these co-occurrences should inform us about the student learning. This led to the development of the three research questions below:

1. How frequently do students discuss each of the five epistemic frame elements in their senior paper?
2. How frequently do these epistemic frame elements co-occur within their senior paper?
3. Do instances of co-occurrence provide us with insight into student learning?

Methods

Compiling a Dataset

IRB approval was sought and gained for this project. Only work from students who have graduated were accessed, de-identified, and used in the coding process. Ten senior papers were randomly selected from the most recent class of graduates from the program. These senior papers consist of six chapters: an introduction, an engineering literature review, applications of technical knowledge, applications of design knowledge, professional experiences, and *The Engineer I Am.* Because the senior papers are 50-100 pages long in their entirety, one section of the paper was chosen for the preliminary validation analysis: *The Engineer I Am*. In this section, students were asked to "[describe] how the experiences described in earlier chapters have created the engineer you have become." This section was chosen because it serves as a summary of the earlier chapters. The prompt is also left open-ended enough for students to feel comfortable discussing their identity and values as engineers (not just their developed knowledge and skills). For the 10 responses that were analyzed in this study, each were between one to two pages.

Identifying Uses of the Five Epistemic Frames

To answer Research Question 1, a code to consensus process was used. Each of the four reviewers individually coded excerpts of the paper that aligned with each of the five epistemic frame elements. All 10 of the participant responses were coded sentence by sentence by the four reviewers. Multiple codes, one code, or zero codes could apply in each sentence. The five frame elements and their description can be found in Table 1. After the first round of individual coding, the coders met to discuss any discrepancies in coding and further refine definitions of how each frame element aligns with the project context. During the discussion, it was also deemed that a paragraph versus a sentence is the appropriate stanza for determining co-occurrence. In other words, if a student mentioned both Skills and Knowledge in the same paragraph, it was deemed that the student was making a connection between both ideas. Because this was the chosen window size, the final coding focused on determining if and which of the five epistemic frames appeared in each paragraph. Consensus was achieved among the coders.

Table 1. Epistemic frame elements and descriptions. The Epistemic Frame Elements each have a unique text formatting style for the paragraph following the table that shows an example of the coding approach.

Epistemic Frame Element	**Description**
Knowledge	The facts and information that students have acquired
Skills	The abilities that students have acquired
Identity	How students view themselves
Values	The ideas, experiences, people, and things that students deem to be important
Epistemology	The mindsets, foundations, and practices of engineering that students recognize and use which lead to decisions and choices

The following paragraph gives an example of an excerpt from one of the student papers that had all five Epistemic Frame Elements present. The different framework elements are coded using the text style, which are indicated in Table 1.

> Through hands-on experiences, such as designing distribution panels, specifying conductors, and implementing protective devices, engineers cultivate a meticulous attention to detail and an acute problem-solving mindset. **The expertise gained in low voltage power distribution design** equips engineers with a strong foundation in electrical systems, fostering skills in load analysis, voltage regulation, and system coordination. These skills are transferable to a variety of engineering contexts, providing a solid framework for tackling complex challenges in diverse projects. All this experience that I've gained from this one co-op has been invaluable to *helping me become the engineer that I want to be*, and was paramount in my transition from one company to another. In my last 6 months of my 2-year long timeline of working as an engineer, I switched industries and **delved into the realm of renewable energy**. I have always been interested in renewable energy, more specifically in solar energy as it is the most common renewable energy source. *As a solar design engineer,* I not only used the skills I've developed in my previous co-op, but I have built upon those skill sets as well. For instance, AutoCAD, although I did have some experience going into this new position, I rarely used AutoCAD in my previous co-op experience, and this new position heavily relied on AutoCAD as their primary tool for designing.

Determining Rate of Co-Occurrence

To answer Research Question 2, preliminary epistemic networks were made to represent each student and the group of ten students as a group. These epistemic networks were made using the webENA platform [15] – an openly available online platform that creates epistemic network visualizations from coded data. For the networks, each student was a unit and each paragraph was a stanza. For each network, the five codes (Knowledge, Skills, Identity, Values, and Epistemology) were nodes, and the edges between those nodes show how frequently a student made a connection between the two ideas. The edge widths are normalized, meaning they represent the relative co-occurrence rather than a raw count of co-occurrences. This allows for a more equal comparison between students who wrote fewer paragraphs and those who wrote more paragraphs. Nodes are placed in the 2-dimensional plot using singular value decomposition to best illustrate the variability in the data.

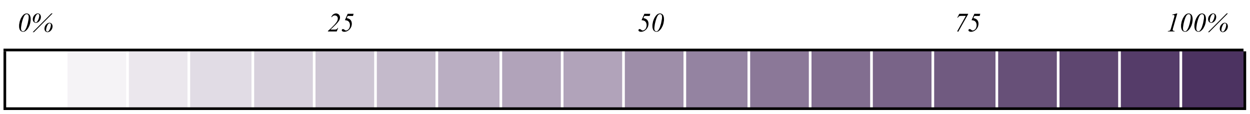
Results

Research Question 1: How frequently do students discuss each of the five epistemic frame elements in their Engineer I Am *section of the senior paper?*

Table 2 shows the frequency in which students mentioned each of the community of practice elements within their response. This was calculated by determining a percentage of the paragraphs in the response that contained a code relating to that framework element at least once. Significantly, seven out of ten students mentioned all five framework elements at least once in their *The Engineer I Am* section. Three of the students did not have any paragraphs that contained the Knowledge element. These frequencies evidence that this framework can be useful in capturing students' learning since all of the students mentioned all or the majority (≧80%) of the framework elements somewhere in their documentation. This is especially significant considering these were only one to two page sections.

Table 2. Frequency of codes appearing in each students' responses. The scale is provided below the table. The darker the cell, the more paragraphs the framework appeared in.

	Student Number									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Knowledge										
Skills										
Identity										
Values										
Epistemology										



Research Question 2: How frequently do these epistemic frame elements co-occur within their senior paper?

Figure 1 shows the average epistemic network for the ten students. The network shows that in general, students are connecting all five epistemic frame elements to each of the other four epistemic frame elements. By extracting the number of connections from the coded data, it was calculated that students on average are making 12.5 connections between frame elements within their *The Engineer I Am* section. The student with the lowest number of connections made 6 connections, and the student with the highest number of connections made 24 connections – showing there is variability in the frequency of connections, but all students were making connections across the frame elements.

Research Question 3: Do instances of co-occurrence provide us with insight into student learning?

While the previous section indicated the average of the co-occurrences that exist between the five elements of the community of practice framework, the individual student participant networks accompanied by representative quotes to give meaning to the connections that students are making in their learning between Knowledge, Skills, Values, Identity, and Epistemology. Three of the ten students' networks will be shown here to represent the type of connections and associated meanings that existed in the networks.

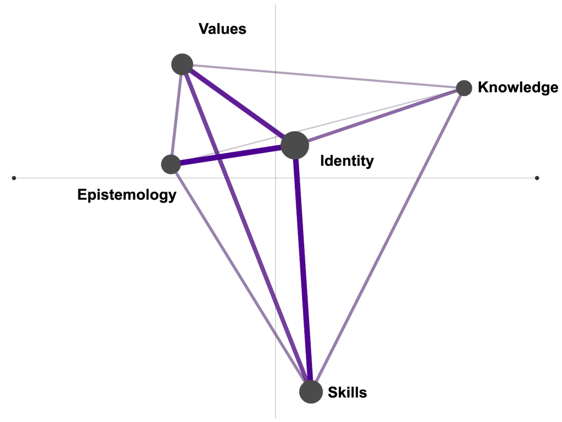


Figure 1. The average epistemic network for the ten students illustrates the connections they are making between epistemic frame elements in *The Engineer I Am* section of their senior papers. Each node represents a frame element. The size of that node represents how frequently students mentioned that frame element. Edges between nodes represent how frequently the two frame elements co-occurred, showing how often students wrote about those ideas in the same paragraph. Positioning of the nodes illustrates how central Identity was in the student responses.

Student 10

Student 10 was a participant who made connections between each of the framework elements (Figure 2); four connections branch from each of the five elements. The co-occurrences were stronger between Identity, Values, and Epistemology. As a reminder from Table 2, student 10 mentioned Knowledge and Skills in 40% of their paragraphs, Identity in 100%, and Values and Epistemology in 80%. This correlates with the size of the nodes in Figure 2.

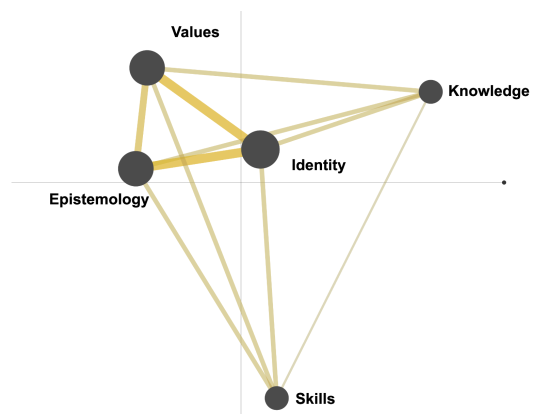


Figure 2. Epistemic network for Student 10.

While each of the paragraphs themselves had between two to five framework elements occurring, Student 10 also had sentences that had two codes in them, showing natural connections in their learning between the framework elements, giving meaning to the lines on the epistemic network on Figure 2. These representative sentences are shown in Table 3.

Table 3. Representative quotes that contain two framework elements from Student 10.

Framework Elements	**Representative Quote**
Skills & Epistemology	Through hands-on experiences, such as designing distribution panels, specifying conductors, and implementing protective devices, engineers cultivate a meticulous attention to detail and an acute problem-solving mindset (Student 10, para. 2)
Knowledge & Epistemology	**learned the importance of standards and regulations** and how they can have an impact on how to design electrical systems in various building types (Student 10, para. 1)
Values & *Identity*	All this experience that I've gained from this one co-op has been invaluable to *helping me become the engineer that I want to be*, and was paramount in my transition from one company to another (Student 10, para. 2)
Identity & Skills	But again, *being a lifelong learner* I took the challenge to not only better my skills in AutoCAD, but be involved in innovating the standards of designs for new types of up and coming design project types, such as floating solar arrays where we can utilize the surface of lakes or other bodies of water as a location to harvest the sun's light energy (Student 10, para. 3)

Student 6

Student 6 was a participant who made connections between most of the framework elements (except Values and Epistemology), similar to Student 10, except their co-occurrences happened more strongly between Identity, Knowledge, and Skills. As a reminder from Table 2, student 6 mentioned Knowledge, Skills, and Identity in 100% of their paragraphs and Values and Epistemology in 50%. This correlates with the size of the nodes in Figure 3.

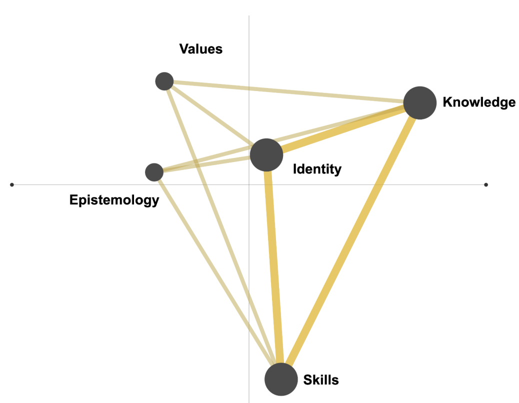


Figure 3. Epistemic network for Student 6.

Each of the paragraphs in Student 6's excerpt contained four of the framework elements. Student 6 showed the connections in their learning between the framework elements throughout both paragraphs, some in the same sentence and others in adjacent sentences, giving meaning to the lines on the epistemic network on Figure 3. These representative quotes are shown in Table 4.

Table 4. Representative quotes that contain two framework elements from Student 6.

Framework Elements	**Representative Quote**
Epistemology & Skills	This was my first real experience doing engineering where I had equal responsibility with the rest of the members on my team and got to see a deliverable through to the hand-off point with the client. As the Finite Element Analysis (FEA) and CAD lead, I was responsible for creating the finite element model of the client's component, correctly applying the loads that the other members of my teams determined, and planning a real life test onsite at [BLINDED] where we could collect data with strain gages to correlate the results of our model (Student 6, para. 1)
Skills & **Knowledge**	In particular, the knowledge I gained from planning and executing the test plan, learning how to use and apply the strain gauges, and setting up the data acquisition equipment were skills that have already proved incredibly useful in my work for [COMPANY]. They brought together my **knowledge in mechanical and electrical engineering and instrumentation fundamental principles** (Student 6, para. 1)
Values & *Identity*	My mentors placing their faith in me to be responsible for large portions of the vehicle and advocate for it to people working at such high levels of Iron Range Engineering gave me the chance to prove what I can do and *feel like I am capable of being an engineer* (Student 6, para. 2)

Student 3

Student 3 was a participant who only made connections between four of the framework elements (no mention of Knowledge) and showed limited connections between those that were mentioned. Their co-occurrences happened less frequently than those in Students 6 and 10's reflections. As a reminder from Table 2, student 3 mentioned Skills, Values, and Epistemology in 40% of paragraphs and Identity in 100%. This correlates with the size of the nodes in Figure 4.

Four out of the five paragraphs in Student 3's documentation contained only two of the framework elements with the other paragraph containing three. Student 3 showed the connections in their learning between the framework elements throughout adjacent sentences in all of their paragraphs, giving meaning to the lines on the epistemic network on Figure 4. These representative quotes are shown in Table 5.

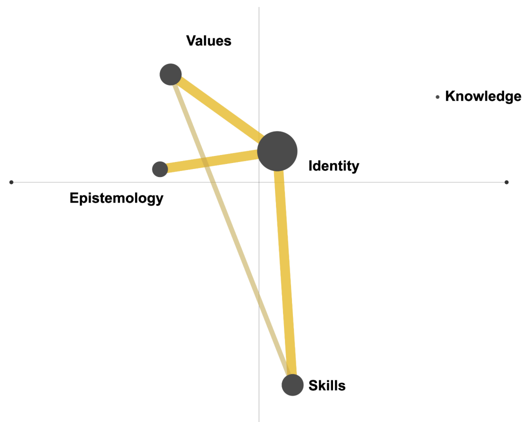


Figure 4. Epistemic network for Student 3.

Table 5. Representative quotes that contain at least two framework elements from Student 3.

Framework Elements	**Representative Quote**
Identity & Values	*These experiences have all come together to make me a better engineer and a better person.* Through all my schooling, I have had almost exclusively positive experiences from my peers and professors. My cohort has become like family to me and bonds were formed that will last a lifetime. These relationships have served as a constant source of inspiration and motivation to keep going and to be the best I can be. My graduating class has been with me through all the highs and lows and we have all come out of them stronger. The faculty at IRE have also been vital for my growth as a person and as an engineer (Student 3, para. 1)
Skills, *Identity,* & Values	From these classes, I have acquired a significant range of skills both technical and otherwise. Perhaps most importantly however, these classes have taught me how to learn efficiently and how to retain information. *This skill above all the rest will help define the engineer that I am. I do not care to be seen as the engineer that knows everything. I would much rather be perceived as the engineer that never turns down a challenge and is ready and capable to learn any new or intricate topic as the job requires. As an engineer I hope to be able to use these technical skills to improve the life of those around me and to benefit humanity at large* (Student 3, para. 2)

Identity & Epistemology	*I am an engineer and I will always be.* I will carry with me the things I have learned here and the relationships and memories I have made here for the rest of my life. I am fully prepared to go out into my career and change the world for the better. (Student 3, para. 5)

Discussion

Learning is invisible, a private experience that happens in the mind of the learner. The primary way that educators can determine the nature and extent of learning accomplished by others is through communication. As educators, we are interested in finding ways to gain insight into the learning that is happening in our programs. Practice-based learning is particularly challenging to "see" since the learner is working in a co-op or similar external environment, away from the campus. Reflective writing is one way for learners in practice-based programs to reflect upon and communicate their learning to professors and others. The senior paper with its six chapters is intended to help students recognize, make sense of, and communicate the complexity and breadth of their practice-based experiences, and to connect their technical learning, design, and professionalism in context of their co-op experiences.

There is value in creating assessment and evaluation tools that are open-ended enough to include the variety of student work being completed while still allowing for ways to quantitatively evaluate and describe the learning that is occurring. The senior paper encourages reflection on experiences and learning. Senior theses in many engineering programs are technical in nature and may not include communication of the students' full range of learning. The open-ended prompts for the six chapters, and especially the chapter titled *The Engineer I Am,* invites student engineers to broadly describe their engineering identity, thus giving insight into learners' view of the five elements in the Community of Practice framework - Knowledge, Skills, Values, Identity, and Epistemology.

Learner reflection and writing on co-op experiences leads to the ability for programs to offer credit for learning achieved and also serves as ABET evidence of student outcomes. In addition, student recognition of learning achieved can aid in deeper connections and integration of that knowledge, which may result in higher levels of knowledge transfer to new contexts.

This research was undertaken to determine if ENA is an appropriate and effective method for evaluating practice-based learning experiences for engineering students on co-op. The five epistemic frame elements (Knowledge, Skills, Identity, Values, and Epistemology) did appear within the ten senior paper excerpts, and these epistemic frame elements did co-occur within the student writing. We feel that the preliminary results are a promising start to information about the extent and depth of student learning recorded in these senior design papers as well as the connections between the five frame elements in ENA.

Transferability of this learning assessment process to other engineering programs is possible and encouraged. To access student writing that sufficiently communicates learning accomplished, students need to practice reflective writing on their learning processes. Instruction in the process of learning and time to reflect on their own learning is likely important. Feedback from faculty on the writing process is important so students know that their metacognition is valued. The ENA analysis process used in this research can be replicated using the steps outlined in this paper.

Future Work

For future work, we plan to extend the positive impact of the epistemic network to other parts of the senior paper, such as contemporary issues and engineering ethics. The approach of epistemic networks allows us to gain insights on students' mindset development not only on themselves, but also on the environment around them. This also could include other deliverables in the curriculum as well, not limited to just these senior papers. These techniques could be applied to learning journals, oral exams, project reports, etc. In addition, the epistemic networks should also be enriched by adding sub-codes, to identify the process of identify/value formation. This will help us understand how students define their identity. Having coders outside our program will be essential to mitigate the bias and improve accuracy. A systematic training mechanism would be utilized to help coders understand the context and coding procedures.

In the long run, by analyzing a larger database of student documentation, we will be able to connect this research with equity and inclusion. We plan to analyze the impact of gender, race and socioeconomic status on engineering identity. Demographics were not considered in this study because of the limited population and the goal was to verify the coding mechanisms, not to tie anything to demographic identities. The epistemic network will serve as an effective tool to visualize such impact. We also plan to extend this to other institutions' design deliverables to determine its applicability. This will give a broader spectrum of perspectives from a diverse set of participants since the population in this specific study was limited as it was a pilot study.

Conclusion

This study demonstrated the potential of epistemic network analysis to be used to better understand student learning in practice-based engineering environments. By performing analysis on a set of ten senior paper excerpts, it was shown that students mention all or most of the five epistemic frame elements (Knowledge, Skills, Identity, Values, and Epistemology), that these frame elements co-occur with enough frequency to create epistemic networks, and that these epistemic networks align with the student writing and provide insight on how students are integrating their learning.

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