Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #46991

Analysis of Client Letters Embedded in Pre-College STEM Integration Curricula (Fundamental)

Christine H. McDonnell, Purdue University at West Lafayette (COE)

Christine H. McDonnell is a PhD student in the school of Engineering Education at Purdue University. Christine is interested in exploring the connections between integrated STEM education in K-12 classroom settings and the impact on student learning, career interests, and reducing premature departure from STEM pathways.

Emily M. Haluschak, Purdue University at West Lafayette (COE)

Emily M. Haluschak is a PhD student in the school of Engineering Education at Purdue University. Emily is interested in leveraging integrated curriculum development in K-12 settings to positively impact underserved populations in the field of engineering. She utilizes past experiences in STEM program evaluation, education policy, and chemical engineering research.

Dr. Morgan M Hynes, Purdue University at West Lafayette (COE)

Dr. Morgan Hynes is an Associate Professor in the School of Engineering Education at Purdue University and Director of the FACE Lab research group at Purdue. In his research, Hynes explores the use of engineering to integrate academic subjects in K-12 cla

Siddika Selcen Guzey, Purdue University at West Lafayette (PWL) (COE)

Dr. Guzey is a professor of science education at Purdue University. Her research and teaching focus on integrated STEM Education.

Dr. Mary K. Pilotte, Purdue University at West Lafayette (COE)

Mary Pilotte is an Emerita Professor of Engineering Practice from the School of Engineering Education (ENE) at Purdue University, West Lafayette, Indiana. She served ENE as Director of undergraduate degree programs, including First-Year Engineering, and ultimately was Director of and instructor for Multidisciplinary engineering degree programs, IDES and MDE. She worked in a range of engineering and leadership roles in consumer products, aerospace and automotive industries during her 25+ year professional career. Recently, she served as industry liaison and curriculum specialist for Dr. Tamara Moore and the SCALE K-12 microelectronics education initiative.

Kristina Maruyama Tank, Iowa State University of Science and Technology

Kristina M. Tank is an Assistant Professor of Science Education in the School of Education at Iowa State University. She currently teaches undergraduate courses in science education for elementary education majors. As a former elementary teacher, her rese

Dr. Greg J Strimel, Purdue University at West Lafayette (PPI)

Greg J. Strimel, Ph.D., is an assistant professor of Technology Leadership and Innovation and coordinator of the Design & Innovation Minor at Purdue University. Dr. Strimel conducts research on design pedagogy, cognition, and assessment as well as the pre

Prof. Tamara J Moore, Purdue University at West Lafayette (PWL) (COE)

Tamara J. Moore, Ph.D., is a Professor of Engineering Education and University Faculty Scholar at Purdue University, as well as the Executive Co-Director of the INSPIRE Research Institute for Precollege Engineering. Dr. Moore's research is focused on the integration of STEM concepts in K-12 and postsecondary classrooms in order to help students make connections among the STEM disciplines and achieve deep understanding. Her work investigates engineering design-based STEM integration, computational thinking, and integration of high-level content in K-14 spaces. She is creating and testing innovative, interdisciplinary curricular approaches that engage students in developing models of real-world problems and their solutions.

Analysis of Client Letters Embedded in Pre-College STEM Integration Curricula (Fundamental)

I. Abstract

Real-world contexts help students engage with learning activities. The Framework for K-12 Science Education and the Next Generation Science Standards emphasize integrating STEM content and real-world contexts into K-12 learning experiences, highlighting the need for high-quality curriculum. In engineering design-based STEM integration curricula, the potential for client letters to help foster student learning and engagement has been understudied. We conducted a qualitative document analysis of fifty-eight embedded client letters in fifteen engineering design-based K-12 STEM integration curricular units. Through the lens of the STEM Integration Framework, we explored the following research questions: (1) What is the role of client letters in context-rich, engineering design-based K-12 STEM integration curriculum? (2) How do client letters add value to engineering design-based STEM integration curriculum? The analysis revealed unique roles of different client letters and the important contextual elements to convey in each role, deepening the connection between content and real-world scenarios in support of problem scoping, knowledge building, engineering design, and concluding response. Additionally, we found that client letters add value to the curriculum by strengthening motivating and engaging context anchored in authentic experiences, connecting content and the engineering design challenge to real-world scenarios, supporting student-centered instructional strategies, and enhancing other ties to STEM integration. This study provides evidence that client letters embedded in K-12 STEM integration curricula support essential elements of high-quality curriculum, which have the potential to foster student learning through deepening student engagement, applying crosscutting concepts from multiple STEM disciplines, and supporting high quality pedagogies. Teachers should consider the use of client letters to support their use of student-centered pedagogies, while curriculum developers should embed client letters to integrate context and real-world content into STEM learning resources. Additionally, professional development trainers could help teachers effectively implement client letters to maximize their impact, potentially fostering deeper student engagement with both the context and content of STEM integrated learning.

Keywords: engineering design, STEM integration, client, pre-college, qualitative document analysis

II. Introduction

Recent research has inspired the integration of content and real-world contexts into K-12 learning experiences, calling for quality instructional materials to support this integration. The Framework for K-12 Science Education [1] and the Next Generation Science Standards (NGSS) [2] provide guiding principles for integrating STEM content and real-world contexts into K-12 learning experiences. Updating expectations for students learning science, the Framework for K-12 Science Education encourages a strong connection between content and relevant and interesting contexts. This vision promotes learning experiences that reflect real-world practices in science and engineering. In a study focused on engaging learners and supporting learner agency, Reiser and colleagues suggest that implementing this vision strengthens the connection between "students' interests, ideas, and learning targets" [3, p. 825]. The NGSS identifies learning outcomes for students and encourages the development of quality curricular materials to help integrate content and authentic context into K-12 classroom experiences [2]. The Lead States report suggests that there is value in requiring that "students operate at the intersection of practice, content, and connection" [2, p. XVI]. Additionally, the report asserts that education standards themselves do not constitute learning experiences, calling for the development of instructional models and materials to support classroom implementation. These combined initiatives provide inspiration for developing quality curricular materials that connect real-world contexts with content. While the framework provides guiding principles, teachers and curriculum may be lacking the pedagogical tools and resources to put these principles into practice.

In this study, we examine the role of client letters in engineering design-based K-12 STEM integration curricula and the value they bring to the curriculum. We chose STEM integration curricula as they provide opportunities to connect real-world context with discipline specific (i.e., learned) content [4]. Additionally, connecting content to real-world experiences helps motivate student learning [5]. Research supports the use of client-based scenarios and context-rich storylines in connecting real-world experiences to content [6], [7]; however, little is known about the use of client letters in this capacity. In this study, we analyze the use of client letters in 15 engineering design-based K-12 STEM integration curricular units and explore two research questions:

- *RQ1*: What is the role of client letters in context-rich, engineering design-based K-12 STEM integration curricula?
- *RQ2*: How do client letters add value to engineering design-based STEM integration curricula?

The STEM Integration Framework [8] can be used to analyze the quality of curricular materials that connect real-world contexts with content. The STEM Integration Framework asserts that there are nine elements that are critical for quality engineering design-based STEM integration curricula. Using this framework as a starting point and adding in codes specifically related to the use of client letters, we analyzed the client letters both individually and in aggregate. The analysis revealed unique roles of different client letters and the important contextual elements to convey in each role. Additionally, we found that client letters have the potential to foster student learning and engagement by anchoring context in authentic experiences, connecting content and the engineering design challenge to real-world scenarios, supporting instructional strategies, and enhancing other ties to STEM integration. This study provides evidence that client letters embedded in K-12 STEM integration curricula support essential elements of high-quality curricula and have the potential to foster student learning and engagement.

III. Literature Review

Before exploring the role of client letters in context-rich, engineering design-based K-12 STEM integration curricula, we must first understand what is meant by engineering design-based K-12 STEM integration and the characteristics of successful implementation. Successful implementations include a motivating and engaging context, using engineering design as the integrator for multiple STEM disciplines, and applying high-quality pedagogies [8]. These elements are described and expanded upon in the following sections.

A. Engineering design-based K-12 STEM integration

While many definitions of STEM integration exist, we use STEM integration to reference a type of curriculum integration applied in a K-12 classroom setting. STEM integration represents an excellent opportunity to integrate real-world contexts into content [4]. Successful STEM integration incorporates grade-level aligned learning outcomes across multiple STEM disciplines. STEM disciplines are interconnected through crosscutting concepts that integrate discipline-specific learning outcomes and skills [1], [2], [9]. Crosscutting concepts support the assertion that STEM disciplines build upon each other, reinforcing content and developing new skills in ways that would not be possible within a single discipline [9]. Examples of grade level aligned cross-cutting concepts are represented in the NGSS, where grade-level appropriate learning outcomes are explicitly connected across disciplines.

STEM integration often leverages engineering design to connect disciplines and apply their concepts to real-world scenarios. The Framework for K-12 Science Education [1] emphasizes the inclusion of engineering practices as foundational dimensions for science education, highlighting their role in integrating and applying knowledge from multiple disciplines. Similarly, the NGSS developed grade-level aligned engineering design standards to emphasize the value of engineering design in STEM integration. This is, in part, because engineering design challenges provide a compelling context for exploring and applying mathematics, science, and other STEM skills to scope, design, and test solutions to real-world problems [10], [11]. Such challenges not only connect crosscutting concepts across disciplines but also reinforce the use of engineering to contextualize learning, often involving a client or end user with specific needs [11]. This interdisciplinary approach supports student learning and demonstrates how engineering design serves as a powerful integrator of STEM disciplines [1], [12], [13], particularly through context and content integration [9].

B. Motivating and engaging contexts

Students engage more strongly with content when instructors provide a motivating and engaging context. Here the word “context" is used to describe a narrative or a scenario that helps students understand or apply content. Students are motivated when they understand the utility of the content being learned and can apply the learning to be of use to others [5]. Additionally, when personal connections to content are clear, students are more inclined to persevere through challenges and demonstrate an increased desire to learn [14]. In this way, student engagement is strengthened through the inclusion of a motivating and engaging context.

Authentic experiences are one way that instructors can develop a motivating and engaging context. The use of authentic experiences that exemplify real-world applications of abstract concepts can motivate student learning by making personal and meaningful connections with students. Motivating and engaging contexts include “realistic situations [that] address issues of personal meaningfulness to students, incorporate issues that are relevant to students with a variety of backgrounds, and provide a compelling purpose for doing the STEM integration activity” [15, p. 15]. Furthermore, connecting content in an authentic way “supports deep engagement in learning” [16, p. 1]. Using authentic experiences to help explain and apply content is one way to create motivating and engaging context.

Client-based scenarios are one approach to creating a motivating and engaging context through authentic experiences. For example, client-based scenarios are used in model-eliciting activities (MEAs) to connect content to real-world experiences [17]. Instructors use MEAs to teach modeling and problem solving of complex tasks; the client’s problem is used as a lens to help students evaluate the practical application of a design solution by determining how their work meets a client’s needs. By applying a client-based context to the design project, students are more inclined to consider how their design solution impacts or affects others. When a student can put themselves in the “problem space” with a client’s needs that are “plausible, realistic, and compelling”, the personal meaningfulness inspires the student to more deeply consider the solution and its impact on the client [6, p. 85]. When executed within a team experience, the application of lived experiences to solution generation can prompt argumentation and stronger reasoning to justify a proposed solution [6]. In this way, client-based scenarios help develop motivating and engaging contexts by connecting content to real-world experiences.

Storylines are another way to use authentic experiences to develop motivating and engaging contexts. Storylines are referenced throughout a curriculum and can cohesively connect instructional content with student experiences while encouraging exploration of new skills [3]. Context-rich storylines can include detailed contextual features, such as criteria and constraints defined by the client, that reflect real-world situations [16]. In STEM integration, detailed contextual features illustrate situations that target student engagement through “asking questions and defining problems, constructing explanations and designing solutions, engaging in argument from evidence, and obtaining, evaluating, and communicating information” [16, p. 30]. This deep engagement in the context helps students understand what they are learning and why, providing justification for content. In this way, context-rich storylines help develop a motivating and engaging context by connecting content to real-world experiences.

While there are limitations to the extent that authentic experiences can fully incorporate real-world elements, they still enhance student engagement. Kostøl & Remmen [18] explored a case of high school teachers and students in which an authentic situation was integrated into the learning experience, but the students viewed the project as disingenuous. According to student feedback, the “context was realistic – the transport company’s transition to renewable transport technologies, but the commission – or the problem – was a fictive situation: the transport company did not really need the students’ help” [18, p. 11]. Although students challenged the authenticity of the client’s need for student help, the researchers claim that student engagement was still greater than with typical instruction, adding that despite “the slight difference in the authenticity between the context and the commission [authentic problem], both the teachers and students reported an increased effort among students compared to normal teaching, and that the students were better at thinking and reflecting” [18, p. 11].

Research has shown that student engagement in content is enhanced through a motivating and engaging context. Motivating and engaging contexts are strengthened through the use of authentic experiences, including client-based scenarios and context-rich storylines. The use of these methods can help students make a stronger connection to what they are learning and help justify why they are learning it.

C. High-quality pedagogies

Multiple high-quality pedagogies are often leveraged when STEM integration curricula are implemented in the classroom. In general, these pedagogies are learner-centered and support different teaching and learning methods like inquiry-based learning and evidence-based reasoning [9], [12], [13], [19].

With a learner-centered approach, students carry more responsibility for their learning, processing new information through the lens of their existing knowledge. In addition, a learner-centered approach acknowledges that students are less inclined to learn a new concept if it does not connect in some way to what they already know [20]. One of the defining characteristics of a learner-centered approach is the use of challenges or inquiry to provide context for knowledge development and application [20]. The use of challenges or inquiry reinforces active-learning as students raise questions, engage in discussions, and solve problems. Some might argue that learner-centered instructional methods claim to have students take more ownership of their learning, but in reality, there are limits to that ownership. This line of thinking refers to barriers educators face, like being held accountable to education standards which can restrict students' agency [3]. However, the use of inquiry-based learning can help educators balance student agency with restrictive barriers they may face.

Inquiry-based learning supports student agency in questioning and investigating problems. Students learn by finding answers to the questions that they ask and are motivated when the content is applied "in an authentic learning context" [21, p. 7]. When applied to STEM integration, the use of questions to investigate and apply information helps students develop new understandings of content from multiple disciplines [19].

Evidence-based reasoning involves the use of facts (or evidence) in the form of knowledge or observations to justify a decision, encouraging the collection and assessment of information before finalizing a decision [22], [23]. Used in STEM integration, evidence-based reasoning is applied to real-world situations, providing a way for students to synthesize their learnings and justify their conclusions or recommendations with logical reasoning [23]. When evidence-based reasoning builds upon an authentic experience, the collection and assessment of information supports the integration of content and context.

As we reviewed engineering design-based K-12 STEM integration efforts with high-quality pedagogies and a motivating and engaging context, we found the use of client letters in STEM integration curricula has been under-studied. In the following section, we introduce the framework we used to understand the use of client letters in engineering design-based STEM integration curricula.

IV. Theoretical Framework

This research focuses on client letters used for engineering design purposes and are therefore embedded within an engineering design-based STEM integration curricula. Thus, this study will employ two related frameworks to help with the analysis of the client letters: the STEM Integration Framework and the related Framework for Quality K-12 Engineering Education.

The STEM Integration Framework is an engineering design-based STEM integration framework and therefore, it is important to consider engineering first. The Framework for Quality K-12 Engineering Education [24] was designed to help educators consider the many facets of engineering that are important for students to learn. It defines nine key indicators: Process of Design (POD)—which is further broken into POD-PB (problem and background), POD-PI (plan and implement), and POD-TE (test and evaluate); Apply Science, Engineering, and Mathematics (SEM); Engineering Thinking (EThink); Conceptions of Engineers and Engineering (CEE); Engineering Tools (ETool); Issues, Solutions, and Impacts (ISI); Ethics (Ethics); Teamwork (Team); and Communication Related to Engineering (Comm-Engr) [24]. These indicators informed, in part, the development of an engineering design-based STEM integration curricula assessment tool called the STEM Integration Framework [8].

We use the STEM Integration Framework to analyze client letters embedded in K-12 STEM integration curricula. Although the STEM Integration Framework is an assessment tool for evaluating the completeness of engineering design-based STEM integration curricula, we apply the framework to client letters embedded in curricular units. Using applicable elements of the STEM Integration Framework, client letters are analyzed for their role within the curricular unit and the value they bring to the curriculum. We summarize the STEM Integration Framework developed by Guzey & Moore [8] and share the subsequent overview below.

The STEM Integration Framework is comprised of nine elements used to assess engineering design-based STEM integration curricula: (1) motivating and engaging context; (2) an engineering design challenge for a compelling purpose that is tied to the context; (3) integration of science content; (4) integration of mathematics content; (5) instructional strategies; (6) teamwork; (7) communication; (8) organization; and (9) performance and formative assessment.

Table 1 presents an overview of each element in the STEM Integration Framework, including a description of the criteria each encompasses. Additionally, each element of the STEM Integration framework is mapped to the coordinating indicator found in the Framework for Quality K-12 Engineering Education, noted by the abbreviations included in parentheses. Researchers found that the STEM Integration Framework elements of motivating and engaging context, an engineering design challenge, integration of science content, integration of mathematics content, instructional strategies, communication, and performance and formative assessment were most applicable to the review of client letters.

Table 1. Overview of STEM Integration Framework

STEM Integration Framework Elements (related Framework for Quality K-12 Engineering Education indicators)	**Description**
Motivating and Engaging Context (ISI, CEE)	Criteria help evaluate motivating and engaging context based on its connectedness to students and the real-world
An Engineering Design Challenge (POD, EThink, CEE, Ethics)	Criteria help evaluate the design challenge based on how the design challenge engages students and enhances the goals of the curriculum
Integration of Science Content and Integration of Mathematics Content (SEM, ETools)	Criteria help evaluate the integration of math or science content based on the content's alignment with education standards, its integration of grade-level concepts, and its explicit use of content specific skills
Instructional Strategies	Criteria help evaluate instructional strategies that emphasize student-centered learning and activities, incorporate evidence-based reasoning, and explicitly connect content and context to help students understand why they are learning what they are learning
Teamwork (Team)	Criteria help evaluate teamwork based on the inclusion of opportunities for students to collaborate and the experience of each team member
Communication (Comm-Engr)	Criteria help evaluate the content, the mode, and the method of the communication
Organization	Criteria help evaluate the cohesiveness of the curriculum
Performance and Formative Assessment	Criteria help evaluate the purpose and method of assessment

* NOTE: STEM Integration Framework elements are from [8]; Framework for Quality K-12 Engineering Education indicators are from [24]

V. Methods

The authors conducted a qualitative document analysis [25] of client letters embedded in K-12 STEM integration curricular units, as defined by our theoretical framework. Differentiating between curriculum and lessons, we defined a curricular unit as a group of lessons interrelated around a specific theme or topic and aligned to achieve standards-based student outcomes. The authors used purposive sampling to identify appropriate documents for analysis. Curricular units were identified through online searches and outreach to experts. The online search process included iterating on search strings. Since the use of the term "STEM integration curricular unit" is not universal, researchers iterated on the phase to include search sequences like "K-12 integrated STEM units," "integrating science, technology, engineering, and mathematics [and] curricula," and "STEM curricular modules." Additionally, researchers engaged experts in the field to help identify qualified documents. In all, fifteen K-12 STEM integration curricular units were identified, downloaded, and stored in digital repositories. Table 2 provides a list of the units, grade level, number of client letters included, and a URL to access the letters.

Table 2. STEM integration curricular units with client letters used for this study

Curricular Unit All units can be found at: picturestem.org, engrteams.org, & scalek12.org	**Grade Level**	**Number of Client Letters**
Designing Paper Baskets	ES	3
Designing Hamster Habitats	ES	3
Designing Toy Box Organizers	ES	4
Ecuadorian Fisherman	MS	1
Water Water Everywhere But Not a Drop to Drink	MS	6
Game On!	MS+HS	7
Let the Chips Fall Where They May	MS+HS	8
Let the Good Ideas Roll!	MS+HS	6
Carbon Sink Investigation	HS	5
Lock it Up!	HS	2
You Light up My Life	HS	4
Make Sense	HS	1
Safe Chips Inc (Business)	HS	1
Safe Chips Inc (Engineering & Technology)	HS	2
Stressed Out!	HS	5

* NOTE: ES=Elementary School, MS=Middle School, HS=High School

Next, researchers scanned the curricular units for embedded client letters. At the screening level, we defined client letters as any form of communication simulating a conversation between the students and a person, or group of people. We identified client letters by examining both their content and their reference titles within the curricular unit. This included many different curricular unit reference titles such as “Client Letter”, “Client Memo”, “Client Response”, or “Email from [client].” As a document form, client letters manifested as an actual letter, email, or other type of communication. One document form, the client letter template, was eliminated from analysis. The client letter template was a blank form intended to be filled out by an educator in response to specific student questions. Since it is impossible to analyze a blank form for relevant information, client letter templates were removed from the data sample. In all, fifty-eight client letters were identified. Each client letter was individually extracted from the STEM integration curricular unit and stored digitally. No modifications or manipulations were made to the client letters.

The methods applied to analyzing client letters were iterative and involved several steps. The researchers began by applying thematic analysis. Aligned with Braun and Clarkes [26] thematic analysis method, researchers became familiar with the data, used open coding to generate codes and categories for a codebook, and began analyzing the data. See Figure 1 for our final list of themes that describe the aggregate use of client letters within a curricular unit: strengthen motivating and engaging context, connect content and the engineering design challenge, support instructional strategies, and enhance other ties to STEM integration. They were developed from our final codes and categories (See Table 3). The numbered list contains the codes, and they are grouped on the left by the categories. The coded data were then aligned into our themes. After the thematic analysis, an alignment between the codes, categories, and themes was identified as mapping to the K-12 STEM Integration Framework [8]. This framework was previously described in the Theoretical Framework section. The K-12 STEM Integration Framework included all themes generated through the thematic analysis while providing additional elements that could be applied to the analysis (i.e., performance and formative assessment). Utilizing the K-12 STEM Integration Framework, the research team re-analyzed the role of client letters. Research is already in process in support of identifying a conceptual framework for client letter development and inclusion in STEM integration curricula [27].

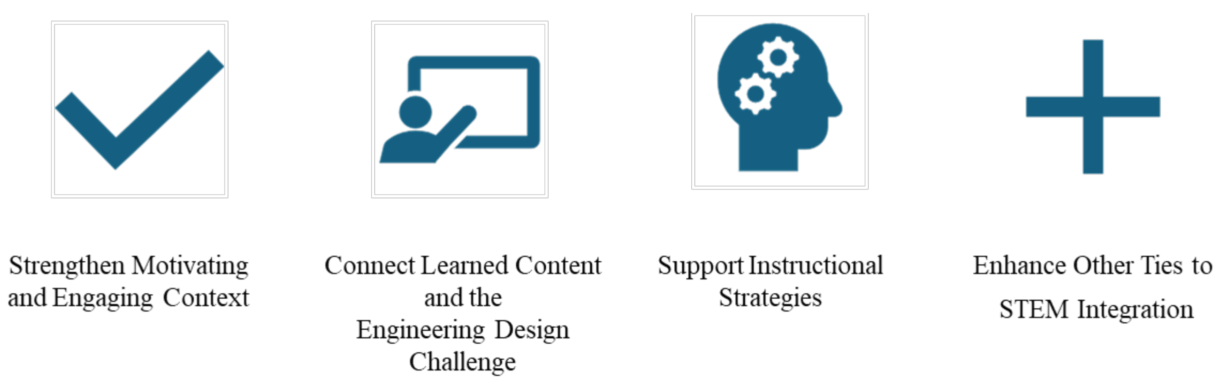

Figure 1. Aggregate Client Letter Analysis Themes

Table 3. Individual Client Letter Analysis Final Categories and Codes

Coding Category	Client Letter Codes
Motivating and engaging Context	1 Client 2 (optional) Job titles with simple org chart 3 Product/Service 4 Market/Industry 5 End User 6 Context/setting (original, evolving) 8 Urgent need for help/importance of problem 9 Exit from iteration cycle/design cycle 10 Solution impact on end user 11 Feedback (on information, design, or solution shared)
Engineering Design Challenge	7 Problem Statement (original problem statement, interim problems, revised problem statement) 12 Criteria/competing criteria 13 Constraints/competing constraints 14 Ideation (content related questions, concept exploration, and data collection) 15 Design Challenge (mini design challenge, final design challenge) 16 Evidence based reasoning 17 Iterate 18 Solution (prototype, design, model)
Communicate	19 Communicate (explaining concepts, thinking, solutions)
Integrated Content	20 Content (application of prior knowledge, acquisition of new knowledge)

VI. Positionality Statement

The research team brings diverse but complementary perspectives to this work, including expertise in integrated STEM curricula development, engineering education, K-12 science, mathematics, and technology education, and qualitative research methods. Several authors have contributed to the design or dissemination of some of the curricula analyzed in this study. To maintain analytic rigor, we employed systematic coding processes, used multiple rounds of collaborative thematic analysis, and engaged in regular peer debriefing to challenge our assumptions and interpretations.

Our collective approach to STEM education emphasizes authentic learning experiences, student agency, and the integration of disciplinary content through engineering design. We view curriculum not only as a tool for delivering content but as a vehicle for shaping engaging and broadly relevant learning environments. As such, we are attentive to how curriculum features like client letters can support both rigorous content learning and relevance to students' lives. Our positionalities as educators, designers, and researchers influenced our commitment to exploring how client letters function within and add value to STEM integration curricula, and by extension the resulting learning environment.

VII. Findings & Discussion

The findings and discussion section is divided into two major sections based on each of the two research questions:

- *RQ1*: What is the role of client letters in context-rich, engineering design-based K-12 STEM integration curricula?
- *RQ2*: How do client letters add value to engineering design-based STEM integration curricula?

The first section answers RQ1 and looks at the individual letters, describing their roles within their curricular unit, and the variations in sequencing that are seen across the letters that serve the same purpose. The second section answers RQ2 by taking a macro view of the letters to consider the overall purpose of client letters in terms of pedagogy and, in particular, STEM integration. The findings are presented along with the discussion to situate the findings within the research questions. Each section ends with an overview answer to the research question from the findings.

A. Findings and discussion based on RQ1: What is the role of client letters in context-rich, engineering design-based K-12 STEM integration curricula?

In this section, we discuss the role of the individual client letter within the curricular unit and identify critical information included in the narrative of the letter. Through the lens of the STEM Integration Framework [8], we have identified four different roles for the use of client letters: Problem Scoping , Knowledge Building, Design Project, and Concluding Response (see Figure 2). Each client letter has a different purpose and conveys specific contextual elements related to that role. More than one client letter is often used within a curricular unit. While the typical order and structure of client letters within a curricular unit is shown in Figure 2, later in this paper we will discuss instances where variations in sequencing are warranted. While all client letters identified in the methods section were used as primary data, figures provide examples from a subset of client letters studied.

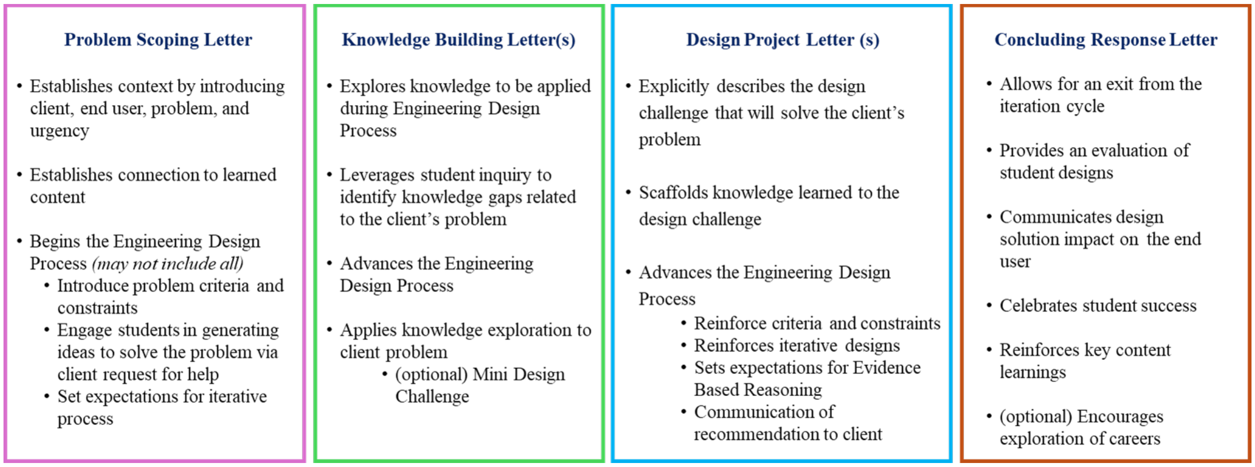

Figure 2. Overview of Client Letter Roles

1. Problem Scoping Letter

As summarized in Figure 2, the role of the *problem scoping letter* within engineering design-based K-12 STEM integration curricula is to establish a context, establish a connection to content, and begin the engineering design process. To fulfill this role, the narrative content of the *problem scoping letter* must establish a connection with students while conveying critical information. Key information shared by the *problem scoping letter* includes client, job titles (optional), product/service, market/industry (if warranted), end user, context/setting, urgency, problem statement, criteria/constraints (if warranted), ideation, and a connection to content.

In the unit called Designing Paper Baskets (henceforth, designated "Paper Baskets") [28], a Kindergarten literacy curricular unit, the *problem scoping letter* (see Figure 3) establishes a connection with students and conveys critical information defined by its role. The narrative is rich with an interesting client, a descriptive context relatable to kindergarten students, and unanswered questions intended to begin the engineering design process. In Paper Baskets, Max and Lola are two children who collect rocks. Their favorite places are the park and the creek. Max and Lola are exhibiting at the local nature center and want to help others start their own rock collection. Max and Lola ask students for ideas about what they can give away to help others with their rock collecting. Through this engaging narrative, students begin to understand the context for the unit: the clients are Max and Lola, the product/service is rock collecting, the end users are people who visit the nature center and collect rocks, the setting is the nature center, and the urgency is a fast-approaching display table at the nature center. Students are also provided with information to initiate the engineering design process: the problem is deciding what to give away to help others start rock collecting and ideation begins with Max and Lola asking students for ideas about what to give away. Initial criteria and constraints are established with the requirement shared by Max and Lola the giveaway "will allow them [visitors to the nature center] to have as much fun collecting rocks as we have." Solution ideation is inspired by a question from Max and Lola; students are asked to "send us some ideas about what we might give away to help others with their rock collecting." Finally, the connection to content is signaled: the unit will integrate science content. By integrating critical information in an engaging context, the *problem scoping letter* in Paper Baskets connects with students and conveys critical information defined by its role.

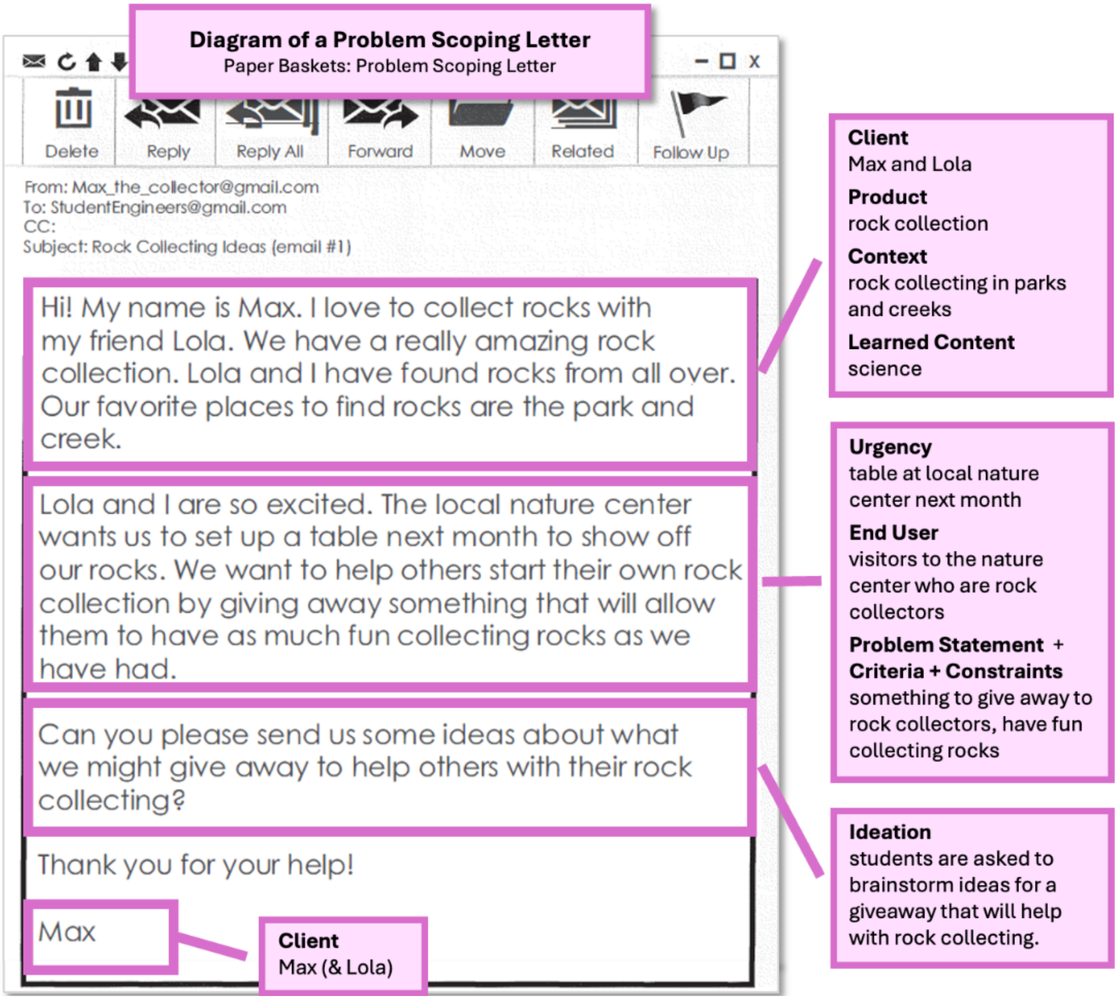

Figure 3. ***Problem Scoping Letter*****, Paper Baskets**

In the curricular unit Let the Chips Fall Where They May (henceforth designated "Let the Chips Fall") [29], a middle school and high school geometry and engineering design unit, the *problem scoping letter* (see Figure 4) establishes a complex context while conveying critical information. In Let the Chips Fall, Skylar Geti, CEO of GETI games, is manufacturing a gaming controller with skyrocketing demand. Unfortunately, their supplier shares that the current process for manufacturing microchips will not be able to keep up with demand. Skylar shares the calculation used to estimate the number of dies cut per wafer and asks students to help understand why the manufacturing process is not yielding the expected number of dies. As we saw in Paper Baskets, the *problem scoping letter* in Let the Chips fall establishes a connection with students and conveys critical information defined by its role: the client is Skylar Geti, the product/service is gaming controllers, the end users are people who use gaming controllers, the setting is microchip manufacturing, and the urgency is increased volume of microchips to support skyrocketing demand for the gaming controller. As the context is more complex than that of Paper Baskets, the engineering design process is initiated by a request to identify the fault in a mathematical calculation. Finally, the connection to content is signaled: the unit will integrate mathematics content. By integrating critical information in an engaging context, the *problem scoping letter* in Let the Chips Fall connects with students and conveys critical information defined by its role.

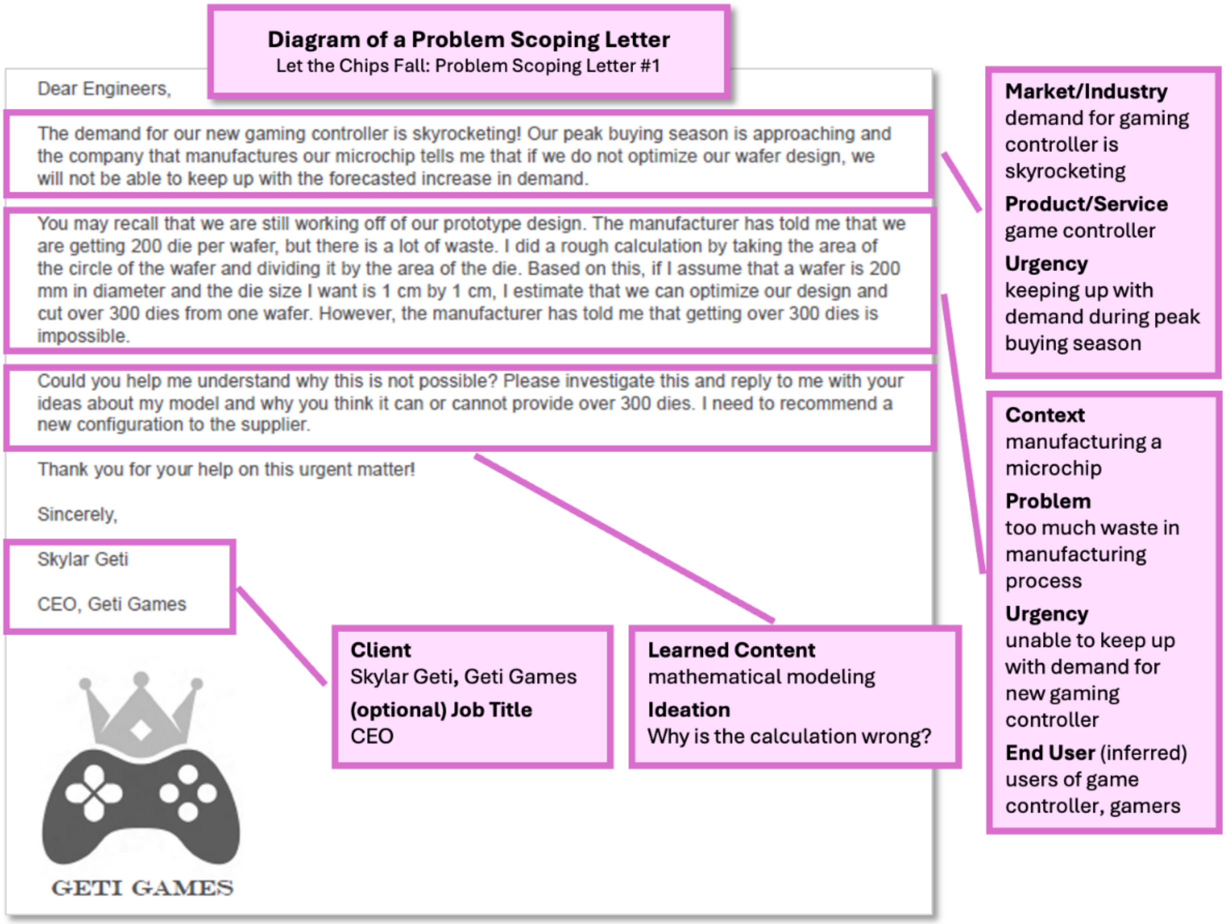

Figure 4. *Problem Scoping Letter*, Let the Chips Fall

The role of the *problem scoping letter* is to establish the context for the engineering design project, connecting the context to the instructional content. In setting the context, the *problem scoping letter* introduces students to the client, end user, and the problem. Without identifying a prescriptive solution to the problem, this letter describes the challenging problem and can include criteria and constraints important to both the end user and the client. While setting the context, the *problem scoping letter* also establishes a connection with the subject matter content to be learned and applied in the curricular unit. The letter places students in a setting rich with strong characters, descriptive details, and unanswered questions to spark curiosity and learning. The *problem scoping letter* initiates the knowledge building journey with an open-ended question or quest that encourages solution ideation and exploration for the engineering design project, setting expectations for an iterative process.

2. Knowledge Building Letter

As summarized in Figure 2, the role of the *knowledge building letter* within engineering design-based K-12 STEM integration curricula is to explore knowledge to be applied during the engineering design process, leverage student inquiry to identify knowledge gaps related to the client's problem and advance the engineering design process. To fulfill this role, the narrative content of the *knowledge building letter* must inspire curiosity and exploration of content while conveying critical information. New information shared by the *knowledge building letter* includes evolution of the context/setting, evolution of the problem statement, continued ideation, an (optional) mini design challenge, and a continued connection to content.

In Let the Chips Fall, the first *knowledge building letter* explores material waste in manufacturing, leverages student inquiry to understand how to calculate the waste, and advances the engineering design process with a mini design challenge (see Figure 5). In this letter, the context evolves to focus on the inefficient layout of a silicon wafer that is generating a lot of material waste. The problem evolves to include understanding the waste produced when cutting dies from a silicon wafer. Ideation explores how to calculate material waste when cutting dies from a silicon wafer. The client asks students for help in understanding the waste produced when manufacturing silicon wafers of different thicknesses. Specifically, the client asks the students to "help me understand how much material is wasted." This request leads to an (optional) mini design challenge in which students are asked to create a mathematical "model that allows me [the client] to calculate waste" for similar configurations. The client provides a visual image in which a square is situated inside of a circle. Based on the narrative in this *knowledge building letter*, the connection to content applies geometric concepts like area and volume in the calculation of waste and develops new knowledge through the mathematical modeling of waste calculation. By integrating knowledge exploration while advancing the engineering design process, the role of the *knowledge building letter* is fulfilled.

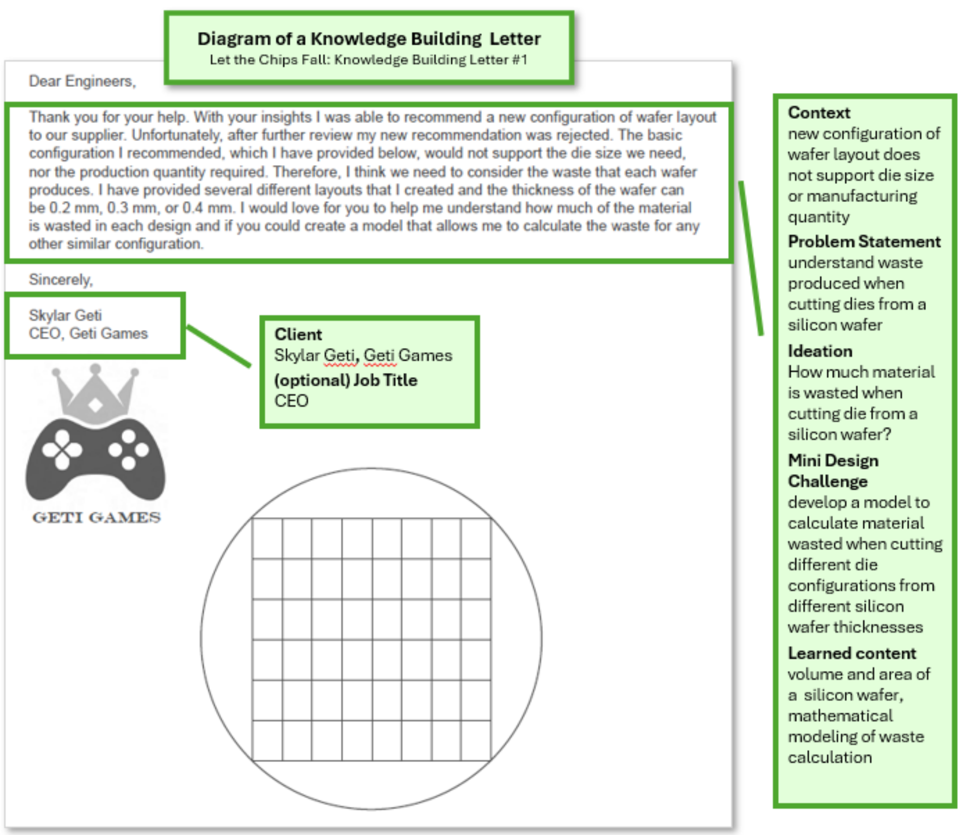

Figure 5. ***Knowledge Building Letter*** **#1, Let the Chips Fall**

A different *knowledge building letter* in Let the Chips Fall (see Figure 6) demonstrates the scaffolding of more complex content. While keeping true to the previously explained structure of the *knowledge building letter*, in this letter the context evolves include the client moving the manufacture of microchips in-house. As such, the client asks for help understanding the boule-to-wafer process, exploring where pockets of waste exist. In order to calculate yield and waste as requested by the client, the complex geometric shape of the boule (Figure 7) must be broken down into different geometric components (i.e., cone, cylinder, hemisphere) and multi-step calculations of volume and area applied. By scaffolding complex knowledge exploration while advancing the engineering design process, the role of the *knowledge building letter* is fulfilled.

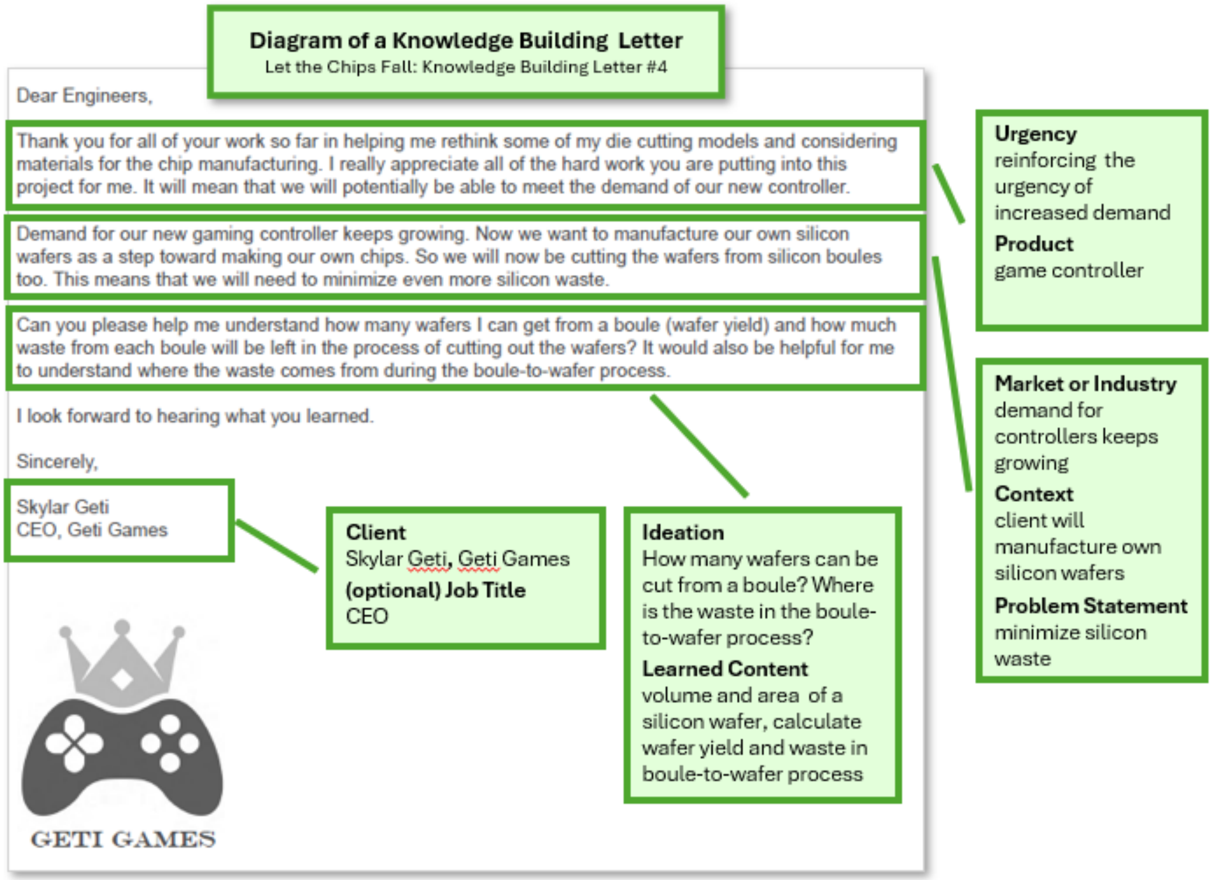

Figure 6. ***Knowledge Building Letter*** **#4, Let the Chips Fall**

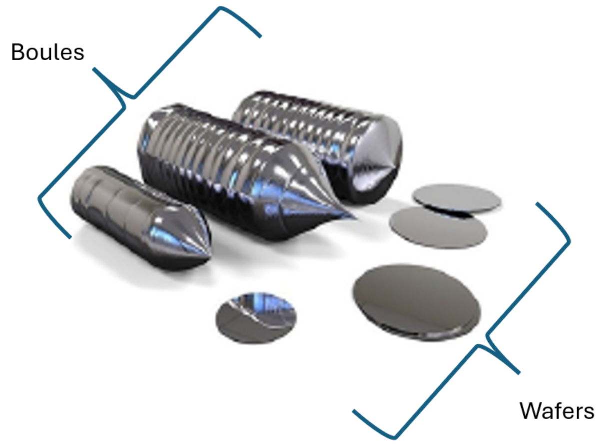

Figure 7: Image of Boules and Wafers, Let the Chips Fall

The role of the *knowledge building letter* is to support knowledge exploration while explicitly connecting content with the real-world context and advancing student progress through the engineering design process. The *knowledge building letter* encourages students to identify knowledge gaps and to close those gaps by engaging in learning and applying knowledge to further understand the client's problem. Learning can take the form of a review of prior knowledge or an exploration of new knowledge. Whatever the form, knowledge developed during the learning opportunity is then applied within the context of the client's problem. In this way, the *knowledge building letter* engages students in learning concepts tied to understanding the client's problem.

3. Design Project Letter

As summarized in Figure 2, the role of the *design project letter* in engineering design-based K-12 STEM integration curricula is to explicitly describe the design challenge that will resolve the client's problem, scaffold content into the design challenge and advance the engineering design process. To fulfill this role, the *design project letter* must provide any clarification to the problem statement if it has evolved over the course of the unit, explicitly summarize criteria and constraints, incorporate content, and set expectations for the use of evidence-based reasoning, iterating on the design solution, identifying the form of the solution (i.e., prototype, model, or other design type) and communicating back to the client.

In the unit Ecuadorian Fisherman [30], a middle school Physical Science unit, the *design project letter* is a strong example of how the context, content, and engineering design process are integrated into the narrative (see Figure 8). The *design project letter* conveys the context for the Ecuadorian Fisherman unit. The context is set in the Province of Esmerelda where the Pescadores Foundation helps villages by teaching new methods in "harvesting, preparing, and marketing food." Students learn that fishermen from the Galapagos are asking the Pescadores Foundation to help figure out a way to cook the fish they catch in their solar oven. Through the *design project letter*, the problem statement clearly states the need for a small cooker container for a solar oven. Criteria and constraints are clearly communicated as the Pescadores Foundation asks students to design a cheap, "successful cooker container" that will hold a fish as it cooks in a solar oven. Content is incorporated in the design solution through the application of heat transfer and materials selection. Iteration is implied by the need for a decision on the design, and the form of the solution is conveyed when the letter sets the expectation of deciding on a final prototype design. The letter establishes clear expectations for communicating student recommendations, including the use of evidence-based reasoning to justify their recommendation. The *design project letter* explicitly describes the design challenge, scaffolds content into the design challenge and advances the engineering design process by clarifying the problem statement, summarizing criteria and constraints, incorporating content, and setting expectations for the use of evidence-based reasoning, iterative design, and communication back to the client.

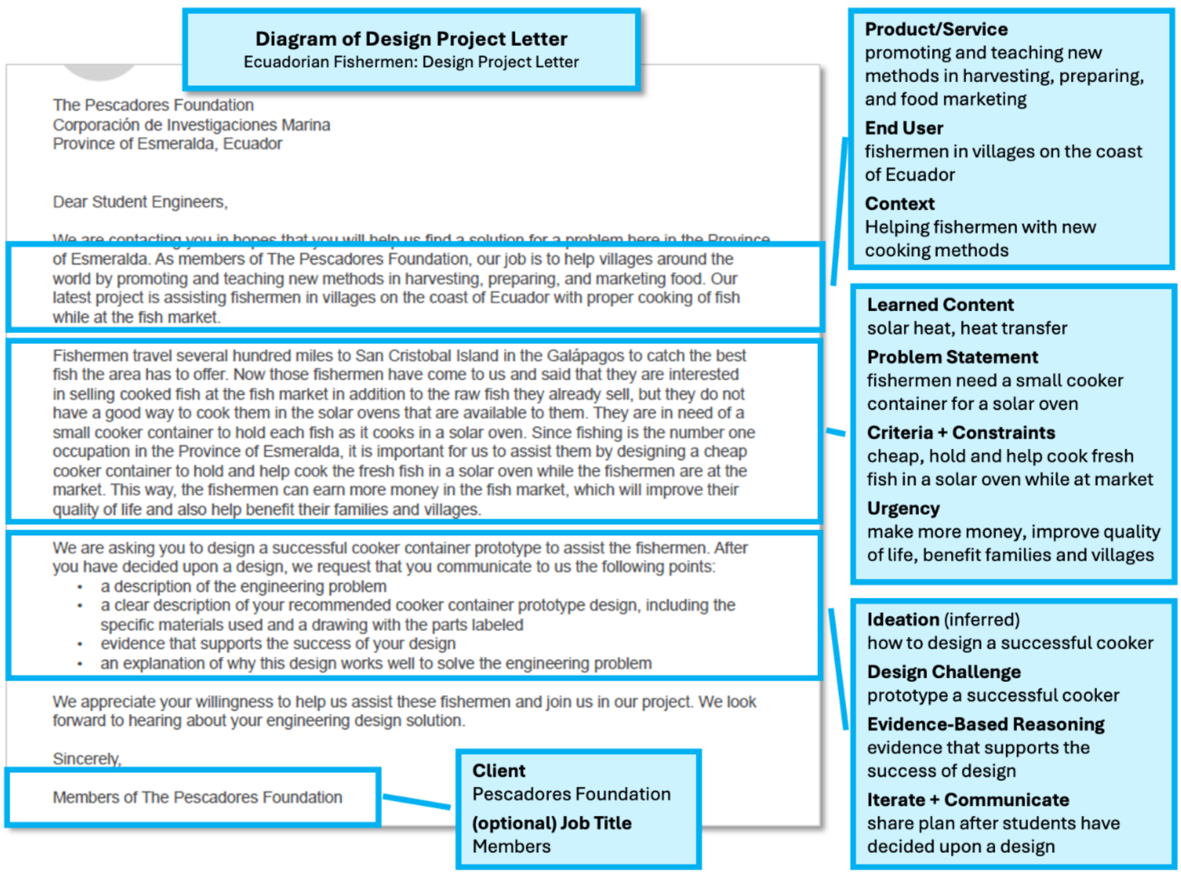

Figure 8. ***Design Project Letter*****, Ecuadorian Fisherman**

In Paper Baskets, the *design project letter* aligns with the previously explained structure, but at a level appropriate for kindergarten students (see Figure 9). This *design project letter* clearly defines the design challenge and the information needed to help Max and Lola understand why students recommend their chosen solution. Criteria and constraints are clearly stated while expectations are set for design iteration and communication back to the client. The *design project letter* explicitly describes the design challenge, scaffolds content into the design challenge and advances the engineering design process.

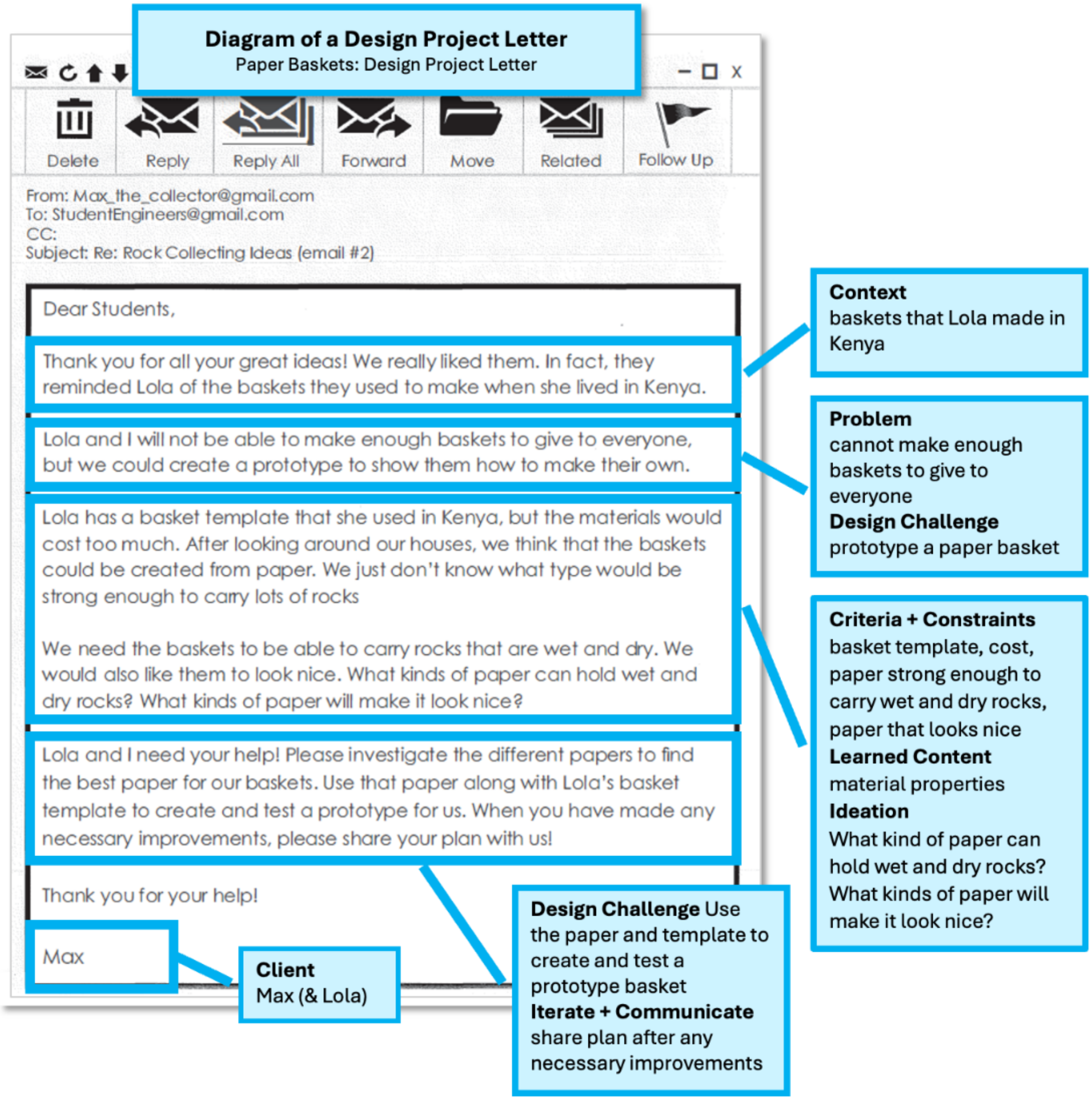

Figure 9: ***Design Project Letter*, Paper Baskets**

In Let the Chips Fall, the *design project letter* aligns with the previously explained structure, but at a level appropriate for middle and high school students (see Figure 10). As the content is middle school and high school geometry, this letter includes extensive and detailed expectations of mathematical calculations included in the criteria. The *design project letter* explicitly describes the design challenge, scaffolds content into the design challenge and advances the engineering design process.

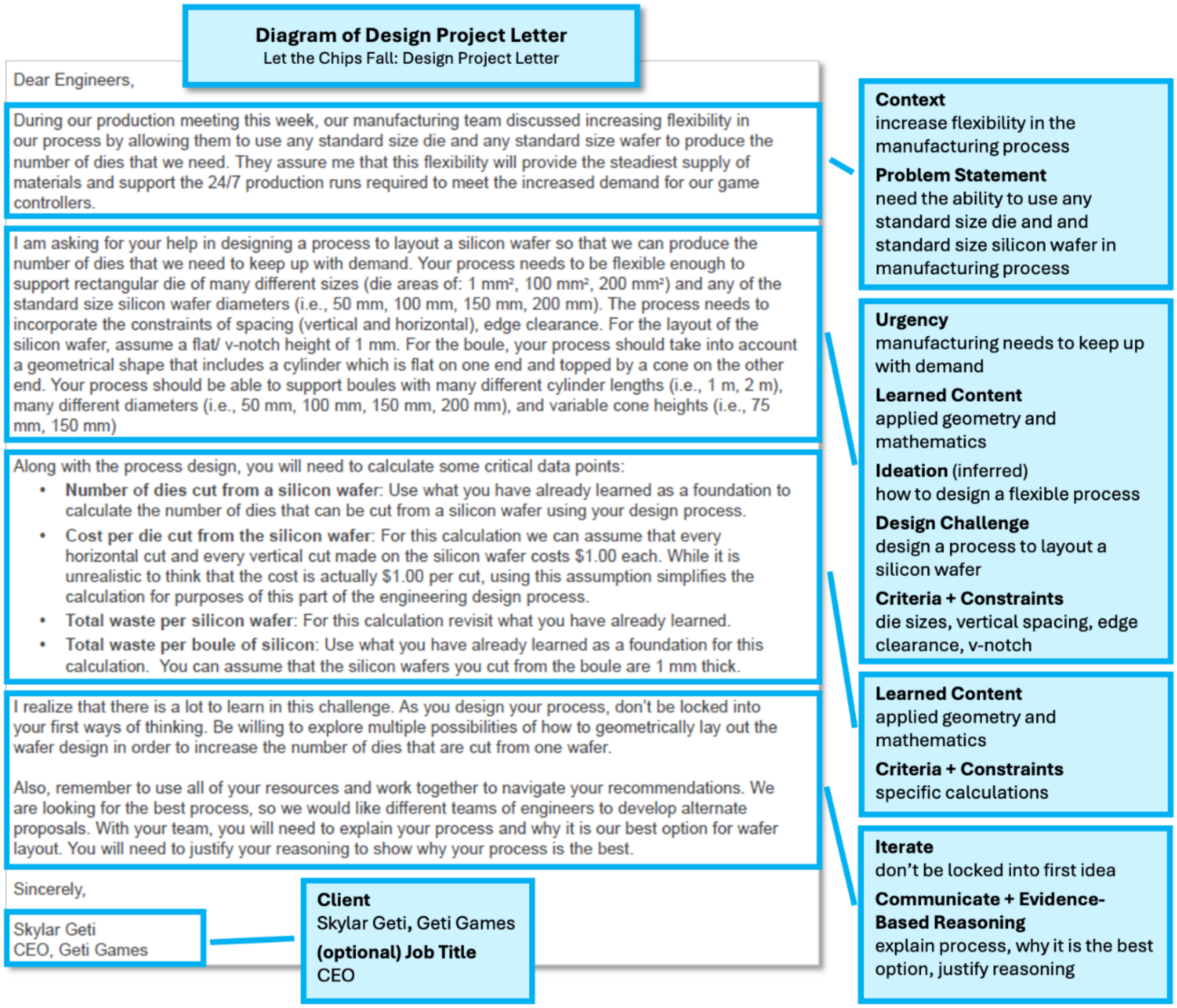

Figure 10. ***Design Project Letter*****, Let the Chips Fall**

The role of the *design project letter* is to integrate the context, content, and engineering design process into a design challenge that will result in identifying a solution to the client's problem. The design challenge leverages the problem scoping and knowledge building that students have gathered throughout the curricular unit. Within the boundaries clearly set by criteria and constraints, students are asked to apply the knowledge learned throughout the unit as they iteratively design, try, and test their solutions. Students are required to communicate their solution to the client using evidence-based reasoning to justify their final design. In this way, the *design project letter* describes the design challenge, scaffolds content into the design challenge and advances the engineering design process.

4. Concluding response letter

As summarized in Figure 2, the role of the *concluding response letter* within engineering design-based K-12 STEM integration curricula is to allow for an exit from the iteration cycle, provide an evaluation of student designs, celebrate student success, and reinforce key content. To fulfill this role, the *concluding response letter* must reconnect students to the client and end user needs.

In Paper Baskets, the *concluding response letter* (see Figure 11) provides an exit from the iteration cycle while celebrating students' success, evaluating the student design solutions, and communicating the design solution impact on the end user. In this letter, Max and Lola acknowledge the hard work students put forth in designing and testing students conducted on their paper baskets (i.e., the design challenge). Max and Lola also evaluate the student designs by providing feedback. Max and Lola share that they "really liked all of the different prototypes you and your classmates designed." Finally, Max and Lola share the impact on the end user by explaining "These paper basket designs will be a hit at the local nature center. We are so excited to have a prototype that other rock collectors can use to make their own baskets." In this way, the *concluding response letter* celebrates the students' success, provides an evaluation of the student design solutions, and communicates the design solution impact on the end user.

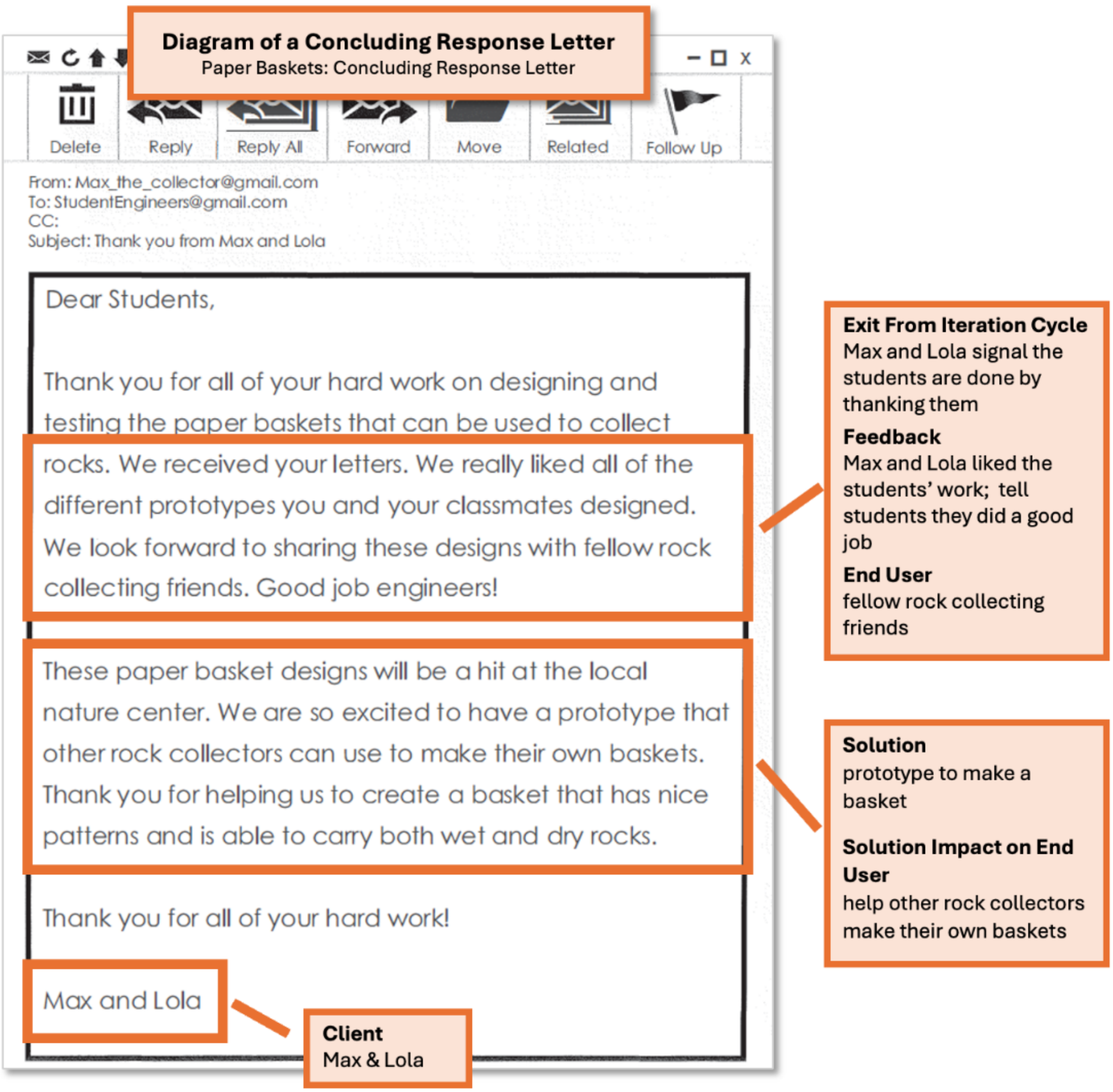

Figure 11: *Concluding Response Letter*, Paper Baskets

In the unit Game On! [31], an English/language arts unit for grades 6-10, the *concluding response letter* (see Figure 12) aligns with the previously explained structure. In this letter Rubi Gonzalez celebrates the students' success by acknowledging their dedication to the engineering design challenge. Rubi provides feedback by explaining that the students' recommendations will be helpful. Finally, Rubi clearly states the impact on the end user as reducing screen time and getting kids excited about board games. In this way, the *concluding response letter* celebrates the students' success, provides an evaluation of the student design solutions, and communicates the design solution impact on the end user.

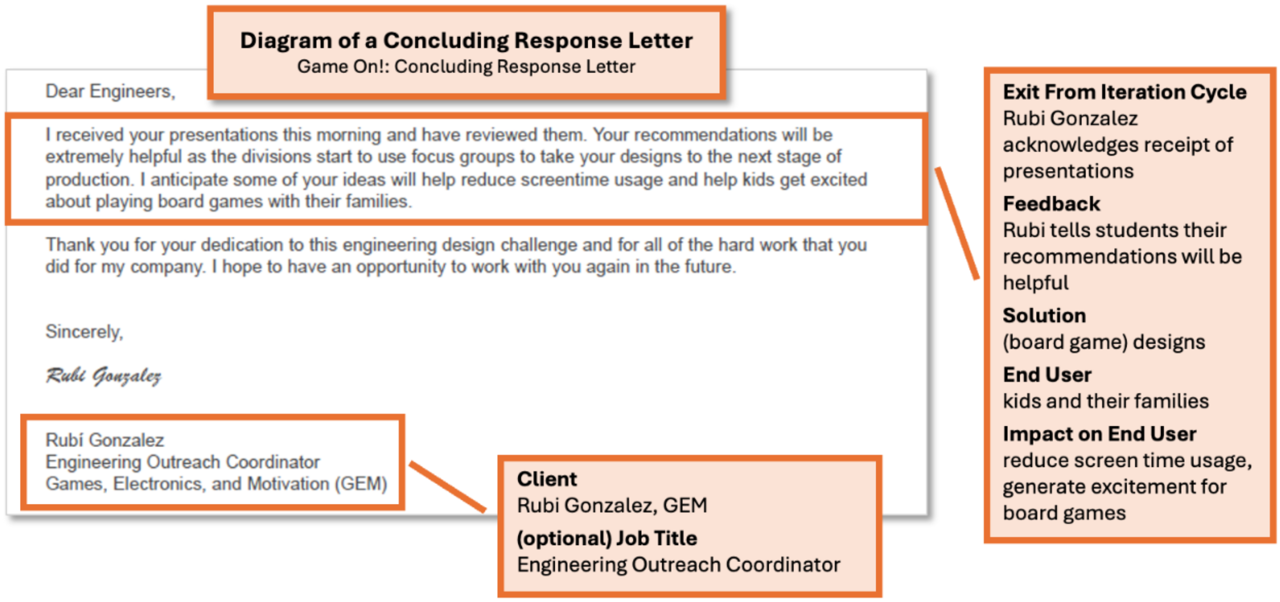

Figure 12. ***Concluding Response Letter*****, Game On!**

The role of the *concluding response letter* is to allow for an exit from the iteration cycle, bringing closure to the client interaction. It celebrates the students' success, provides an evaluation of the student design solutions, and communicates the design solution impact on the end user. Figure 4 summarizes the key elements typically included in the *concluding response letter*.

5. Variations on client letter sequence

Client letter sequencing can vary based on the complexity of the design challenge and/or the complexity of the content. Additionally, sequencing can vary with expectations of student skills and/or prior knowledge. Client letter sequencing is linear when the integration of context and content is applied to simple scenarios. The typical progression of client letters (see Figure 13) includes problem scoping, knowledge building, design project, and concluding response. However, multiple iterations of certain client letters may be required based on the complexity of the engineering design challenge or the content (see Figure 14). Knowledge acquired through content or generated from a mini-design challenge can influence the scope of the problem to be addressed. In these instances, multiple iterations of the *problem scoping letter* and/or the *knowledge building letter* can be helpful to support and connect the context to the content. Let the Chips Fall is a good example of the need for multiple problem scoping and knowledge building letters to help students connect the context to content (see Table 4). In this curricular unit, content is explored over the course of five *knowledge building letters*. The depth of the content impacts student understanding of the client problem, resulting in the need for an additional *problem scoping letter* with updated information related to the client's problem. Additionally, a subset of client letters might be used when the expectation of student skills and/or prior knowledge is high. In this case, students are expected to succeed in the absence of information typically provided within one or more client letters. For example, only one client letter, the *design project letter,* is used in the curricular unit Make Sense (see Table 4), developed for high school students. In this variation, the *design project letter* contains detailed problem scoping information and sets expectations for applying content to find a solution.

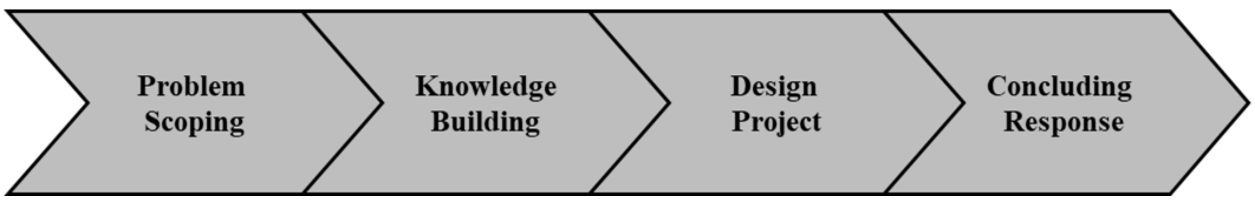

Figure 13. Typical Progression of Client Letters

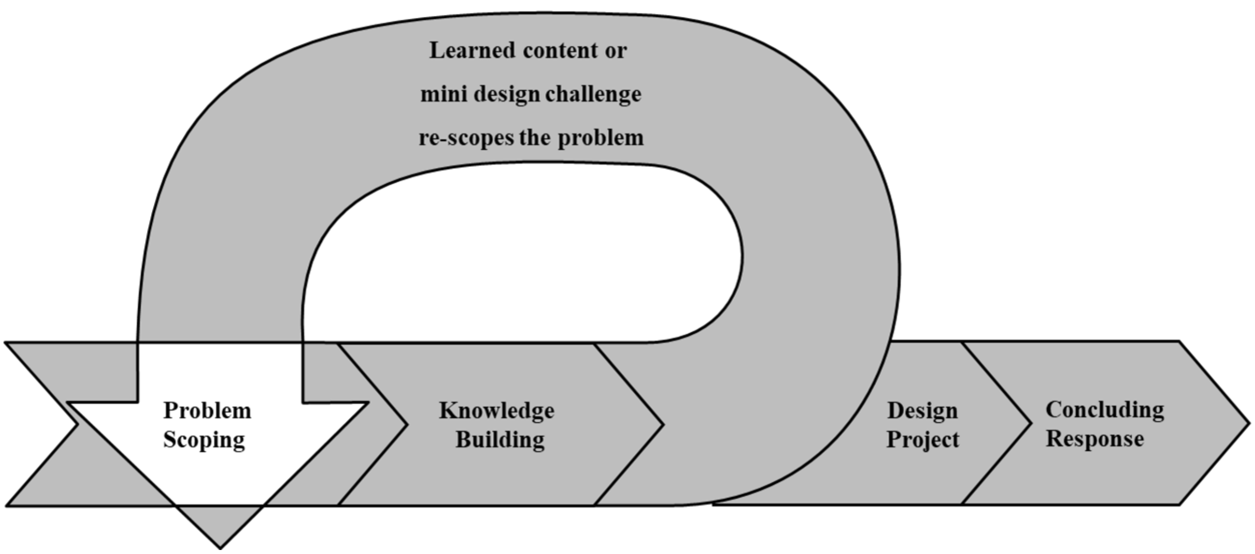

Figure 14: Example Variation of Client Letter Progression

Table 4. Summary of Client Letter Data (number of letters) by Curricular Unit

Curricular Unit	Grade Level	Problem Scoping Letter	Knowledge Building Letter	Design Project Letter	Concluding Response Letter
Designing Paper Baskets	ES	1		1	1
Designing Hamster Habitats	ES	1		1	1
Designing Toy Box Organizers	ES	1	1	1	1
Ecuadorian Fisherman	MS			1	
Water Water Everywhere But Not a Drop to Drink	MS	1	3	1	1
Game On!	MS+HS	1	3	2	1
Let the Chips Fall Where They May	MS+HS	2	5	1	
Let the Good Ideas Roll!	MS+HS	1	2	2	1
Carbon Sink Investigation	HS	1	2	1	1
Lock it Up!	HS	1		1	
Logarithms and Light	HS	1	1	1	1
Make Sense	HS			1	
Safe Chips Inc (Business)	HS	1			
Safe Chips Inc (Engineering & Technology)	HS	1		1	
Stressed Out!	HS	1	1	2	1

* NOTE: ES=Elementary School, MS=Middle School, HS=High School

6. Summary

Client letters embedded in context-rich, engineering design-based K-12 STEM integration curricula explicitly connect real-world context to content. Within the curricula, client letters have four roles which define how they provide information and/or guide the application of content related to the engineering design project. The four roles of the client letter are problem scoping, knowledge building, design project, and concluding response. While each client letter role has a specific purpose and conveys important contextual information related to that purpose (see Figure 4), the sequence of the client letters can vary based on the complexity of the engineering design challenge or the content (see Figures 13-14). Additionally, client letter sequencing can vary with expectations of student skills and/or prior knowledge (see Table 4).

B. Findings and discussion based on RQ2: How do client letters add value to engineering design-based STEM integration curricula?

In this section, we discuss the value that client letters bring to K-12 engineering design-based STEM integration curricula. Through the lens of the STEM Integration Framework [8], we analyzed the collection of client letters in each curricular unit for their overall support of the different elements important in STEM integration. We arrived at the following four areas where client letters collectively provide value to a curricular unit: strengthening the motivating and engaging context anchored in authentic experiences, connecting content and the engineering design challenge to real-world scenarios, supporting instructional strategies, and enhancing other ties to STEM integration. Each value is discussed in detail below.

1. Strengthening motivating and engaging context anchored in authentic experiences

Client letters can be used to strengthen motivating and engaging context by simulating authentic experiences. Authentic experiences are created through client-based scenarios conveyed within client letters. When multiple client letters are used, context-rich storylines emerge, strengthening the possibility of an authentic experience. In Paper Baskets, client letters immerse Kindergarten students in a client-based scenario that includes details of interest to Kindergarteners: Max & Lola (the clients), a nature center, rock collecting, and a desire to help others start rock collecting. In Ecuadorian Fisherman, middle school science students are immersed in a client-based scenario with fishermen (the end users), in Ecuador, growing a business, and a desire to cook fish in a solar oven. In both curricular units, these details provide different points of interest through which students can find real-world connection to the context, see themselves in the problem space, and relate to the realistic and compelling needs of the client/end user.

The use of client letters advances research related to the use of client-based scenarios to create motivating and engaging context as described by Brady et al. [6] and Lesh [17]. Additionally, the use of client letters contributes to context-rich storylines as studied by Leak et. al [16]. Client letters strengthen the motivating and engaging context in a curricular unit through the use of client-based scenarios and context-rich storylines.

2. Connecting content and the engineering design challenge to real-world scenarios

Authentic experiences created by client letters can be used to connect content and the engineering design challenge to real-world scenarios. The narrative within each client letter can be intentionally crafted to help integrate knowledge exploration and application into the process of recommending a solution to the design challenge. In Let the Chips Fall, the CEO of Geti Games asks the students to calculate the waste produced from silicon wafers of different thicknesses and to build a mathematical model that can be used to calculate waste for different configurations. This request from the CEO aligns with middle school mathematics standards related to area and volume. In completing the request, students will explore and apply the concepts of area and volume to the design challenge. In Ecuadorian Fisherman, the Pescadores

Foundation requests students to design a “successful cooker container prototype” to help cook fish in a solar oven [30, p. 29]. In order to design the prototype, students will need to explore and apply concepts related to physical science (i.e., heat transfer, thermal energy, and temperature). These physical science concepts align with middle school science standards. In this way, client letters support the integration of mathematics or science into an engineering design-based STEM integration unit.

Anchored in authentic experiences, client letters convey important information from the real client about the engineering design challenge. Special care is taken to communicate the information without being prescriptive about a solution. In Paper Baskets, Max and Lola share a problem with the students: “We want to help others start their own rock collection by giving away something that will allow them to have as much fun collecting rocks as we have had” [28, p. 20]. This communication conveys important information about the engineering design challenge: problem scoping information along with the needs and wants of the client. Through client letters, Max and Lola further ask students to share ideas “about what we might give away to help others with their rock collecting” [28, p. 20] With this open-ended question, a successful solution is described but not prescribed, and students are encouraged to apply creativity in responding with ideas. Students are connected to the concepts in science as they investigate how to help with rock collecting.

The use of client letters connects content and the engineering design challenge to real-world scenarios. When multiple client letters are used, information related to content and the design challenge can be shared with students as needed. The simulation of real-world client scenarios through the use of client letters furthers the initiative set forth by the National Research Council [1] to integrate K-12 learning experiences into real-world scenarios using engineering design as the integrator. Additionally, the learned knowledge required to resolve client-based scenarios [6], [7], [10] can be integrated through the use of client letters.

3. Supporting instructional strategies

Client letter narratives can be used to leverage learner-centered pedagogies and incorporate different teaching and learning methods like scaffolded inquiry and engineering design-based reasoning. Client letters can support learner-centered pedagogies by engaging students through shared experiences and encouraging inquiry to support knowledge development. In this way, Client letters can help create shared experiences by anchoring the context of the client-based scenario in a relatable scenario. In Paper Baskets, Kindergarten students share rock collecting experiences with Max and Lola. In Let the Chips Fall, middle and high school students share excitement for a new gaming controller with the team at Geti Games. Client letters embedded in STEM integration help advance the research that students are more inclined to engage in learning when it is connected to shared experiences [20].

Client letters use inquiry to encourage student agency in resolving the client-based scenario. Applying inquiry-based learning methods, client letters encourage students to ask themselves “what if” and “why” questions to help identify gaps in student knowledge. In Paper Baskets, students are asked to generate ideas about what Max and Lola could give away to help others with rock collecting. In order to respond to this inquiry, students navigate their own versions of “what if” questions and “why” questions to generate ideas and determine if their ideas will be useful to rock collecting. In Let the Chips Fall, students are encouraged to help the client by investigating how much of the material is wasted. No specific direction is given as to how the waste is to be calculated; in fact, the client asks the students to develop a model that can be used to answer this question in the future. Students will need to ask “why” and “what if” questions to sort through what they currently know and what they will need to learn in order to respond back to the client. In this way, client letters further apply the use of inquiry in STEM integration to navigate and identify knowledge gaps in student learning [19], [20], [21].

Client letters support evidence-based reasoning by requiring students to summarize their insights and justify their design decision to the client based on how well the design met the client’s needs (i.e., criteria and constraints). In Ecuadorian Fisherman, the client explicitly asks students to share “an explanation of why this design works well to solve the engineering problem.” [30, p. 29]. This requires students to justify their recommended design using facts and logical reasoning. In Paper Baskets, the client thanks the students for creating baskets that had nice patterns and were able to carry both dry and wet rocks. This ties the success of the students’ designs to the needs of the client. By incorporating evidence-based reasoning into the narrative, client letters support the use of evidence-based reasoning in STEM integration curricula to synthesize learnings and justify conclusions with logical reasoning [22], [23].

4. Enhancing other ties to STEM integration curricula

Opportunities for students to communicate and self-assess are important elements for a quality STEM integration curricula [8]. Client letters support the development, understanding, and application of skills related to communication by acting as the vehicle through which information is communicated and initiating requests for students to share knowledge back to the client. In Paper Baskets, Max and Lola not only describe their problem, but ask students to “send us some ideas” [28, p. 20]. As such, students are engaged in analysis of the content of the client letter to understand the problem being communicated. Additionally, students are requested to share their ideas with Max and Lola, encouraging the communication of synthesis of knowledge. In Ecuadorian Fisherman, the Pescadores Foundation describes a very clear structure for how students are to communicate their design solution. The implication is that students must respond back to the client with all of the requested information so that the Pescadores Foundation can make an informed decision.

Client letters can be used to support students in their journey to self-assess their own understanding of content and gauge the extent to which their design solution meets the needs and wants of the client and end user. Through the sharing of criteria and constraints, client letters provide a rubric that allows students to self-assess the progress they are making in applying content and developing their design challenge solution. In Paper Baskets, Max and Lola ask for something that is not only fun to use in collecting rocks, but also supports the transportation of dry and wet rocks. In Ecuadorian Fisherman, the Pescadores Foundation identified the need for the solution to be cheap but durable enough to hold the fish while cooking in a solar oven. In Let the Chips Fall, students need to build a mathematical model that supports different diameters and different layouts and different wafer thicknesses. These criteria and constraints help students evaluate the success of their solutions.

5. Summary

Client letters add value to K-12 engineering design-based STEM integration curricula. Applying the STEM Integration Framework [8], we identified four areas where client letters brought value to the curricula: strengthening motivating and engaging context anchored in authentic experiences, connecting content and the engineering design challenge to real-world scenarios, supporting instructional strategies, and enhancing other ties to STEM integration. By adding this value, client letters support important research in K-12 STEM integration.

IX. Limitations of the study

This research study is designed to consider only client letters embedded in K-12 STEM integration curricular units. As such, the use of client letters outside that scope are not included in the analysis. Additionally, client letters were analyzed for their individual roles and aggregate contributions within curricular units. This did not allow for studying the impact of all client letter sequence variations.

X. Conclusion and Implications

This study provides evidence that client letters embedded in K-12 STEM integration curricula support essential elements of high-quality curricula, which have the potential to foster student learning and engagement. Analysis of individual client letters revealed unique roles of different client letters and the important contextual elements to convey in each role. These results align with the requirements put forth in the STEM Integration Framework [8]. Client letters deepen the connection between content and real-world scenarios through their roles in support of problem scoping, knowledge building, engineering design, and concluding response. We even saw how different variations in the sequencing of client letters can layout different levels of complexity in the content or the engineering design challenge. Additionally, we found that client letters add value to the curricula by strengthening motivating and engaging context anchored in authentic experiences, connecting content and the engineering design challenge to real-world scenarios, allowing for student-centered instructional strategies, and enhancing other ties to STEM integration. Client letters also have the potential to enhance participation and opportunity in STEM education by providing personally relevant contexts that reflect a variety of communities, industries, and real-world challenges. By carefully designing client letters that represent a broad range of perspectives, educators can foster learning environments that support all students in seeing themselves as problem solvers and innovators. Additionally, professional development efforts could help teachers effectively implement client letters to maximize their impact, ensuring that students engage deeply with both the context and content of STEM learning. These results show that client letters add value to K-12 STEM integration curricula, potentially supporting students' learning experience through deepening student engagement, applying crosscutting concepts from multiple STEM disciplines, and supporting high quality pedagogies.

Research is already in process to expand the selection of client letters, iterate on the coding structure, and analyze client letters more holistically in support of identifying a conceptual framework for client letter development and inclusion in STEM integration curricula [27]. Additional research could include understanding how teachers use the client letter in their discourse to connect authentic context to the content being instructed, how client letters can be used outside of engineering design-based STEM Integration curricula, and how client letters can be used to support different student-centered teaching and learning methods. Teachers should consider the use of client letters to support their use of student-centered pedagogies, while curriculum developers embed them to integrate context and real-world content into STEM learning resources. Additionally, professional development providers can use this analysis of client letters in planning, implementing, and reflecting on client letter use to potentially foster student engagement.

XI. Acknowledgements

We acknowledge support from the U.S. Department of Defense [Contract No. W52P1J-22-9-3009], Indiana Economic Development Corporation [Contract No. A281-3-IPF-1028 424208], and U.S. Department of Defense through Applied Research Institute [Contract No. SA-22036.001].

XII. References

[1] National Research Council, *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, D.C.: National Academies Press, 2012, p. 13165. doi: 10.17226/13165.

[2] NGSS Lead States, *Next Generation Science Standards: For states, by states*. Washington, D.C.: National Academies Press, 2013, p. 18290. doi: 10.17226/18290.

[3] B. J. Reiser, M. Novak, T. A. W. McGill, and W. R. Penuel, "Storyline units: An instructional model to support coherence from the students' perspective," *Journal of Science Teacher Education*, vol. 32, no. 7, pp. 805–829, Oct. 2021, doi: 10.1080/1046560X.2021.1884784.

[4] H.-H. Wang, T. J. Moore, G. H. Roehrig, and M. Park, "STEM integration: Teacher perceptions and practice," *JPEER*, 2011, doi: https://doi.org/10.5703/1288284314636.

[5] National Research Council, *How people learn: Brain, mind, experience, and school: expanded edition*. Washington, D.C.: National Academies Press, 2000. doi: 10.17226/9853.

[6] C. Brady, C. Eames, and R. Lesh, "The student experience of model development activities: going beyond correctness to meet a client's needs," in *Evaluierte Lernumgebungen zum Modellieren*, S. Schukajlow and W. Blum, Eds., Wiesbaden: Springer Fachmedien, 2018, pp. 73–92. doi: 10.1007/978-3-658-20325-2_5.

[7] T. J. Moore, "Model-eliciting activities: A case-based approach for getting students interested in material science and engineering." Journal of Materials Education, Jan. 2008.

[8] S. S. Guzey and T. J. Moore, "Engineering design-based STEM integration curriculum assessment overview." 2017. [Online]. Available: https://doi.org/10.4231/R7G44NHG

[9] T. J. Moore, A. C. Johnston, and A. W. Glancy, "STEM integration: A synthesis of conceptual frameworks and definitions," in *Handbook of research on STEM education*, C. C. Johnson, M. J. Mohr-Schroeder, T. J. Moore, and L. D. English, Eds., Routledge, 2020, pp. 3–16.

[10] L. K. Berland, "Designing for STEM integration," *Journal of Pre-College Engineering Education Research (J-PEER)*, vol. 3, no. 1, Apr. 2013, doi: 10.7771/2157-9288.1078.

[11] T. J. Moore, M. S. Stohlmann, H.-H. Wang, K. M. Tank, A. W. Glancy, and G. H. Roehrig, "Implementation and integration of engineering in K-12 STEM education," in *Engineering in precollege settings: Research into practice*, Ş. Purzer, J. Strobel, and M. Cardella, Eds., West Lafayette, IN: Purdue University Press, 2014, pp. 35–60. [Online]. Available: https://doi.org/10.2307/j.ctt6wq7bh
[12] T. R. Kelley and J. G. Knowles, "A conceptual framework for integrated STEM education," *IJ STEM Ed*, vol. 3, no. 1, p. 11, Jul. 2016, doi: 10.1186/s40594-016-0046-z.
[13] L. S. Nadelson and A. L. Seifert, "Integrated STEM defined: Contexts, challenges, and the future," *The Journal of Educational Research*, vol. 110, no. 3, pp. 221–223, May 2017, doi: 10.1080/00220671.2017.1289775.
[14] A. Kirn and L. Benson, "Engineering students' perceptions of problem solving and their future," *J of Engineering Edu*, vol. 107, no. 1, pp. 87–112, Jan. 2018, doi: 10.1002/jee.20190.
[15] S. S. Guzey, T. J. Moore, and M. Harwell, "Building up STEM: An analysis of teacher-developed engineering design-based STEM integration curricular materials," *Journal of Pre-College Engineering Education Research (J-PEER)*, vol. 6, no. 1, p. Article 2, 2016.
[16] A. E. Leak, L. M. Owens, K. N. Martin, and B. M. Zwickl, "Contextualizing and integrating practices: Reclaiming authenticity lost from translating workplace engineering practices into K-12 standards," *Journal of Pre-College Engineering Education Research (J-PEER)*, vol. 13, no. 2, Jun. 2023, doi: 10.7771/2157-9288.1333.
[17] R. Lesh, H. Doerr, and H. Doerr, *Beyond constructivism: Models and modeling perspectives on mathematics problem solving, learning, and teaching*. Mahwah, NJ: Lawrence ErlbaumLesh, R., 2003.
[18] K. B. Kostøl and K. B. Remmen, "A qualitative study of teachers' and students' experiences with a context-based curriculum unit designed in collaboration with STEM professionals and science educators," *Discip Interdscip Sci Educ Res*, vol. 4, no. 1, p. 26, Oct. 2022, doi: 10.1186/s43031-022-00066-x.
[19] L. Thibaut, H. Knipprath, W. Dehaene, and F. Depaepe, "How school context and personal factors relate to teachers' attitudes toward teaching integrated STEM," *Int J Technol Des Educ*, vol. 28, no. 3, pp. 631–651, Sep. 2018, doi: 10.1007/s10798-017-9416-1.
[20] M. J. Prince and R. M. Felder, "Inductive teaching and learning methods: Definitions, comparisons, and research bases," *Journal of Engineering Education*, vol. 95, no. 2, pp. 123–138, Apr. 2006, doi: 10.1002/j.2168-9830.2006.tb00884.x.
[21] C. Kuhlthau, L. Maniotes, and A. Caspari, *Guided inquiry: learning in the 21st century: Learning in the 21st century*. 2015. doi: 10.5040/9798400660603.
[22] A. M. Rynearson, T. J. Moore, K. M. Tank, and E. Gajdzik, "Evidence-based reasoning in a kindergarten classroom through an integrated STEM curriculum," presented at the 2017 ASEE Annual Conference & Exposition, Jun. 2017. Accessed: Dec. 12, 2024. [Online]. Available: https://peer.asee.org/evidence-based-reasoning-in-a-kindergarten-classroom-through-an-integrated-stem-curriculum-fundamental
[23] E. A. Siverling, E. Suazo-Flores, C. A. Mathis, and T. J. Moore, "Students' use of STEM content in design justifications during engineering design-based STEM integration," *School Science and Mathematics*, vol. 119, no. 8, pp. 457–474, Dec. 2019, doi: 10.1111/ssm.12373.
[24] T. J. Moore, A. Glancy, K. Tank, J. Kersten, K. Smith, and M. Stohlmann, "A framework for quality K-12 engineering education: Research and development," *Journal of Pre-*

College Engineering Education Research (J-PEER), vol. 4, no. 1, May 2014, doi: 10.7771/2157-9288.1069.
[25] H. Morgan, "Conducting a qualitative document analysis," *The Qualitative Report*, vol. 27, no. 1, pp. 64–77, Jan. 2022, doi: 10.46743/2160-3715/2022.5044.
[26] V. Braun and V. Clarke, "Using thematic analysis in psychology," *Qualitative Research in Psychology*, vol. 3, no. 2, pp. 77–101, 2006, doi: 10.1191/1478088706qp063oa.
[27] C. H. McDonnell *et al.*, "From context to connection: Client letters in STEM integration curricula," *STEM Synergies special issue of Education Sciences*, in press.
[28] K. M. Tank, T. J. Moore, C. Pettis, and E. Gajdzik, "PictureSTEM Designing Paper Baskets." Purdue University Research Foundation, 2017. [Online]. Available: www.PictureSTEM.org
[29] T. J. Moore *et al.*, "Let the Chips Fall Where They May." SCALE K-12 Project, 2024. [Online]. Available: https://nanohub.org/resources/39066
[30] K. Berg *et al.*, "Ecuadorian Fishermen: An EngrTEAMS Curricular Unit." 2022. [Online]. Available: https://nanohub.org/resources/36120.
[31] E. Haluschak *et al.*, "Game On!" SCALE K-12 Project, 2024. [Online]. Available: https://nanohub.org/resources/39034