The Importance of Implicit Knowledge in Chemistry Teaching and Learning

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Abstract – The term "implicit knowledge" encompasses a variety of subfields, including but not limited to experiential knowledge, tacit knowledge, and accidental learning paradigms. This article explores the concept of implicit knowledge and its perceived importance in the process of learning. The concept of tacit knowledge holds significant importance in the development of research aimed at investigating student cognition and comprehension in the field of chemistry, as well as in the analysis and application of research outcomes in educational settings. Literature on cognition argues that most knowledge, which individuals utilize when evaluating their environment and executing decisions is not available to conscious reflection. As a result, scholars in the realm of chemistry education must explore alternative methods to elicit tacit knowledge, which holds significant ramifications for their research endeavors. Hence, it is crucial to consider that the outcomes of numerous chemistry-related investigations, which document the conceptions of students, may reflect cognitive processes that rely on tacit knowledge to some extent. The differentiation between implicit and explicit information is paramount in understanding the cognitive process of learning chemistry, as the former operates subconsciously without conscious effort.

Keywords – Implicit Knowledge, Explicit Knowledge, Chemistry Learning, Chemistry Teaching, Cognitive System.

I. INTRODUCTION

To comprehend the significance of implicit learning for development, it is necessary to examine the features of experimental settings frequently utilized in this research domain. Implicit learning is frequently experiential when individuals are not explicitly instructed to discern the configuration of their surroundings. Rather than being instructed to simply focus on the training presentation, participants are frequently directed to engage in an activity that occupies their cognitive faculties while still enabling them to remain attentive to the material being presented. The displayed patterns are exclusively those that are ordered. Within the artificial grammar paradigm, participants exclusively receive accurate instances of the material to be acquired, specifically grammatical strings, during the entirety of the training process. Demonstrating instances of a rule that contain errors or negative outcomes can potentially induce a change in the learner's mindset towards adopting a problem-solving approach.

However, it may also result in interferences that impede the learning process, which will be elaborated on later. The third characteristic of implicit learning is the comparative intricacy of occurrences. Empirical evidence in [1] suggests that individuals are capable of comprehending intricate information that would otherwise be challenging to grasp through explicit instruction. Consequently, the conditions conducive to implicit learning bear a striking resemblance to the situations commonly encountered by both young children and mature individuals in their everyday experiences. Implicit learning processes are widely acknowledged to be essential throughout an individual's lifespan, as they enable the continual behavioral adjustment required by constantly changing environmental circumstances.

This article provides a theoretical examination of the significance of implicit knowledge in the process of learning chemistry. Additionally, it evaluates how this concept aligns with a broader research initiative that seeks to enhance chemistry education by exploring the contextual aspects of student learning. As per the prescribed syllabus, the assimilation of novel information is predicated upon and steered by antecedently acquired knowledge and proficiencies. It is postulated that educators will be more proficient in imparting knowledge to their students if they possess a comprehensive understanding of their students' pre-existing comprehension and conceptualization of the subject matter being taught in the classroom. The introductory section of the article initiates a discourse on tacit knowledge and its interconnection with the wider investigation of learners' comprehension of knowledge. Following the establishment of a definition for implicit knowledge, the article proceeds to expound upon its cognitive functions and the mechanisms by which it is acquired. Subsequently, an examination is conducted on the application of aforementioned concepts in chemistry research that investigates the cognitive processes of students. This involves a critical analysis of pioneering studies that have investigated the role of tacit knowledge components in scientific pedagogy. The challenges associated with broadening the scope of the research program are evaluated in light of the limited existing literature in the domain of chemistry education research (CER) and the potential value of this standpoint.

The acquisition and understanding of knowledge by students holds significant value within the context of chemistry classrooms. The acquisition and understanding of the subject matter constitute a significant determinant of the ultimate evaluation. Enhancing students' understanding and mastery of chemistry is a fundamental objective of chemistry instruction. Educators are advised to perform diagnostic evaluations of their pupils' aptitudes and competencies to customize their instructional strategies to suit the specific needs of each particular cohort. It is reasonable to assert that textbooks which document CER prioritize the achievement of student learning outcomes.

Despite frequent usage in educational discourse, operational definitions of terms like "knowledge" and "understanding" are infrequently reported in CER literature. Frequently used terms in pedagogical literature are often assumed to be comprehended by readers. However, the concept of 'implicit knowledge' explored in this article, which refers to knowledge that an individual utilizes but cannot consciously access, may not be acknowledged as 'knowledge' in the conventional sense of the term. In a scientific context, particularly in CER research, it is imperative to establish clear definitions for the terms 'knowledge' and 'implicit knowledge'. The rest of the paper has been organized as follows: Section II presents a introduction of implicit and explicit knowledge. Section III provides an overview of implicit knowledge in cognition and its development. This section discusses the cognitive system, and implicit learning in aging, childhood, and infancy. Section IV reviews the strategies to defining implicit knowledge in scientific education. In Section V, an application of implicit knowledge viewpoint in chemistry learning is discussed. Finally, Section VI draws a conclusion to the article.

II. IMPLICIT AND EXPLICIT KNOWLEDGE

The act of obtaining knowledge in a structured written form is an instance of explicit knowledge. This type of data is highly amenable to being stored and transmitted across diverse geographical locations and among various individuals. This data is readily accessible through various media outlets, with encyclopedias serving as a particularly intriguing source of information. The difficulty associated with explicit information pertains to its maintenance and universal availability. This article aims to elucidate the fundamental differences between tacit and overt comprehension. **Table 1** presents the differences between these two forms of comprehension (implicit knowledge and explicit knowledge). Tacit or implicit knowledge can be considered as the opposite of explicit information.

Articulating this concept is not a straightforward task and conveying it to another individual is not a simple matter. Unrecorded or unencoded knowledge encompasses the aptitude to employ intricate computer programming languages or operate sophisticated machinery. The transmission of tacit knowledge is limited to interpersonal communication. Merely possessing the ability to ride a bike or swim does not necessarily qualify one to effectively instruct another individual in these activities. One cannot effectively instruct another individual on the skills of cycling or swimming without first providing them with a thorough demonstration and physical exertion.

Table 1. Differences Between Implicit and Explicit Knowledge

Implicit knowledge	Present understanding	Explicit knowledge	Criteria
Early learning favored	Theoretical support	Late explicit teaching favored	Trainable
High	Empirically unsupported	Low	Dimension of certainty in feedback
Consistent	Empirical proof for variable explicit knowledge	Vary	Feedback systematicity
Feedback as per feel	Undependable as reliable on self-report	Feedback as per rules	Dimension of awareness
Not needed	Theoretical support	Encouraged	Metalinguistic knowledge
Restricted	Empirical support	Unrestricted	Time present
Meaning	Empirical support	Form	Major focus of attention

Implicit knowledge constitutes the predominant portion of human information, and it appears to encompass all animal knowledge. The resolution of numerous enigmas in the field of cognitive science, which have thus far remained unexplained, is contingent upon the provision of a satisfactory depiction of the diverse strata of implicit representation. The investigation of conceptual knowledge is significantly dependent on establishing a distinct demarcation between explicit and implicit comprehension. It is widely acknowledged that individuals tend to offer diverse and distinct responses when queried about the contents of their conceptual knowledge, as per the findings of Safaie [2]. In the study, an investigation was conducted on the correlation between individuals' evaluations of the typicality of specific instances of a concept and their prioritization of different criteria aspects of the concept. The study's participants successfully executed two assigned tasks.

The primary objective was to ascertain the comparative significance of a set of criteria in delineating a particular category. The second objective was to establish a hierarchy of typicality within a set of category instances. The collected data was utilized to compute the similarity between participants on each task. In the event of any inherent variability within a given population, it is reasonable to expect that the similarity between two individuals on one task will be associated with their similarity on another task, provided that the individuals possess explicit knowledge regarding the rationale behind their perception of certain instances as being more typical than others. Upon comparing the two sets of similarities, no discernible correlation was found between the centrality of characteristics and the instance typicality in terms of the pattern of similarity between individuals. Hence, it appears that a significant portion of our conceptual knowledge remains implicit.

The primary concern arises when the implicit information influences the representational language of conscious understanding, given that conceptual understanding may not always be conscious. The task of achieving a knowledge representation that can account for differing levels of explicit and implicit comprehension is a challenging one. Does the conceptual representational language remain consistent across all levels of the system, or is there a distinction solely in the attribution of attributes to objects, events, and the self as knower? It appears that D&P holds this perspective. Alternatively, is it appropriate to solely employ explicit levels of representation in the portrayal of knowledge through a lexicon derived from natural language? According to Koblik, Red'kin, Volkov, and Mosalov [3], the proper interpretation of concept names such as "bird" and "bachelor" should not rely on their implicit semantic properties or responsibilities. According to the authors, the term "bird" has a conceptual function as a particle that is symbolically linked to the category of birds in the physical world. Its significance is derived solely from this symbolic connection. Despite the identification of a set of propositions that pertain to birds in general, such as the ontological assertion that birds exist, it is insufficient to constitute the entirety of the concept of birds.

An atomic entity that cannot be broken down into smaller components can be perceived as possessing a property configuration that is implicitly conveyed. While the term "bachelor" can be deconstructed into its individual components, it can be utilized in an implicit manner without the inclusion of said components in any given context. One may articulate a statement such as, "I possessed the knowledge that I sought an individual possessing a bachelor's degree, however, I had overlooked the prerequisite that the individual must not be wed." There exists a discernible distinction between the aforementioned type of atomism and the variant of atomism advocated by Esfeld [4]. The author's conceptual atomism posits that the relationship between the class of bachelors and the ability to make informed generalizations about said class is solely based on an informational semantic connection. The complexity of determining the implicit conceptual structure of a representation and the constraints or decisions involved in selecting the relevant data are evident upon careful consideration.

Poulin-Dubois and Rakison [5] posit that implicit conceptual structure necessitates supporting facts that are deemed necessary. The user suggests that a comprehensive analysis of the terms "bachelor," "male," and "unmarried" is only hinted at in the aforementioned sentence. By employing the term "bachelor," an individual is implicitly subscribing to a multitude of other assertions, which encompass characteristics such as "not being a vegetable" and "being comprised of cells that contain DNA." Additionally, the use of this term also connotes adherence to the more archetypal attributes associated with bachelorhood, such as residing alone, exhibiting caution towards matrimony, and possessing an affinity for solitude. Due to the existence of an infinite number of essential conclusions that ensue from a given concept and the presence of numerous probabilistically associated attributes in our conceptual knowledge, it is not a simple task to logically determine the specific aspects of a concept's meaning that constitute its implicit conceptual structure.

A more comprehensive explication of the distinction between implicit and explicit comprehension of conceptual data is required in the realm of cognitive inquiry. The identification of linkages across various cognitive domains has significant implications, as it opens up the possibility of a comprehensive account of the observed distinction. The presence of a language-like representational medium in the implicit representation of knowledge remains uncertain, despite its existence in explicit conceptualization.

III. OVERVIEW OF IMPLICIT KNOWLEDGE IN COGNITION AND ITS DEVELOPMENT

The Cognitive System

The term "mental representations" is employed to denote hypothetical units of information by Jabłońska and Mirucka [6], premised on the notion that an individual's encounters elicit modifications in the neural structure. The modifications mentioned could potentially lead to the development of new cognitive abilities during the stages of childhood and adolescence. The human central nervous system plays a crucial role in promoting adaptive behavior by facilitating the interpretation of sensory input. The system exhibits a dual functionality, serving as both a decision-making and model-building system, with the aim of achieving optimal performance. Within the realm of research, it is often advantageous to explicate and scrutinize cognitive processes through the lens of data processing in cognitive systems. While it is commonly acknowledged that the cognitive system's functionality can be explicated in terms of biochemistry, physiology, and anatomy of tissues comprising the system, this level of description is deemed more advantageous than discussing the physical structure of the brain for various intents. However, it should be noted that this is applicable in theory, if not always in practice.

Fig 1 depicts a cognitive system. In the realm of educational inquiry, the degree of explication pertaining to the cognitive system serves as a valuable intermediary between the vernacular lexicon employed to discuss mental processes (such as thinking, understanding, knowing, and insight) and the physical level definition of nervous and synapses impulses (which constitute the foundation of cognition, but are exceedingly intricate and not typically advantageous for pedagogical purposes). The brain engages in the processing of sensory information by utilizing its constantly evolving perception of the external world, which is constructed based on prior experiences of detecting and responding to environmental stimuli. The concept of memory encompasses a broad range of cognitive processes, extending beyond the limits of conscious recollection.

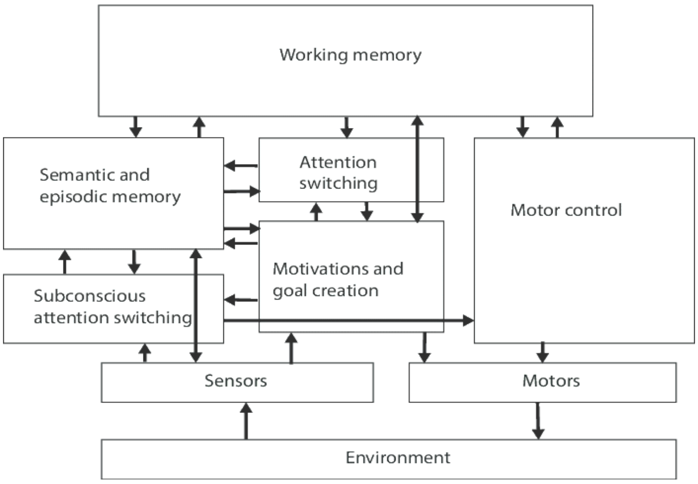

Fig 1. An Illustration of the Cognitive System

The phenomenon whereby conscious experience is limited to accessing resources beyond a particular threshold within the framework suggests that it may be indicative of a higher level within the system. The terms "higher" and "above" are utilized as metaphors to denote a greater distance from unprocessed sensory input within the realm of cognitive processing. Multiple stages of processing are involved in the transformation of sensory impulses, which are representations of sensory information within the nervous system, into conscious percepts. The act of assigning a higher value to a product that has undergone more processing is a subjective matter. It is possible to use alternative metaphors, such as "deeper," to convey the same meaning.

Substantial cognitive processing occurs at a subconscious level. Upon visual inspection of a laboratory flask, it is evident that the object in question is an entity. Prior to discriminating an object from a complex visual field, various mental processes must occur at a subconscious level. These processes occur irrespective of the observer's viewpoint, distance from the object, lighting intensity, background color, and other factors. For instance, a flask may appear different in terms of shape, size, color, and other attributes, depending on the viewing conditions. Similar to the way in which speech is perceived in awareness as a distinct flow of words that are differentiated from the contextual, and akin to the manner in which individuals are capable of executing intricate muscle contractions patterns, such as ascending stairs, without possessing a conscious awareness of the specific muscles that are being engaged or the precise sequencing of the multitude of individual actions, we can acknowledge the requisite processing that must have transpired, albeit without conscious cognizance thereof.

The retina serves as a sensory interface by converting photonic stimulation patterns into electrical impulses that can be interpreted by the nervous system during the visual perception process. Cognitive processes within the mind engage in the analysis of these transmissions, identifying unique features that are subsequently employed in the formation of mental representations of the surrounding environment. There exist cognitive mechanisms that facilitate the conversion of incoming sensory information into a cohesive internalized representation of the surrounding environment. In order to construct significant cognitive representations for the conscious mind, specific input patterns are decoded by these cognitive resources. The representations that come to consciousness are produced by cognitive elements that are not immediately within the reach of conscious awareness. Working memory is often regarded as the locus of conscious cognition, but it has restricted access to the sensory input that was initially encoded in the system. Due to the fact that implicit information operates beneath the level of conscious awareness, it is frequently accepted without scrutiny. For instance, in a public setting, if an individual perceives to have identified an acquaintance but receives no response to their cordial greetings, they may begin to question the dependability of their implicit cognitive processes.

A significant portion of cognitive processes that we commonly refer to as 'thinking' occurs beyond the confines of our conscious awareness, similar to how a considerable portion of our physical actions and perceptions operate. Creative problem-solving often involves individuals experiencing a "lightbulb moment" while engaging in activities unrelated to the problem at hand, such as taking a leisurely walk, participating in a physical activity, or viewing a film. The prevalent cultural motif of a "light bulb illuminating" at the exact moment of an epiphanic realization is widely recognized. One of the most prominent instances of scientific insight is exemplified by Mohammed's [7] discovery of the cyclic organization of the benzene particle, which he arrived at through a mental image that arose during a reverie. Another well-known example is Archimedes' eureka moment, which led to the formulation of his principle, and occurred while he was taking a bath. The process of generating a potential solution to a problem does not occur spontaneously, but rather, it is initiated at a preconscious level within the brain before being presented to conscious awareness. The aforementioned cognitive process frequently takes place subconsciously, while our conscious attention is directed towards other matters, although it may occasionally be a deliberate and purposeful attempt to arrive at a solution. The process of problem-solving remains elusive to awareness, while only the outcome is perceivable.

Implicit Learning in Aging, Childhood, and Infancy

Robinson [8] employed the conventional methodology to evaluate implicit learning of the paradigm of artificial grammar in infants about 12 months old. To effectively adapt the aforementioned strategy for neonates, the author employed auditory syllables instead of written symbols, as per their research. Valid sequences were produced during the training process by mixing these phonemes in accordance with the principles of an artificial grammar. Infants underwent a series of assessments that involved exposure to both typical and atypical arrangements of lawful and unlawful vocabulary. The results indicate that the infants exhibited an increased sensitivity to the composition of the training dataset, as evidenced by their prolonged orientation times towards both familiar and novel grammatical strings in comparison to non-grammatical strings. Furthermore, this study suggests that comparable mechanisms are operative in the process of acquiring natural languages, in light of the fact that it demonstrates the potential for children to proficiently acquire an artificial grammar through implicit methods. The author arrived at a comparable finding through their investigation of the incidental acquisition of lexical segmentation.

The study conducted by Feldman [9] demonstrates that infants at the age of eight months utilize comparable learning mechanisms for the purpose of segmenting non-linguistic stimuli. The author has conducted additional studies that demonstrate the effectiveness of implicit learning mechanisms during the initial phases of growth (between four and five years of age). Recent research by Babakr, Soran University, Mohamedamin, and Kakamad [10] has shown that children as young as two years old possess the ability to acquire a set of geographical locations through intuitive means. The study aimed to investigate the distinctions in implicit learning task performance among children aged 6-7 years and those aged 10-11 years, and adults. The participants in the traditional serial reaction time task were required to rapidly press one of four keys upon the target appearance in any of the four possible positions on the screen. The study involved the inadvertent exposure of participants to a sequence of repeated target appearances, which were alternated with random trials. The study revealed that children as young as 6 years old exhibited comparable learning efficacy to adults in terms of sequence acquisition. This was evidenced by their enhanced response times on the repeated sequence relative to the random segments.

Furthermore, it was observed that both juvenile and mature participants exhibited enhancement in identical segments of the sequence, thereby providing further support to the notion that implicit learning is not contingent upon chronological age. The aforementioned assertion is substantiated by scholarly research, as evidenced by Icenogle et al. [11]. The study found that there were no significant differences in implicit performance on an artificial language test among children aged 6-7, 9-11, and 12-15 years. The study was primarily inspired by Pfeifer and Berkman's [12] assertions regarding age-independence. However, the results obtained from their investigation were incongruous. The authors in [13] conducted an investigation into the distinctions between two cohorts of children, one ranging from 5-7 years and the other from 10-12 years.

In the above research, participants were assigned an incidental covariation task, wherein they were required to establish a correlation between the matrix board color and its cover, and the location of an image within a 4 by 4 grid. In the post-training assessment, it was observed that individuals between the ages of 10 and 12 exhibited superior performance in accurately identifying the placement of photographs in comparison to those between the ages of 5 and 7. The results indicate that the younger children did not exhibit a statistically significant performance above chance level, suggesting that they did not acquire an implicit understanding of the covariations. The study indicates that the performance of children and adolescents on a serial time reaction test is contingent upon their exposure to explicit learning instructions.

The literature presents inconsistent findings regarding the age-independence of implicit learning processes. The assertion lacks empirical evidence. The study revealed the presence of an age-related influence. One possible rationale for this outcome is the potential impact of explicit information contamination on the performance of individuals in the implicit task. Classical models pertaining to implicit learning lack the ability to eliminate the potential utilization of explicit information in a deliberate manner. Furthermore, it is reasonable to expect a universal age-related impact on performance enhancement if explicit factors are involved in implicit learning. Hence, it is imperative to select a methodology that mitigates the deleterious influence. In pursuit of their objective, Vinter and Perruchet [14] devised the "neutral parameter procedure," a technique aimed at mitigating the influence of extraneous variables on the performance of the task. This methodology is centred on two fundamental pillars. The criterion of the task necessitates that the focus of participants' attention should not be on the behavioral components utilized to assess unconscious influences. Conversely, the neutral effect criterion necessitates that these influences should be evaluated using a metric that is unrelated to the successful completion of the task.

Diekema [15] demonstrated that children as young as four years old are capable of making subtle adjustments to their drawing techniques without conscious awareness, using the aforementioned approach. Furthermore, it is noteworthy to mention that the trials conducted using the "neutral parameter procedure" did not reveal any age-related disparities, which is of utmost significance for the present discourse. It can be inferred that explicit factors may have an impact on the participant's performance, leading to age effects. The empirical investigation pertaining to implicit learning in the elderly population highlights the apparent likelihood of age-related alterations that may stem from alternative factors. The postulate of age-independence appears to be a subject of debate, particularly in the context of aging. Several studies have reported inconclusive results regarding the disparity in implicit learning abilities between young and elderly adults, e.g., in [16]. According to the study, there was no observable decline in cognitive performance associated with aging when older individuals were tasked with memorizing letter strings that featured a consistent placement of a specific letter. Individuals of varying age groups, including both the youthful and the elderly, demonstrated implicit recognition of this particular pattern. The authors demonstrated that the process of encoding is the mechanism through which learning occurs.

IV. STRATEGIES TO DEFINING IMPLICIT KNOWLEDGE IN SCIENTIFIC EDUCATION

The Experimental Causation Gestalt

The term "experiential gestalt of causation" was introduced by Andersson [17]. This concept pertains to the cognitive processes involved in the perception of the world and the understanding of the causal relationship between actions and their outcomes. During the process of childhood socialization, individuals are taught to hold the belief that events occur due to a specific cause and effect relationship, which involves an active agent and a passive recipient. Our intuitive comprehension of the world operates in a manner that accounts for the three elements of the gestalt, namely the instrument, patient, and agent. This understanding is not necessarily limited to situations where these components are explicitly evident, as demonstrated by the example of a golf ball being propelled by a golfer with a golf club. Upon encountering an event, individuals tend to spontaneously assign a causal agent and instrument/mechanism, which occurs prior to conscious awareness. Consequently, the conscious perception of the event is presented as an effectively explained gestalt.

There is pertinence of this notion in the context of scientific learning by explicating how numerous "mundane physical and chemical conceptions"- which frequently contradict canonical scientific perceptions - might be comprehended as the implementation of this fundamental anticipation regarding the functioning of the world. Üce and Ceyhan [18] postulated a diverse range of prevalent "misconceptions" in the fields of physics and chemistry that arise from the functioning of implicit information.

Knowledge-in-pieces and the issues to alternative models

The significance of implicit knowledge components has been emphasized by critics of certain methods used in the presentation of alternative conceptualizations and frameworks in published reports. There were individuals who held the view that the depictions of students' alternative conceptualizations of scientific topics were overstated in terms of their similarity to established theories. The emergence of alternative interpretations in lieu of the prescribed theoretical models and scientific principles highlighted in the scientific curriculum does not show that these interpretations hold the same weight as the scientific conceptions they replace. The scientific concepts held by children were not typically cohesive collections of abstract, global ideologies that might be steadily employed across a wide range of contexts. Rather, they often differed significantly in nature from such concepts. Zargar, Adams, and Connor [19] proposed that children's comprehension of the natural world generally comprises what he termed as "gut science," as opposed to scholarly knowledge. The study emphasized the disparity between the scientific thought processes of students and adults. He observed that individuals typically assume a "natural attitude", which lacks the evidential and logical principles of the science discourse.

It is not reasonable to anticipate that learners' knowledge will mirror scientific conceptual frameworks, and those who opposed this notion were justified in doing so. The level of intricacy, amalgamation, consistency, and methodical implementation of scientific students' alternative conceptualizations was, nonetheless, somewhat underestimated. According to Mnguni [20] researches on the alternative ideologies of learners in science, it has been observed that there exist instances of extensively applied highly consistent and coherent thinking within an area, as well as the cases of incoherent, unstable and isolated conceptions. Even the most proficient scientists were once inexperienced learners.

According to diSessa [21], a study group referred to students' knowledge as "knowledge-in-pieces" owing to the perceived absence of consistency and coherence in applications of reasoning by many students. The study employed the terminology "may gradually change, in bits and pieces in different ways" to depict intricate substructures and multifarious elements of knowledge systems. The author in question expressed curiosity regarding the developmental process by which a novice's fragmented knowledge framework could evolve into a state of proficiency. They underscored the importance of constructing advanced knowledge by utilizing the resources at hand, which encompassed the learner's pre-existing knowledge.

Learning Science and Phenomenological Primitives

The concept of phenomenological primitives, also known as p-prims, has been introduced by diSessa in his works published in [21]. These p-prims are a form of implicit knowledge element. The author conducted extensive interviews with students of college-level physics and discovered that the majority of their explicit reasoning regarding physical systems and phenomena could be traced back to implicit knowledge components known as p-prims. The proposition posits that p-prims, comprising of representations of similarities in experience, arise due to the inherent inclination of the brain to comprehend experience by detecting patterns. As an illustration, consider the adage that "proximity to the source often amplifies the impact of effects," a phenomenon that frequently applies to our initial recollections and encounters.

When considering early life experiences, it is important to note that children lack the conceptual framework and language necessary to articulate such experiences. It is possible that repeated exposure to stimuli such as fire, loudspeakers, desk lamps, sputtering garden hoses, and similar objects may result in an increased perception of the intensity of sound, heat, brightness, splashing, and related sensations. One potential strategy involves the progress of a p-prim, which can be denoted as "closer-stronger," as a means of implementing countermeasures. Conversely, it is noteworthy that the p-prim is not rooted in language but rather operates as a cognitive mechanism for identifying patterns within the human psyche. The activation of a child's preconceived primitive notion, or p-prim, may occur through engagement with potent magnets, leading to the realization that the magnets exhibit greater repulsion when forcefully brought into proximity. Although not a deliberate action, this phenomenon can create a sense of familiarity with magnets, rendering the experience less foreign and more intuitive, thereby reducing the perceived need for details.

It is imperative to bear in mind that a p-prim exhibits substantial variation in comparison to "alternative conceptions" across multiple ontological strata. The ability of a student to effectively communicate their own ideas through various means such as verbal, nonverbal, and written communication can enhance their capacity to analyze and discuss those ideas in a critical manner. P-prims are not immediately accessible to conscious awareness. Instead, they constitute a constituent element of the manner in which our experiences are construed and conveyed to conscious awareness. Their mode of operation is primarily based on perception rather than conceptualization. This characteristic not only renders them more challenging to investigate but also enhances their harmful nature as they operate subconsciously, precluding any conscious interpretation. Through a meticulous analysis of students' verbal accounts, Zheyu, Weijin, Jihui, Yuan, Ghani, and Zhai [22] was able to develop his own conceptual frameworks of their tacit knowledge, which he subsequently documented. The former p-prims representations in educational reports are characterized by their explicit and vocal nature, which differs from the implicit nature of p-prims themselves.

Similarly, it is fundamental to remember that p-prims should not be evaluated based on their correctness or incorrectness, or their status as canonical/non-canonical, unlike conceptions. In the event that a student maintains a persistent belief that a sulfur atom is exclusively capable of forming two bonds, it is indicative of a misconceived notion that requires rectification. On the contrary, implicit knowledge fragments function as tools for interpretation in order to comprehend current experiences through generalizations derived from past experiences (and are therefore not deemed as significantly erroneous). To comprehend the world, a student who has recognized the p-prim that motion lessens has merely acknowledged a salient trend in their observations and is currently utilizing it as a "prediction." A reasonable generalization, such as the one presented, can aid in comprehending a greater number of occurrences throughout one's life. The cognitive state of anticipation may pose a challenge in comprehending the principle of inertia (Newton's first law of motion). The law states that an object in motion will maintain its velocity unless an external force is applied to it. As a consequence, an alternative hypothesis predicated on the notion that motion is sustained solely by an unvarying propulsive force is anticipated to surface.

The alternative interpretation that deviates from the established canon, although easily expressible and useful for tackling physics problems in academic settings, may be deemed incorrect. Despite the fact that verbalizing p-prims is necessary for discussing them, it should be noted that the p-prim itself possesses distinct characteristics. Thus, it can be argued that p-prims do not possess an inherent correctness or incorrectness, but rather their utilization has the potential to foster the emergence of novel perspectives. According to Lynch [23], the documentation of "intuitive knowledge structures" that could function as reference points for the assimilation of conventional scientific concepts could facilitate the establishment of canonical conceptualizations. Students who excel in science courses frequently express an innate understanding of scientific concepts upon initial exposure.

P-prims can be a valuable cognitive tool for comprehending and retaining intricate subjects such as chemistry, as they establish connections with our pre-existing knowledge and intuition. The learner's pre-existing beliefs about the universe may lead them to perceive events that activate a familiar cognitive pattern (p-prim) as credible upon initial observation. The scientific method entails the formulation of a query regarding a particular occurrence, followed by the search for a theoretical framework or a set of fundamental principles that can account for the observed phenomenon. The concept of 'natural attitude' is commonly observed in everyday life, where individuals tend to acknowledge the usual and focus on exploring the exceptional. This phenomenon can be explained from an evolutionary perspective, as novel environmental stimuli are more likely to elicit a response for further exploration as potential risks or benefits. Numerous students would experience difficulty if prompted to elucidate the genesis of a phenomenon that has become familiar to them in the realm of nature. The concept of commonplace is readily comprehensible as it aligns with our pre-existing cognitive frameworks. It is a common tendency among students to justify the commonplace by attributing it to the natural order of things.

As highlighted by several commentators on research into student cognition and education, investigators exploring individuals' conceptualizations face the potential challenge of inquiring about subjects for which the participant has not previously established any explicit opinions. A child would engage in a process of "romancing" an answer in order to conform to social expectations and fulfill the obligation of providing a response to a question. This required the capacity to distinguish between a child's authentic cognitive process and a response that was contrived to align with the idiosyncrasies of the interviewer's inquiry. This phenomenon is not restricted to sources of information that are relatively recent or youthful. In the event that an individual of a young age has not previously contemplated the topic, they may proffer a plausible response, such as "due to the earth's proximity to the sun being closer during the Summer season," in response to the inquiry regarding the reason for the disparity in temperature between Summer and Winter. In the event that this response remains unchallenged, it has the potential to become entrenched in the student's memory. It is advisable to introduce a counterpoint, such as inquiring about the reason for the occurrence of Summer in Australia while Winter prevails in Canada. The reason behind this phenomenon is that the student is utilizing pre-existing cognitive resources, such as a p-prim, i.e. closer-stronger pattern.

Hence, students may perceive that a concept does not necessitate further clarification once they implicitly recognize its alignment with an established p-prim. Consequently, it can be arduous for educators to steer students away from this cognitive approach when their intuitive understanding contradicts the scientific explanation, thereby rendering p-prims occasionally unconstructive for pedagogical purposes. P-prims are versatile instruments that can be employed across various stages of the academic journey. The notion that proximity correlates with greater influence could potentially facilitate the attainment of our objectives in educating individuals on the periodic relationship between ionization energy and atomic composition.

V. EMPLOYING THE IMPLICIT KNOWLEDGE VIEWPOINT IN CHEMISTRY LEARNING

Implicit and Explicit Knowledge, Teaching and Learning: Evaluating Student Rational in Chemistry

As per Peterson, Rubie-Davies, Osborne, and Sibley [24], the hallmark of explicit learning is the student’s intentional and conscious endeavor to acquire proficiency in a particular subject matter or address a specific issue. In the context of explicit learning, the learner possesses a conscious awareness of the learning objective and may engage in the formulation and evaluation of hypotheses pertaining to it. As an illustration, the scholar could engage in a quest for patterns, principles, or concepts within the spoken input that encapsulate specific regularities. The process of explicit learning requires significant investment of both time and effort due to the need for strategic knowledge and skill. Immediate learning, also known as one-trial learning, is a viable option that offers a swift outcome. In contrast to explicit learning, implicit learning is an induction process, which occurs unconsciously, and offline, yet still results in the acquisition of information. The process of learning is gradual and requires a substantial amount of time and data to reach completion. However, once the information is acquired, it can be accessed rapidly and without conscious effort.

According to Hughes, Riccomini, and Morris [25], explicit instruction refers to instructional approaches that involve the provision of discussions on regularities or rules by either the instructor or instruction materials utilized. The pedagogical approach of explicit instruction involves guiding students to concentrate on linguistic forms, with the ultimate goal of developing metalinguistic generalizations. The explicit methods of teaching, namely deductive and inductive approaches have been acknowledged as such in many academic literature texts. Therefore, it is pertinent to investigate the adequacy of explicit learning and knowledge in isolation and the indispensability of eliciting prior knowledge in this regard. Regarding the initial query, it is widely acknowledged that acquiring proficiency in a second language necessitates a combination of deliberate and automatic techniques, and that the ability to effectively communicate in L2 is contingent upon the acquisition of both forms of knowledge. The correlation between explicit and implicit information and learning has been a subject of varied assumptions, leading to discourse on the latter matter.

The three conventional interface states are commonly referred to as no interface, weak interface, and strong interface. As per the no-interface perspective proposed by Spit, Andringa, Rispens, and Aboh [26], there exists a complete segregation between explicit and implicit knowledge, with no possibility of any mutual influence or interaction between the two. This perspective, which can be considered a less prevalent viewpoint in contemporary research, is frequently associated with a generative nativist framework utilized in the acquisition of a second language.

The perspective of strong-interface stands in direct contrast to the aforementioned viewpoint, as it posits that the availability of explicit data plays a fundamental role in implicit knowledge’s development during the process of learning. The acquisition of a particular type of information facilitates the development of related knowledge through frequent utilization and repetition. Ananthajothi, Karthikayani, and Prabha [27] have posited that the expansion of both implicit and explicit knowledge can occur simultaneously. Specifically, gaining a deeper understanding of a linguistic structure through implicit learning need not result in a reduction of explicit knowledge about said structure.

The position of weak-interface, as its nomenclature suggests, is situated within an intermediary stance. The aforementioned perspective is corroborated by scholars such as Liao, Deng, Wan, and Liu [28], who posit that there exists a distinction between explicit and implicit information and learning, but these two types of learning may have an interdependent relationship through the conduit of consciousness. The study has suggested a pathway that leads from explicit to implicit knowledge. The proposition posits that the acquisition and application of language can be attributed to the conscious comprehension and deliberate instruction of linguistic principles. Through the use of language, individuals generate supplementary input, thereby creating opportunities for implicit learning. Explicit practice, as a result, can lead to enhanced implicit learning, which support the weak-interface position creating a distinction between metalinguistic descriptions and linguistic constructions. The study argues that the former refers to phrases such as "She moves quickly" and "John takes a walk every morning," while the latter pertains to rules expressed as verbal propositions, such as "In English, a -s is added to a third-person verb in the present tense." These advocates contend that it is the language's sequence, which conform to these rules that become implicit, rather than the rules themselves. The weak-interface theory posits that explicit knowledge has the potential to enhance and refine the precision of implicit knowledge.

The investigation of students' cognitive processes holds significant value as it has the potential to enhance the efficacy of pedagogical practices in the classroom. Students often possess prior beliefs regarding various natural phenomena when they engage in science education. These pre-existing beliefs can significantly impact their ability to learn science. However, by acknowledging and addressing these preconceptions, science educators can enhance the effectiveness of their teaching.

It is widely recognized that alternative conceptions may arise from various sources, such as intuitive reasoning, misconceptions that are socially accepted, inferences derived from linguistic cues, and other similar factors. The etiology of a stimulated concept may not invariably be readily discernible. The prevalent yet scientifically inaccurate notion that motion necessitates a force may be accounted for by the interpretations of commonplace experiences. The conventional concepts and techniques employed in defining acids, as a result of which orange juice is not typically classified as an acid in daily parlance, engender the conception that all acids possess inherent perilousness. It appears that the presumption of a neutral outcome resulting from neutralization is based on a verbal cue.

Conversely, the field of chemistry is replete with commonly accepted yet seemingly unsubstantiated notions that are not derived from individual observation, linguistic cues, or logical reasoning. When presented with miniature representations of the material world, students frequently generate novel ideas, some of which appear to be widely adopted. A plausible hypothesis is that erroneous or antiquated beliefs have been transmitted across generations via pedagogical approaches that have remained static. The persistence and reproduction of certain erroneous concepts in the field of chemistry, despite their deviation from established principles, within the context of tertiary education and teacher training programs, can only be considered a limited rationale for this phenomenon.

It is a prevalent occurrence among students to generate notions founded on the principal notion that atoms experience chemical reactions to attain complete electron shells/octets. However, this notion is incongruous with internal inconsistency and conical chemistry. This is due to the fact that in several instances where learners utilize this conception, the ions or atoms of the reactants already hold the required electronic configuration. The concept in question is frequently generated by students, and despite exposure to alternative concepts that align more closely with scientific literature, they exhibit a tendency to maintain their original perspective. The 'octet rule principle', which posits that chemical processes result in 'complete' electron shells, seems to have been influenced by students' understanding of instruction in relation to implicit knowledge components. The brain's subconscious mechanisms facilitate the formation of connections between novel sensory input, which may include information obtained through training, and pre-existing patterns. This occurs prior to the conscious representation of the information, resulting in its comprehension within the framework of an established pattern of the world. The components of knowledge that are implicit in nature operate without conscious awareness, and may serve as a foundation for the development of explicit knowledge elements that are formed through more formal means. In other words, implicit knowledge forms the basis upon which explicit ideas, which are readily accessible and can be articulated verbally, are constructed.

The contention posited by the knowledge-in-pieces perspective is that redirecting students' thought processes becomes increasingly challenging when they possess firmly entrenched explicit conceptions. As previously stated, this perspective does not attribute inherent correctness or incorrectness to p-prims and other forms of implicit knowledge. Instead, they are regarded as a set of instruments that can aid in comprehending the world, even when the learner is oblivious to their existence. The concept of p-prims can be likened to a reflective surface that mirrors the patterns and regularities observed in our daily experiences. At certain instances, a student's p-prim can prove to be advantageous; particularly when they possess a comprehension that the force required to remove an electron increases as it approaches the nucleus. However, there are also instances when such p-prim may not be beneficial, such as when the student holds the belief that the earth is nearest to the sun in summer or that a complete electron shell can be achieved through chemical change. Considering that individuals accumulate a reservoir of implicit knowledge fragments, it is logical to assume that effective instruction should encourage learners to conceptualize new ideas and principles in manners that align with their existing knowledge reservoir and the established scientific framework. Educators ought to strive towards facilitating the utilization of p-prims by students that align more cohesively with scientific concepts.

The Research Programme Challenge

Although the concept appears to be logically sound, the practical application of this approach in educational settings may not be readily apparent to educators. To enhance support for educators, it is imperative for researchers to gain a deeper comprehension of how to direct learning towards specific p-prims while avoiding the activation of others. This can be achieved by identifying the range of p-prims that are operational within the population. There exists significant potential for enhancement in this area. Ferreira, Lemmer, and Gunstone [29] indicate that specific alternative concepts are readily acquired and challenging to eradicate through instruction. Therefore, any approach that could impede their initial establishment would represent a significant advancement in the pedagogy of chemistry. Instead of prioritizing the enhancement of students' self-awareness, research endeavors to assist educators in effectively delivering course material that is more likely to captivate students' most productive cognitive frameworks, known as p-prims.

The extent to which individuals acquire comparable primitive misconceptions (p-prims) remains a topic of inquiry. The identification of p-prims cannot be accomplished through a mere report by students; rather it necessitates the inference of their existence from other related information. Gil, Girela, De Juan, Gomez-Torres, and Johnsson [30] seminal research offers a comprehensive compilation of potential p-prims that can be effectively utilized in pedagogical settings, as per the feedback received from students of physics. P-prims are considered to be general-purpose elements that can be utilized to comprehend data from diverse origins, rather than being restricted to a particular domain. Consequently, it appears that p-prims could potentially have an impact on both physics and chemistry pedagogy. Nevertheless, it is important to note that generalizing research findings obtained from a specific group of participants in a particular field of science to students in different academic institutions may not be appropriate. Although there may be challenges in furthering this research direction in Comparative Effectiveness Research (CER), the potential advantages for enhancing chemistry education offer a convincing rationale for conducting further exploration of this approach.

VI. CONCLUSIONS

The research on the science of learning provides support for recognition of the utilization of tacit knowledge in scientific investigation. This indicates that implicit information has a noteworthy impact on learning and other cognitive procedures. Scholars in the domain of positive education research (PER) have underscored the importance of reframing the constructivist approach as scientific learning using a knowledge-in-pieces framework. This framework acknowledges that learners' reasoning frequently draws upon implicit cognitive resources, rather than relying solely on explicit concepts. Within the field of Chemistry Education Research (CER), a significant amount of research has been conducted on students' conceptual understanding of chemistry. However, the discourse surrounding the significance of determining implicit knowledge elements, such as p-prims, which are involved during the chemistry learning process, has only had a limited impact on this body of research. The investigation of students' intuitions regarding chemical phenomena has been previously conducted, albeit limited to a singular setting and solely among secondary school students.

The objective of implicit knowledge in the acquisition of knowledge has been subject to debate, and a more comprehensive comprehension of its influence could have noteworthy consequences for the field of chemistry education. The constructivist program has been criticized for not effectively applying the knowledge gained from identifying features of student thought to teaching, despite the significant effort put into this endeavor. Consequently, it could be more advantageous to aid educators in devising pedagogical approaches that leverage the most efficacious pre-existing intuitions to facilitate the formation of more conventional foundational notions, rather than urging them to contest firmly entrenched alternative conceptions through instructional means.

The intricacy lies in the fact that certain alternative conceptions elucidated in the realm of chemistry education do not appear to be impervious to pedagogy, despite frequently embodying implicit knowledge. Further inquiry is required to explore the underlying assumptions that learners unconsciously hold, commonly referred to as 'hard core' assumptions. These assumptions give rise to alternative conceptions that are highly resistant to change, often persisting even after instructional efforts aimed at dismantling them. The literature examined in this study raises the inquiry of whether a differentiation exists between the relatively stable alternative conceptions utilized in the learning of chemistry and the less stable ones. This differentiation can be based on their association with a 'framework theory' or their representation of misclassification in relation to the ontological trees of learners.

The main focus of this article pertains to the inquiry of whether implicit knowledge facilitates or impedes conceptual learning. Researchers emphasized the importance of tacit knowledge in laboratory settings, where scientists accumulate procedural knowledge that enables them to perform practical operations with speed and efficiency. Exploring the acquisition of automation skills among students and the potential impact of modifications to instructional settings or experiential learning could prove to be a promising domain of research in the field of discipline-based education research (DBER). The investigation of this domain has the potential to enhance the pedagogy of subjects such as spectral interpretation and the construction of synthetic pathways. Furthermore, it is linked to the exploration of proficiency, as skilled individuals are capable of promptly and efficiently making judgments and identifying resolutions to challenges by employing a harmonized utilization of systems' processing.

Data Availability

No data was used to support this study.

Conflicts of Interests

The author(s) declare(s) that they have no conflicts of interest.

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