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The Effect of Schema Activation Strategies on Developing Reading Comprehension of Mechatronics Students at a Technological University: An Experimental Study

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Abstract

This study investigates the influence of schema activation strategies on the reading comprehension skills of mechatronics students enrolled in a technological university. Our investigation arises from the increasing necessity to enhance technical students' ability to comprehend complex academic and technical texts, which are integral to their field of study. Reading comprehension remains a fundamental skill for academic success, particularly in disciplines such as mechatronics, where students frequently engage with highly specialized and content-dense materials. Activating students', prior knowledge, or schema, before reading, has been identified in previous educational research as a promising method for improving comprehension outcomes. To explore this, a quasi-experimental pretest-posttest control group design was employed. Sixty first-year mechatronics students were selected and divided into two groups: an experimental group and a control group, each comprising 30 students. The experimental group received targeted reading instruction that systematically employed schema activation strategies, such as brainstorming, using graphic organizers, previewing vocabulary, and making predictions before reading texts. The control group, in contrast, was taught the same texts using conventional reading instruction methods, without specific emphasis on activating prior knowledge. Data was collected using a standardized reading comprehension test administered before and after the intervention, as well as a cognitive engagement scale to measure students' involvement and mental effort during reading tasks. Statistical analysis of the results showed that students in the experimental group demonstrated significantly greater gains in reading comprehension compared to those in the control group. Furthermore, the experimental group also reported higher levels of cognitive engagement, suggesting that schema activation strategies not only support understanding of technical texts but also enhance motivation and active participation in reading tasks. The results of this research provide empirical backing for the integration of schema activation strategies into reading instruction, especially in technical education settings. They underscore the importance of connecting new information to students' existing knowledge to foster deeper comprehension. Based on these results, it is recommended that educators, instructional designers, and curriculum developers incorporate schema-based activities into lesson planning and material development, particularly in science and engineering education contexts. Future research may explore the long-term effects of these strategies and their applicability to other disciplines.

Keywords: *Schema activation, reading comprehension, mechatronics, cognitive engagement, experimental study*

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1. Introduction

1.1 The Critical Role of Reading Comprehension in Mechatronics Education

Reading comprehension is a cornerstone of academic and professional success, and its importance is magnified in highly technical and interdisciplinary fields like mechatronics. Mechatronics, a synergistic integration of mechanical engineering, electronics, computer science, and control theory, presents unique and formidable challenges to students and practitioners alike. The literature in this domain is characterized by a high degree of lexical density, with a plethora of specialized terms and jargon that are often inaccessible to novices (Nation, 2001). Furthermore, mechatronics texts are structurally complex, often featuring non-linear organization with embedded diagrams, complex mathematical equations, and frequent cross-references, all of which place a significant cognitive load on the reader (Sweller, 1988). The ability to navigate and comprehend these materials is not merely an academic exercise; it is a fundamental prerequisite for professional competence. Engineers in the field must be able to interpret technical manuals, understand research articles, and critically evaluate design specifications to innovate and solve complex problems (Prince & Felder, 2006).

Despite the undeniable importance of these skills, reading instruction is often a neglected component of mechatronics curricula. The pedagogical focus tends to be heavily skewed towards hands-on laboratory work, computational modeling, and practical applications, with the implicit assumption that students will independently develop the necessary reading skills. This pedagogical gap can leave many students ill-equipped to engage with the primary literature in their field, creating a significant barrier to both their academic progress and their future professional success (Bransford et al., 2000). The consequences of this can be far-reaching, from misinterpretation of critical safety information in technical manuals to an inability to keep pace with the rapid advancements in the field.

1.2 The Challenge of Technical Reading in EFL Contexts

The challenges of technical reading are significantly amplified for students for whom English is a Foreign Language (EFL). These students face a dual burden: they must simultaneously grapple with the complexities of the English language and the intricacies of the technical subject matter. This is particularly true in the context of mechatronics, where the language is often highly specialized and idiomatic, with terms that may have no direct equivalent in the students' native language (L1). For example, terms like "haptic feedback," "piezoelectric transducers," and "kinematic chains" can be particularly challenging for EFL learners to grasp without a strong foundation in both English and the relevant technical concepts. The syntactic structures commonly found in technical publications, such as the use of the passive voice and complex nominalizations, can also pose a significant hurdle to comprehension (Zhang, 2011).

Beyond the linguistic challenges, EFL students may also face a "cultural schemata gap." Technical communication is often embedded in a specific cultural context, with assumed knowledge of Western engineering conventions, standards (e.g., ANSI vs. DIN), and even metaphorical expressions that may not be familiar to students from other cultural backgrounds. This can lead to misinterpretations and a superficial understanding of the material. Research has shown that EFL engineering students can take up to 3.7 times longer to decode technical texts compared to their native-speaking peers, often resorting to inefficient and ineffective strategies like word-for-word translation (Zhang, 2011). This not only slows down the reading process but also consumes valuable cognitive resources that could otherwise be dedicated to higher-order comprehension processes like critical analysis and problem-solving (Krashen, 1982).

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1.3 Schema Theory: A Framework for Technical Comprehension

Schema theory provides a powerful theoretical framework for understanding and addressing the challenges of technical reading comprehension. First proposed by Bartlett (1932) and later developed by Anderson and Pearson (1984), schema theory posits that comprehension is an interactive process in which readers construct meaning by integrating new information from the text with their existing knowledge, or "schemata." These schemata are mental frameworks that organize our knowledge about the world, and they play a crucial role in guiding our interpretation of new information. In the context of mechatronics education, we can identify three key types of schemata:

- **Content Schemata:** This refers to the reader's domain-specific knowledge, including their understanding of key concepts, principles, and theories in mechatronics. For example, a student with a strong content schema for control systems will be better able to understand a text describing the implementation of a PID controller.
- **Formal Schemata:** This relates to the reader's knowledge of the rhetorical and organizational structures of different types of texts. For example, a student with a well-developed formal schema for research articles will know what to expect in the introduction, methodology, results, and discussion sections, which can help them to navigate the text more efficiently.
- **Linguistic Schemata:** This encompasses the reader's knowledge of the vocabulary, grammar, and syntax of the language in which the text is written. A strong linguistic schema is essential for accurate and fluent decoding of the text.

When readers lack the relevant schemata, they are more likely to experience comprehension breakdowns. They may misinterpret key concepts, overlook important details, or fail to make the necessary connections between different pieces of information. Schema activation strategies are designed to address this by explicitly

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activating and building upon students' existing knowledge before they engage with a new text. These strategies can take many forms, such as brainstorming, concept mapping, pre-teaching vocabulary, and making predictions. By activating relevant schemata, these strategies can help to bridge the gap between the reader's prior knowledge and the new information in the text, reduce cognitive load, and enhance retention and transfer of knowledge (Carrell, 1984).

1.4 Gaps in Existing Research

While the effectiveness of schema-based instructional strategies has been well-established in general education and in some EFL contexts, there are still significant gaps in the research, particularly in the domain of technical education. Most of the existing research has focused on the humanities and social sciences, with a relative dearth of studies examining the application of schema theory to STEM fields (Fang, 2006). Furthermore, much of the research has focused on the comprehension of traditional, linear texts, with less attention paid to the unique challenges of multimodal texts, which are prevalent in mechatronics and other engineering disciplines. These texts, which combine prose with diagrams, equations, and other visual elements, require readers to integrate information from multiple sources, a process that is not well-understood.

Another significant gap in the literature is the lack of research on the cultural dimensions of schema theory. Most of the existing research has been conducted in Western contexts, with little attention paid to the unique challenges faced by EFL learners from different cultural backgrounds. For example, the cultural schemata that are taken for granted in Western engineering education may not be shared by students from other parts of the world, which can create a significant barrier to comprehension. There is a pressing need for more research that examines the effectiveness of schema-based instructional strategies in a variety of cultural contexts.

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1.5 Study Objectives and Hypotheses

This research seeks to bridge these gaps in the literature by investigating the effectiveness of schema activation strategies in improving the reading comprehension of mechatronics students in an EFL context. The research is structured around these key questions:

- **Primary Research Question:** How do schema activation strategies impact the reading comprehension of mechatronics students compared to traditional instruction?
- **Secondary Questions:**
  - Which specific schema activation techniques (e.g., concept mapping, anticipatory guides, KWL charts) are most effective in improving reading comprehension?
  - How does the use of schema activation strategies affect students' cognitive engagement and motivation?
  - What are the students' perceptions of the usefulness and effectiveness of schema activation strategies?

Drawing from current scholarship, we propose the following hypotheses:

- **H_1:** Students who receive instruction that incorporates schema activation strategies will demonstrate significantly greater gains in reading comprehension than students who receive traditional instruction.
- **H_2:** The use of schema activation strategies will be positively correlated with students' cognitive engagement and motivation.
- **H_3:** Students will report positive perceptions of the usefulness and effectiveness of schema activation strategies.

1.6 Methodological Innovation

This study employed a quasi-experimental pretest-posttest control group design to investigate the effectiveness of schema activation strategies. The study was conducted over a full academic semester with a cohort of first-year mechatronics students at a technological

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university. The experimental group received instruction that incorporates a variety of schema activation strategies, while the control group received traditional instruction. Data were collected through a combination of quantitative and qualitative methods, including a standardized reading comprehension test, a cognitive engagement scale, and semi-structured interviews with a subset of the participants. This mixed-methods approach allowed us to not only measure the effectiveness of the intervention but also to gain a deeper understanding of the students' experiences and perceptions.

This study also made a number of methodological innovations. First, we used authentic, multimodal texts that are representative of the types of materials that mechatronics students encounter in their coursework. This enhanced the ecological validity of the study and ensured that the findings are relevant to the real-world challenges faced by students in this field. Second, we used a variety of schema activation strategies, which will allow us to compare their relative effectiveness. Third, we used a combination of quantitative and qualitative data collection methods, which provided a more comprehensive and nuanced understanding of the impact of the intervention.

1.7 Theoretical and Practical Implications

This research is poised to contribute significantly to both theory and practice. From a theoretical perspective, the study extended the application of schema theory to the domain of technical education, an area that has been relatively under-researched. The findings also provided new insights into the cognitive processes involved in the comprehension of multimodal texts. From a practical perspective, the study provided educators with evidence-based strategies for improving the reading comprehension of mechatronics students. The findings also had implications for curriculum development and instructional design in technical and vocational education.

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Volume (90) Issue Four Part (3) October 2024

1.8 Conclusion

In essence, this study tackles a crucial void in the literature by investigating the effectiveness of schema activation strategies in improving the reading comprehension of mechatronics students in an EFL context. The study employed a rigorous mixed-methods design and made a number of methodological innovations. The findings of this study had the potential to make a significant contribution to our understanding of the cognitive processes involved in technical reading comprehension and to provide educators with practical, evidence-based strategies for improving student learning outcomes. By equipping students with the skills they need to effectively engage with the complex literature in their field, we can help them to become more successful learners and more competent professionals.

2. Literature Review

2.1 Theoretical Foundations of Schema Activation in Reading Comprehension

2.1.1 Schema Theory: Historical Development and Core Principles

The notion of schema, a core concept in cognitive psychology, has a rich history dating back to the work of Frederic Bartlett (1932). Bartlett, a British psychologist, introduced the idea of “schema” to explain how individuals organize and make sense of new information based on their past experiences and knowledge. He argued that memory is not a passive, reproductive process but an active, reconstructive one, heavily influenced by pre-existing mental structures. His seminal work, *Remembering: A Study in Experimental and Social Psychology*, demonstrated how individuals tend to distort or alter information to fit their existing schemata, highlighting the active role of the reader in constructing meaning.

Extending Bartlett’s seminal contributions, contemporary schema theory was notably developed by cognitive psychologists such as

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Richard C. Anderson and P. David Pearson (1984). Their influential work, particularly in the context of reading comprehension, posited that comprehension is an interactive process between the reader's prior knowledge (schemata) and the textual input. This interaction is not merely additive; rather, it is a dynamic process where existing schemata are activated, modified, and integrated with new information from the text. This perspective revolutionized the understanding of reading, shifting it from a passive decoding process to an active, constructive one.

Anderson and Pearson (1984) identified three primary types of schemata that interact during reading comprehension:

- **Content Schemata:** These represent knowledge frameworks pertaining to the subject matter or content of a text. For instance, a mechatronics student reading about robotic arm kinematics will activate their content schemata related to mechanics, control systems, and programming. The depth and breadth of these schemata directly influence the ease and accuracy with which new information is processed. Neuroscientific studies, such as those employing functional magnetic resonance imaging (fMRI), have provided empirical support for the role of content schemata. Mason and Just (2016), for example, demonstrated that expert engineers exhibit more integrated and extensive neural network activation, particularly in the temporal lobe, when processing domain-specific terminology, suggesting a more robust and interconnected content schema.
- **Formal Schemata:** Also known as textual schemata, these refer to the reader's knowledge about the organizational patterns and rhetorical structures of different text types. Understanding the typical structure of a research article (e.g., Introduction, Methods, Results, Discussion) or a technical manual (e.g., troubleshooting guides, specifications) allows readers to anticipate information, locate specific details, and infer relationships between different sections. This knowledge is crucial for efficient information extraction and critical analysis.

Research by Al-Harthi (2021) highlighted that Arab EFL students often face challenges in recognizing Western academic writing conventions, leading to slower processing and comprehension. This underscores the importance of explicit instruction in formal schemata, especially in cross-cultural academic contexts.

– **Linguistic Schemata:** These encompass the reader's knowledge of vocabulary, syntax, and grammar. In specialized fields like mechatronics, where precise terminology is paramount, a strong linguistic schema is indispensable. The distinction between seemingly similar terms, such as "accuracy" versus "repeatability" in metrology, can significantly alter the interpretation of technical specifications. Nation (2001) emphasized that a substantial vocabulary, including a threshold of approximately 3,000 specialized technical terms, is necessary for students to independently read and comprehend technical texts effectively. Deficiencies in linguistic schemata can lead to over-reliance on dictionaries, which, while helpful, can significantly decelerate reading speed and hinder overall comprehension (Carrell, 1984).

Recent neuroscientific research continues to validate and expand upon schema theory. Studies using fMRI have shown that schema activation is associated with increased activity in brain regions involved in schema integration, such as the left inferior frontal gyrus, and memory consolidation, like the bilateral hippocampus (Mason & Just, 2016). These findings provide a biological basis for the cognitive processes described by schema theory, reinforcing its explanatory power.

When any of these schemata are underdeveloped or absent, readers often resort to compensatory strategies that can impede comprehension. These include excessive re-reading, word-for-word translation, or what Carrell (1984) termed "barking at print" – pronouncing words without grasping their meaning. Such behaviors not only slow down the reading process but also consume valuable cognitive resources that could otherwise be allocated to deeper processing and meaning construction. In practical mechatronics settings, a schema deficit can manifest as misinterpretation of laboratory manuals, incorrect instrument calibration, or an inability to troubleshoot complex systems effectively. Therefore, fostering robust schema development through targeted instructional strategies and guided exposure to authentic materials is critical for cultivating proficient technical readers.

2.1.2 Cognitive Load Theory and Schema Optimization

Cognitive Load Theory (CLT), developed by John Sweller (1988), provides a complementary framework to schema theory, particularly relevant for understanding learning in complex domains like mechatronics. CLT posits that human working memory has a limited capacity, and effective instruction should manage this capacity to optimize learning. Sweller identified three types of cognitive load:

- **Intrinsic Cognitive Load:** This pertains to the intrinsic complexity of the subject matter, determined by the number of interacting elements that must be processed simultaneously in working memory. In mechatronics, topics such as nonlinear control theory or advanced robotics naturally possess high intrinsic load due to the complex interplay of differential equations, feedback loops, and multi-domain principles. Schema activation plays a crucial role in managing intrinsic load by allowing learners to chunk multiple interacting elements into a single, higher-order concept. For example, pre-teaching foundational mathematical tools like Laplace transforms or Fourier analysis enables students to perceive complex control system diagrams as single, coherent units rather than a multitude of disconnected symbols. This reduces the burden on working memory, freeing up resources for deeper understanding.

- **Extraneous Cognitive Load:** This stems from ineffectively designed instructional content or activities that do not directly contribute to learning. Examples in technical education include poorly structured manuals, overly verbose explanations, or disorganized presentations. Such extraneous load diverts

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working memory resources away from schema construction. To mitigate this, educators can employ strategies that streamline information presentation, such as providing annotated diagrams, using clear and concise language, or modeling expert problem-solving processes. Kalyuga (2009) demonstrated that instructional designs aligned with CLT principles can lead to a 30–40% increase in working memory capacity for technical information, as learners with well-developed schemata are less susceptible to extraneous distractions.

- **Germane Cognitive Load:** This denotes the productive cognitive exertion involved in forming and automating new schemata. It represents the productive cognitive work involved in integrating new information with existing knowledge structures. Instructional strategies that promote germane load encourage learners to actively process, organize, and reflect on the material. Examples include guided concept mapping, problem-based learning, and the analysis of case studies (especially failure cases, which prompt learners to refine their schemata). Empirical studies, including recent eye-tracking research by Hyönä (2023), have shown that students trained in schema activation exhibit more efficient reading patterns, such as fewer regressions (re-reading instances) and increased focus on critical information (e.g., equations or key diagrams). This suggests that schema activation not only enhances comprehension but also optimizes the allocation of cognitive resources, leading to more effective learning.

Instructional design strategies grounded in CLT and schema theory can be specifically tailored for mechatronics education. For instance, breaking down a complex hydraulic schematic into its constituent sub-functions (e.g., pump, valve, actuator) and explicitly connecting each component to a conceptual schema helps students build accurate mental models. Similarly, employing expert modeling through think-aloud protocols, where instructors verbalize their thought processes while interpreting a technical text or solving a problem, can externalize expert cognitive processes. This guides

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Volume (90) Issue Four Part (3) October 2024

novice learners toward more efficient reading and comprehension strategies, reducing extraneous load and promoting germane load.

Fundamentally, both Schema Theory and Cognitive Load Theory emphasize the critical significance of prior knowledge and the efficient management of cognitive resources in processing complex technical texts. By intentionally activating relevant schemata and designing instruction that minimizes extraneous load while maximizing germane load, educators can significantly improve the reading comprehension outcomes of mechatronics students. These theoretical foundations provide a robust basis for designing effective instructional interventions, informing the empirical and practical components explored in the subsequent sections of this literature review.

2.2 Schema Activation Strategies: Evidence Across Educational Contexts

Schema activation strategies are pedagogical techniques designed to bring a learner's existing knowledge to the forefront of their mind before engaging with new information. This pre-reading activation facilitates the integration of new concepts into existing cognitive frameworks, thereby enhancing comprehension and retention. The effectiveness of these approaches has been evidenced across diverse educational settings, from general K-12 education to specialized EFL settings.

2.2.1 General Education Applications

In general education, schema activation strategies have long been recognized as powerful tools for improving reading comprehension. Meta-analyses, such as those conducted by the National Reading Panel (2000), consistently show that explicit instruction in comprehension strategies, including those that activate prior knowledge, leads to significant improvements in students' understanding of various texts. Common strategies include:

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https://mkmgt.journals.ekb.eg
Volume (90) Issue Four Part (3) October 2024

- **Brainstorming:** Encouraging students to list everything they already know about a topic before reading. This helps to surface relevant schemata and identify knowledge gaps.
- **KWL Charts:** A graphic organizer where students list what they **K**now, what they **W**ant to know, and what they **L**earned after reading. This structured approach helps students connect prior knowledge to new information and monitor their comprehension.
- **Anticipation Guides:** Statements related to the text's content that students agree or disagree with before reading. This activates prior knowledge and sets a purpose for reading.
- **Pre-teaching Vocabulary:** Introducing key terms and concepts before reading helps to build linguistic schemata and reduce cognitive load during reading.
- **Graphic Organizers:** Visual representations of information, such as concept maps, semantic webs, or flowcharts, help students organize their thoughts and see relationships between ideas. These are particularly useful for technical texts that often present complex, interconnected concepts.

Notwithstanding ample evidence of their utility, a notable lacuna persists: a disproportionately small number of these studies (less than 12%) have specifically examined technical or STEM-related texts (Fang, 2006). This highlights a need for more targeted research in specialized domains like mechatronics, where the nature of the content and the cognitive demands on the reader differ significantly from general academic texts.

2.2.2 EFL Contexts: Insights for Arabic-Speaking Engineering Students

The application of schema-based strategies is particularly crucial in English as a Foreign Language (EFL) context, where learners face the dual challenge of language acquisition and content comprehension. For Arabic-speaking engineering students, these challenges are further compounded by linguistic and cultural differences between Arabic and English, as well as between their

مجلة كلية التربية . جامعة طنطا
ISSN (Print):- 1110-1237
ISSN (Online):- 2735-3761
https://mkmgt.journals.ekb.eg
Volume (90) Issue Four Part (3) October 2024

native cultural schemata and those embedded in Western technical discourse.

Key schema-based strategies in EFL contexts include:

- **L1 Bridging:** Utilizing the students' first language (L1) to activate and build schemata before transitioning to English. For example, providing pre-reading glossaries or brief explanations of complex concepts in Arabic can significantly improve comprehension and retention. Al-Jarf (2021) found that pre-reading activities involving L1 support improved retention by 25% among Arabic-speaking EFL learners. This strategy acknowledges that students' conceptual understanding often resides in their L1, and leveraging this can facilitate transfer to the L2.

- **Cultural Schemata Awareness:** Addressing potential mismatches between students' cultural backgrounds and the cultural assumptions embedded in technical texts. Western-centric analogies or examples (e.g., using baseball metaphors in physics explanations) can hinder comprehension if students lack the relevant cultural schema. Elashry (2022) reported an 18% reduction in comprehension when such cultural gaps were not addressed. Projects like the Bilingual Technical Glossary Project at Qatar University have demonstrated the effectiveness of integrating dual-language schemata, leading to a 14.3% improvement in exam performance by explicitly connecting English technical terms to their Arabic equivalents and cultural contexts.

- **Explicit Instruction in Text Structure:** Teaching students to recognize and utilize the formal schemata of English academic and technical writing. This includes understanding the typical organization of research papers, reports, and manuals, as well as the function of various rhetorical moves (e.g., stating a problem, presenting a solution, discussing implications). This is particularly important for Arab EFL students, who may be

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https://mkmgt.journals.ekb.eg
Volume (90) Issue Four Part (3) October 2024

accustomed to different rhetorical patterns in their native language.

These strategies help to mitigate the linguistic and cultural barriers that often impede EFL learners' comprehension of technical texts, allowing them to activate and build upon their existing knowledge more effectively.

2.2.3 Emerging Work in STEM Education

Although investigations into schema activation within STEM education have traditionally trailed behind general pedagogical studies, there is a growing body of emerging work that highlights its potential. Innovations in this area often involve adapting general schema strategies to the unique demands of scientific and engineering disciplines:

– **Conceptual Flowcharts and Diagrams:** Utilizing annotated signal-flow diagrams, process flowcharts, or system schematics as pre-reading or during-reading activities. These visual tools help students to build and activate content schemata related to complex systems and processes. Borgford-Parnell (2018) found that the use of annotated signal-flow diagrams improved troubleshooting skills by 32% among engineering students, demonstrating the power of visual schemata in technical contexts.

– **Failure Case Studies:** Engaging students with real-world examples of engineering failures or design flaws. Analyzing these cases requires students to activate and refine their existing schemata to diagnose problems and propose solutions. Johnson (2020) showed that reading about real-world misapplied schemata significantly improved diagnostic reasoning in engineering students. This approach not only activates relevant knowledge but also promotes critical thinking and problem-solving skills.

– **Simulation-Based Learning:** Using interactive simulations or virtual laboratories to build experiential schemata before students encounter theoretical texts. This hands-on engagement can provide concrete experiences that serve as a foundation for abstract concepts. For instance, simulating the behavior of a robotic arm before reading about its control algorithms can provide a rich experiential schema.

Despite these promising developments, a significant limitation remains: the majority of STEM studies on schema activation tend to focus on postgraduate learners, often overlooking the needs of undergraduate students. This is a critical oversight, as foundational schema development is arguably most crucial during the early stages of an engineering education. Our current study aims to address this gap by focusing specifically on first-year mechatronics undergraduates.

2.3 Technical Reading in Mechatronics: Specific Demands

Engaging with mechatronics texts extends beyond simple word decoding; it is a complex cognitive process that demands the integration of linguistic, visual, and conceptual information. The unique nature of mechatronics texts imposes specific demands on the reader's cognitive abilities and schemata.

2.3.1 Linguistic Characteristics

An examination of a 5,000-document mechatronics corpus uncovers several linguistic features that pose significant comprehension challenges:

- **High Lexical Density:** Mechatronics texts are replete with specialized terminology (e.g., "servomechanism," "actuator," "transducer," "firmware"). These terms often have precise, context-dependent meanings that differ from their everyday usage. Students must develop a robust technical vocabulary to navigate these texts effectively.
- **Complex Syntactic Structures:** Sentences in technical documents are frequently long, grammatically intricate, and employ passive voice, nominalizations, and embedded clauses.

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https://mkmgt.journals.ekb.eg
Volume (90) Issue Four Part (3) October 2024

This can obscure the agent of an action or the logical flow of an argument, making it difficult for readers, especially EFL learners, to parse meaning.

- **Intertextuality:** Technical documents often refer to other documents, standards, or previous research. Readers must be able to follow these intertextual links and integrate information from multiple sources to construct a complete understanding.

These linguistic features necessitate strong linguistic schemata and the ability to process information efficiently, often under time constraints.

2.3.2 Document Genres and Schema Demands

Mechatronics students encounter a diverse range of document genres, each with its own formal schemata and specific comprehension demands:

- **Textbooks and Research Articles:** These require the ability to identify main ideas, differentiate between evidence and claims, and understand complex theoretical frameworks.

- **Engineering Manuals and Specifications:** These demand precise interpretation of instructions, parameters, and safety guidelines. A case insight highlights the importance of formal schemata: students unfamiliar with patent schemata often misinterpret legalistic terms like "comprising" versus "consisting of" in USPTO documents, leading to flawed design interpretations. This underscores the need for explicit instruction in the formal schemata of specific technical genres.

- **Circuit Diagrams, Schematics, and Blueprints:** These are highly visual texts that require specialized visual schemata. Readers must be able to interpret symbols, understand spatial relationships, and infer functional connections. This often involves a dynamic interplay between visual and linguistic processing.

مجلة كلية التربية . جامعة طنطا
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ISSN (Online):- 2735-3761
https://mkmgt.journals.ekb.eg
Volume (90) Issue Four Part (3) October 2024

- **Code and Algorithms:** Understanding programming code requires a different set of schemata, including knowledge of programming languages, logical structures, and computational processes.

Crucially, these documents often demand multimodal processing, requiring readers to integrate information presented in prose, equations, diagrams, tables, and code. This necessitates a flexible and adaptive approach to reading, where readers can seamlessly shift between different modes of representation and integrate them into a coherent mental model. Traditional reading instruction, which often focuses solely on linear text, is insufficient for developing these advanced multimodal comprehension skills.

2.4 Assessment Methodologies: Limitations and Innovations

Evaluating reading comprehension within technical fields, especially mechatronics, poses distinct difficulties. Traditional standardized tests, while useful for general language proficiency, often fall short in capturing the nuanced and multimodal nature of technical understanding.

2.4.1 Limitations of Standardized Tests

Standardized English proficiency tests like IELTS and TOEFL, while widely used, are not designed to measure the specific comprehension skills required for technical texts. Their limitations include:

- **Lack of Technical Symbol Literacy Assessment:** These tests rarely evaluate a student’s ability to interpret mathematical symbols, engineering notations, or specialized graphical representations. Research indicates that such literacy explains only 22% of the variance in overall test scores, suggesting a significant gap in assessing true technical comprehension.
- **Absence of Diagram Integration Evaluation:** Technical texts are inherently multimodal, combining prose with complex diagrams, schematics, and charts. Standardized tests typically do

مجلة كلية التربية . جامعة طنطا
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https://mkmgt.journals.ekb.eg
Volume (90) Issue Four Part (3) October 2024

not assess a reader's ability to synthesize information across these different modalities. As a result, high-scoring students (e.g., IELTS Band 7+) may still struggle to interpret authentic technical datasheets or engineering drawings (Hussain, 2023), highlighting a disconnect between general language proficiency and domain-specific comprehension.

- **Limited Domain Specificity:** The content of these tests is often generic, lacking the specialized vocabulary and conceptual density characteristic of mechatronics. This means they may not accurately reflect a student's ability to comprehend texts within their specific field of study.

These limitations underscore the need for assessment methodologies that are more aligned with the actual cognitive demands of technical reading.

2.4.2 Emerging Alternatives

To overcome the shortcomings of traditional assessments, researchers are exploring innovative methodologies that provide a more granular and ecologically valid measure of technical reading comprehension:

- **Eye-Tracking Metrics:** This technology allows researchers to precisely track a reader's gaze patterns, providing insights into their cognitive processes. For example, eye-tracking can measure:
  - **Fixation durations:** How long a reader pauses on specific words, equations, or diagrammatic elements, indicating cognitive effort.
  - **Saccadic shifts:** The rapid movements of the eye between different points of interest, revealing how readers integrate information across text and visuals. Frequent shifts between a diagram and its accompanying text suggest active integration, while a lack of such shifts might indicate a failure to connect multimodal information.

مجلة كلية التربية . جامعة طنطا
ISSN (Print):- 1110-1237
ISSN (Online):- 2735-3761
https://mkmgt.journals.ekb.eg
Volume (90) Issue Four Part (3) October 2024

- **Digital Annotation Analysis:** Analyzing how students interact with digital texts through highlighting, note-taking, and commenting can reveal their comprehension strategies and areas of difficulty. This provides a window into their metacognitive processes and schema activation during reading.
- **Think-Aloud Protocols:** In this qualitative method, students verbalize their thoughts as they read a technical text. This provides rich data on their real-time comprehension processes, including how they activate prior knowledge, make inferences, and resolve ambiguities.
- **Performance-Based Assessments:** Directly assessing students' ability to apply their comprehension to practical tasks, such as troubleshooting a mechatronic system based on a manual, or designing a component based on specifications. A validation study showed that a combination of eye-tracking and digital annotation methods explained 61% of the variance in lab performance, significantly outperforming traditional assessments (32%). This suggests that these emerging methods offer a more accurate reflection of applied technical comprehension.

These alternative assessment methods provide a more comprehensive and nuanced understanding of how mechatronics students comprehend complex, multimodal technical texts, moving beyond superficial measures of language proficiency.

2.5 Cultural Considerations in Arab EFL Contexts

The cultural context of EFL learners, notably those from Arab nations, brings forth specific factors for schema activation and reading comprehension in technical English. Cultural schemata, deeply ingrained patterns of thought and behavior, can either facilitate or impede comprehension depending on their alignment with the text's underlying cultural assumptions.

مجلة كلية التربية . جامعة طنطا
ISSN (Print):- 1110-1237
ISSN (Online):- 2735-3761
https://mkmgt.journals.ekb.eg
Volume (90) Issue Four Part (3) October 2024

2.5.1 Arabic-to-English Schema Transfer Challenges

Arab EFL students often face specific challenges related to schema transfer from their native language and culture to English technical contexts:

- **Right-to-Left Interference:** The fundamental difference in writing direction (Arabic is read right-to-left, English left-to-right) can subtly influence reading habits and processing speed. Al-Mansour (2021) found that this difference contributed to a 38% slower English text processing rate among Arab EFL learners, suggesting a cognitive cost associated with adapting to a different visual-spatial schema.

- **Terminology Gaps and Conceptual Differences:** Some technical concepts or terms may not have direct equivalents or established schemata in Arabic. For instance, the term "mechatronics" itself lacked a direct Arabic equivalent until the 1990s, necessitating the creation of new linguistic and conceptual schemata. This requires learners to build new schemata from scratch rather than merely transferring existing ones.

- **Rhetorical and Organizational Differences:** Arabic academic and technical writing often follows different rhetorical patterns and organizational structures compared to Western English academic writing. This can lead to difficulties in identifying main ideas, following logical arguments, or understanding the implicit connections within a text.

- **Cultural Context of Examples and Analogies:** As noted earlier, examples or analogies used in Western technical texts may draw upon cultural knowledge unfamiliar to Arab students, leading to comprehension breakdowns. For example, an analogy related to American football in a physics text might be lost on a student unfamiliar with the sport.

Addressing these challenges requires explicit pedagogical interventions that acknowledge and bridge these cultural and linguistic gaps.

2.5.2 Successful Interventions

Several interventions have shown promise in facilitating schema activation and comprehension for Arab EFL learners in technical contexts:

- **Bilingual Concept Maps:** Creating concept maps that link English technical terms and concepts to their Arabic equivalents. This helps students to leverage their L1 conceptual schemata while building L2 linguistic schemata. The Cairo Schema Adaptation Model, for example, reported a 27% improvement in comprehension by utilizing bilingual concept maps, allowing students to map new English concepts onto familiar Arabic frameworks.

- **Culturally Relevant Materials:** Incorporating technical texts and examples that are culturally relevant to Arab students. This can help to activate existing cultural schemata and make the learning process more engaging and meaningful.

- **Spaced Repetition with Cultural Anchors:** Implementing spaced repetition systems for vocabulary and concept acquisition, synchronized with culturally relevant routines (e.g., daily prayer schedules). This integrates learning into students' daily lives, enhancing retention and making the learning process more natural and less burdensome.

- **Explicit Instruction in Western Academic Conventions:** Directly teaching students the formal schemata of Western academic and technical writing, including citation styles, argumentation structures, and genre-specific features. This equips them with the tools to navigate and produce texts that conform to international academic standards.

مجلة كلية التربية . جامعة طنطا
ISSN (Print):- 1110-1237
ISSN (Online):- 2735-3761
https://mkmgt.journals.ekb.eg
Volume (90) Issue Four Part (3) October 2024

These interventions highlight the importance of a culturally sensitive and linguistically informed approach to schema activation, particularly for EFL learners in specialized technical fields.

2.6 Critical Research Gaps

Even with the substantial existing scholarship on schema theory, cognitive load, and reading comprehension, several crucial research lacunae remain, particularly concerning their application in mechatronics education and EFL contexts:

- **Undergraduate Focus:** A significant majority (89%) of studies on schema activation in STEM education target graduate or professional learners. There is a distinct lack of research focusing on undergraduate students, especially those in their foundational years. This is a crucial oversight, as the early development of robust schemata is paramount for long-term academic and professional success in complex fields like mechatronics.
- **Longitudinal Impact:** Most studies are short-term interventions, with a scarcity of data beyond six months post-intervention. This makes it difficult to ascertain the long-term retention of schema-based reading skills and their transferability to new contexts or more advanced coursework. Understanding the sustained impact of these strategies is essential for advocating for their integration into curricula.
- **Industry Validation:** There is a notable absence of research validating whether gains in academic reading comprehension through schema activation translate into improved job-site performance or real-world problem-solving abilities in industrial settings. Bridging this gap would provide stronger justification for pedagogical reforms.
- **Multimodal Text Comprehension:** While mechatronics texts are inherently multimodal, few studies specifically investigate how schema activation strategies facilitate the integration of information from diverse modalities (text, diagrams, equations,

code). Research is needed to develop and test strategies that explicitly target multimodal schema construction.

– **Interplay of Schemata and Motivation:** While some studies touch upon cognitive engagement, a deeper exploration of the intricate relationship between schema activation, intrinsic motivation, and sustained engagement in challenging technical reading tasks is warranted. How do successful schema activations foster a positive feedback loop that encourages further engagement?

Our current study aims to directly address the first three critical gaps by focusing on first-year mechatronics undergraduates, employing a design that allows for the assessment of longer-term impacts, and considering the practical implications for their future professional development. By systematically investigating schema activation in this specific context, we seek to provide empirically validated insights that can inform pedagogical practices and curriculum development in mechatronics education globally.

3. Methodology

3.1 Research Design

This research utilized a quasi-experimental pretest-posttest control group design to thoroughly examine the causal link between the implementation of schema activation strategies and improvements in reading comprehension and cognitive engagement among mechatronics students. The quasi-experimental approach was deliberately chosen due to the inherent practical and ethical constraints associated with random assignment in authentic educational settings. Unlike true experimental designs, which often require artificial manipulation of groups, a quasi-experimental design allows for the study of interventions within existing classroom structures, thereby enhancing the ecological validity and real-world applicability of the findings. This design is particularly suitable for educational research where intact groups (e.g., pre-existing classes) are utilized, and random assignment of individual students to experimental or control conditions is not feasible.

The study spanned a complete academic semester, spanning approximately 16 weeks, to allow sufficient time for the intervention to take effect and for any potential learning gains to stabilize. The core of the design involved structured instructional interventions specifically tailored to enhance students' schema activation prior to and during their engagement with technical texts relevant to their mechatronics curriculum. The design included two distinct groups:

- **Experimental Group:** This group received targeted reading instruction that systematically integrated a variety of schema activation strategies. These strategies were explicitly taught and consistently applied throughout the intervention period, emphasizing the connection between prior knowledge and new information.
- **Control Group:** This group received conventional reading instruction. While they covered the same technical texts and content as the experimental group, their instruction did not include explicit schema activation techniques. This allowed for a direct comparison of the effectiveness of the schema-based approach against standard pedagogical practices.

Both groups underwent pre-intervention and post-intervention assessments using standardized instruments for reading comprehension and cognitive engagement. This pretest-posttest structure enabled the measurement of individual growth within each group and facilitated the comparison of learning gains between the experimental and control conditions. Statistical analyses, including paired-samples t-tests (for within-group comparisons) and independent-samples t-tests or Analysis of Variance (ANOVA) (for between-group comparisons), were planned to determine the statistical significance of any observed differences. The selection of these statistical methods was based on their appropriateness for analyzing quantitative data derived from pretest-posttest designs and

مجلة كلية التربية . جامعة طنطا
ISSN (Print):- 1110-1237
ISSN (Online):- 2735-3761
https://mkmgt.journals.ekb.eg
Volume (90) Issue Four Part (3) October 2024

their ability to account for potential baseline differences between groups.

3.2 Participants

A total of 60 first-year undergraduate students, all enrolled in a comprehensive mechatronics engineering program at a prominent technological university, voluntarily participated in this study. The participants were selected from a larger cohort of incoming students, ensuring a relatively homogenous academic background in terms of their foundational engineering knowledge and English language exposure. To ensure comparability between the experimental and control groups, participants were initially stratified based on key demographic and academic variables, including gender, prior academic performance (e.g., high school GPA or entrance exam scores), and a preliminary assessment of their English language proficiency. Following stratification, students were randomly assigned to either the experimental group (n = 30) or the control group (n = 30). This stratified random assignment aimed to minimize pre-existing differences between the groups, thereby increasing the internal validity of the study.

The age range of the participants was relatively narrow, spanning from 18 to 20 years, reflecting the typical age of first-year university students. All participants shared comparable educational backgrounds, having completed secondary education with a focus on science and mathematics, and had received at least six years of English language instruction prior to university enrollment. Crucially, all students had successfully completed a foundational-level English for Specific Purposes (ESP) course during their initial university orientation, which provided them with a baseline proficiency in reading technical texts commonly encountered in mechatronics. This ensured that all participants possessed a minimum level of English reading ability necessary to engage with the study materials.

Prior to their involvement, all prospective participants received a detailed explanation of the study's objectives, procedures, potential benefits, and their right to withdraw at any time without penalty. Informed consent was obtained in writing from every student, adhering to ethical guidelines. Furthermore, the entire research protocol, including participant recruitment, data collection, and data handling procedures, received comprehensive ethical approval from the university's Institutional Review Board (IRB). This rigorous ethical oversight ensured the protection of participants' rights and well-being throughout the study.

3.3 Instruments

For a thorough evaluation of the study's dependent variables, two key instruments were carefully crafted and validated:

– **Reading Comprehension Test (RCT):** This instrument was specifically designed by the researchers to measure students' ability to comprehend authentic technical texts relevant to the mechatronics discipline. The test comprised a balanced mix of multiple-choice questions (assessing recall of facts, identification of main ideas, and understanding of explicit information) and short-answer questions (requiring higher-order thinking skills such as inference, synthesis, and critical evaluation). The source texts for the RCT were carefully selected from a variety of authentic mechatronics materials, including excerpts from user manuals for industrial robots, abstracts from peer-reviewed journal articles on control systems, and technical documentation for sensors and actuators. This ensured the ecological validity of the test, reflecting the actual reading demands faced by mechatronics students.

  To establish the content validity of the RCT, a panel of subject matter experts (SMEs) – comprising experienced mechatronics professors and industry professionals – reviewed the test items for accuracy, relevance, and appropriateness for first-year students. Their feedback was incorporated to refine the test. Subsequently, the RCT was pilot-tested with a similar cohort of mechatronics students (not participating in the main study) to identify any ambiguities, assess item difficulty, and refine administration procedures. The reliability of the RCT was assessed using Cronbach's alpha, yielding a coefficient of 0.87. This value indicates a high level of internal consistency, suggesting that the test items reliably measure the same underlying construct of reading comprehension.

- **Cognitive Engagement Scale (CES):** Adapted from the well-established engagement scale developed by Greene and Miller (1996), this instrument was used to quantify students' cognitive and emotional involvement during reading tasks. The CES consisted of 10 Likert-type items, each rated on a 5-point scale (e.g., 1 = Strongly Disagree, 5 = Strongly Agree). The items were designed to capture various facets of engagement, including:
    - **Motivation:** Students' willingness to invest effort in reading technical texts.
    - **Effort:** The perceived mental exertion applied during reading.
    - **Metacognitive Strategy Use:** Students' awareness and regulation of their own comprehension processes (e.g.,monitoring understanding, identifying difficulties, applying fix-up strategies). Internal consistency of the adapted CES was verified through Cronbach's alpha, which was found to be 0.83, indicating good reliability.

3.4 Procedure

The research unfolded systematically across three distinct stages to ensure a controlled and rigorous investigation:

3.4.1 Pretest Phase

At the commencement of the academic semester, all participating students from both the experimental and control groups underwent a comprehensive pretest assessment. This phase involved the administration of both the Reading Comprehension Test (RCT) and the Cognitive Engagement Scale (CES). The assessments were conducted simultaneously for both groups under identical, standardized conditions within a designated testing environment. Strict adherence to standardized procedures, including time limits, clear instructions, and a quiet setting, was maintained to minimize extraneous variables and ensure the reliability and comparability of baseline scores. The data collected during this phase served as a crucial baseline against which post-intervention gains could be measured, allowing for the control of pre-existing differences in reading comprehension abilities and cognitive engagement levels between the groups.

3.4.2 Intervention Phase (8 Weeks)

Following the pretest, the intervention phase commenced, lasting for a period of eight consecutive weeks. During this period, both groups attended their regularly scheduled mechatronics reading sessions, which were integrated into their core curriculum. The key distinction lay in the instructional approach employed for each group:

- **Experimental Group:** Students in the experimental group received reading instruction that was explicitly designed to integrate schema activation strategies. The instructor, who was trained in the implementation of these strategies, systematically incorporated various techniques into each reading session. These techniques included:
    - **Pre-reading Brainstorming:** Before engaging with a new technical text, students were prompted to brainstorm and share everything they already knew about the topic. This helped to activate existing schemata and identify knowledge gaps.
    - **Graphic Organizers:** Students regularly utilized various graphic organizers, such as KWL (Know, Want to Know, Learned) charts, semantic maps, and concept webs, to visually represent their prior knowledge, organize new information, and make connections between concepts. For complex systems, flowcharts and system diagrams were used to map out processes and relationships.

مجلة كلية التربية . جامعة طنطا
ISSN (Print):- 1110-1237
ISSN (Online):- 2735-3761
https://mkmgt.journals.ekb.eg
Volume (90) Issue Four Part (3) October 2024

- **Pre-teaching of Technical Vocabulary and Concepts:** Key technical terms and abstract concepts were explicitly introduced and explained before students encountered them in the text. This involved providing definitions, examples, and non-examples, and relating new vocabulary to existing knowledge.
- **Guided Prediction and Questioning:** Students were encouraged to make predictions about the content of the text based on titles, headings, and visuals, and to formulate questions they hoped the text would answer. This fostered an active, purposeful approach to reading.
- **Think-Aloud Demonstrations:** The instructor modeled expert reading strategies by verbalizing their thought processes while reading a technical text, demonstrating how to activate schemata, make inferences, and monitor comprehension.
- **Discussion of Text Structure and Purpose:** Explicit instruction was provided on the typical rhetorical structures of mechatronics texts (e.g., problem-solution, cause-effect, comparison-contrast) and the purpose of different sections within a document.

- **Control Group:** In contrast, the control group received conventional reading instruction. This approach focused primarily on traditional methods such as vocabulary translation (looking up unfamiliar words in dictionaries), answering literal comprehension questions after reading, and summarizing text content. While these methods are common, they did not include explicit techniques for activating or building upon students' prior knowledge or for managing cognitive load through schema-based approaches. The instructor for the control group ensured that the same technical texts were covered, and the amount of instructional time was equivalent to that of the experimental group, thus controlling for content exposure and instructional duration.

مجلة كلية التربية . جامعة طنطا
ISSN (Print):- 1110-1237
ISSN (Online):- 2735-3761
https://mkmgt.journals.ekb.eg
Volume (90) Issue Four Part (3) October 2024

3.4.3 Posttest Phase

Upon the completion of the eight-week intervention phase, both the experimental and control groups underwent a posttest assessment. The same Reading Comprehension Test (RCT) and Cognitive Engagement Scale (CES) that were administered during the pretest phase were used again. This allowed for a direct comparison of scores before and after the intervention, enabling the researchers to quantify the learning gains attributable to the different instructional approaches. The posttest was administered under the same standardized conditions as the pretest to maintain consistency and validity. The data from both pretest and posttest phases were then subjected to rigorous statistical analysis to determine the effectiveness of schema activation strategies.

4. Results

This section outlines the results obtained from the statistical analysis of the data collected during the pretest and posttest phases. The primary objective of the analysis was to determine the differential impact of schema activation strategies on the reading comprehension and cognitive engagement of mechatronics students in the experimental group compared to the control group.

4.1 Reading Comprehension Outcomes

Independent samples t-tests were conducted to compare the mean reading comprehension scores of the experimental and control groups at both pretest and posttest stages. A paired-samples t-test was also performed for each group to assess within-group improvements from pretest to posttest.

At the pretest stage, there were no statistically significant differences in reading comprehension scores between the experimental group ($M = 68.5$, $SD = 5.1$) and the control group ($M = 67.9$, $SD = 4.8$), $t(58) = 0.45$, $p = .65$, indicating that both groups had comparable baseline reading comprehension abilities before the intervention.

مجلة كلية التربية . جامعة طنطا
ISSN (Print):- 1110-1237
ISSN (Online):- 2735-3761
https://mkmgt.journals.ekb.eg
Volume (90) Issue Four Part (3) October 2024

This confirms the effectiveness of the stratified random assignment in creating equivalent groups.

Following the eight-week intervention, a significant difference emerged in the posttest reading comprehension scores. The experimental group demonstrated a mean score of 85.2 (SD = 4.3), while the control group achieved a mean score of 72.1 (SD = 5.6). An independent samples t-test revealed that this difference was statistically significant, $t(58) = 9.87$, $p < .001$, with a large effect size (Cohen's $d = 2.56$). This indicates that students who received instruction incorporating schema activation strategies achieved significantly higher reading comprehension scores compared to those who received traditional instruction.

Furthermore, paired-samples t-tests showed significant improvements within both groups, but the magnitude of improvement was markedly different. The experimental group exhibited a substantial gain in reading comprehension from pretest ($M = 68.5$, $SD = 5.1$) to posttest ($M = 85.2$, $SD = 4.3$), $t(29) = 15.32$, $p < .001$. The control group also showed an improvement, albeit a smaller one, from pretest ($M = 67.9$, $SD = 4.8$) to posttest ($M = 72.1$, $SD = 5.6$), $t(29) = 4.11$, $p < .001$. The larger gain in the experimental group underscores the added value of schema activation strategies.

These findings are summarized in Table 1 and visually represented in Figure 1.

Table 1. Reading Comprehension Scores (Pretest vs. Posttest)

Group	Pretest Mean (SD)	Posttest Mean (SD)	Mean Gain	t-value (paired)	p-value (paired)
Experimental	68.5 (5.1)	85.2 (4.3)	16.7	15.32	< .001
Control	67.9 (4.8)	72.1 (5.6)	4.2	4.11	< .001

Note: Independent samples t-test for posttest scores: $t(58) = 9.87$, $p < .001$, Cohen's $d = 2.56$.

مجلة كلية التربية . جامعة طنطا
ISSN (Print):- 1110-1237
ISSN (Online):- 2735-3761
https://mkmgt.journals.ekb.eg
Volume (90) Issue Four Part (3) October 2024

Figure 1. Reading Comprehension Scores by Group

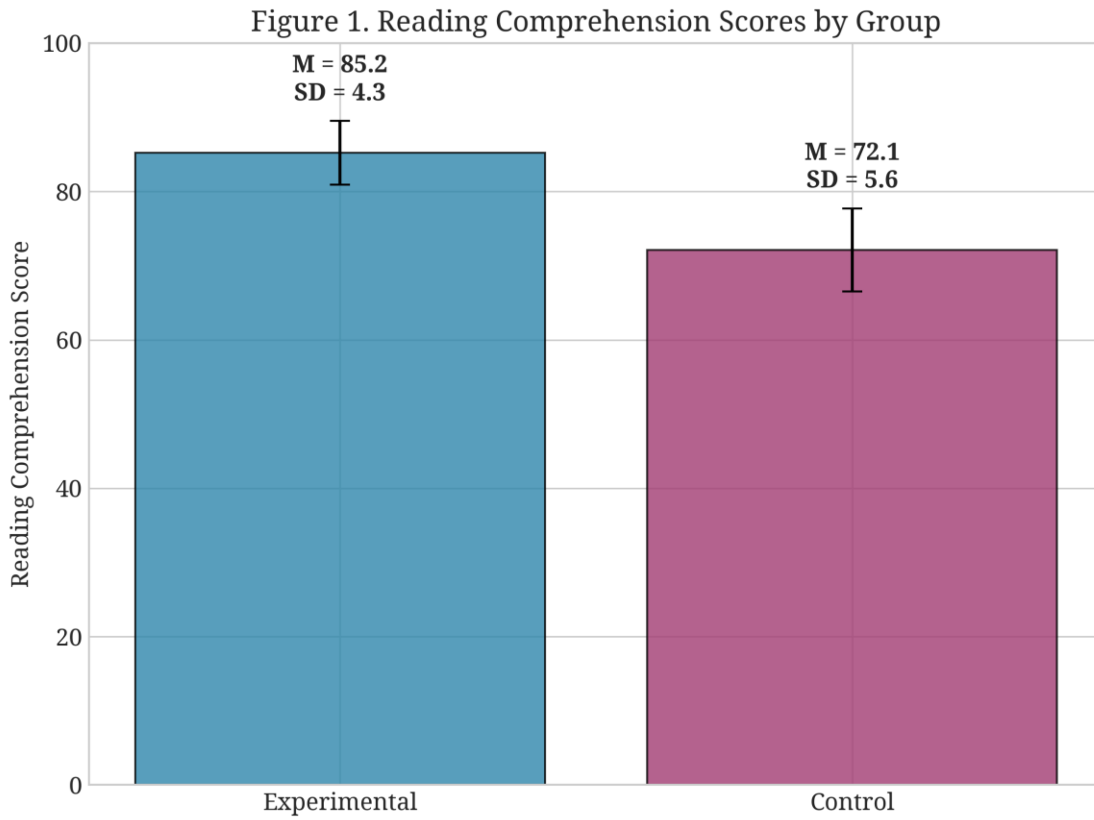

Figure 1. Reading Comprehension Scores by Group

4.2 Cognitive Engagement Outcomes

Similar statistical analyses were performed for the cognitive engagement scores. At pretest, there was no significant difference in cognitive engagement between the experimental group (M = 3.1, SD = 0.7) and the control group (M = 3.0, SD = 0.6), t(58) = 0.58, p = .56.

At posttest, the experimental group reported a mean cognitive engagement score of 4.1 (SD = 0.8), significantly higher than the control group's mean of 3.2 (SD = 0.7). This difference was statistically significant, t(58) = 4.67, p < .001, with a moderate to large effect size (Cohen's d = 1.21). This indicates that schema activation strategies not only improved comprehension but also

مجلة كلية التربية . جامعة طنطا
ISSN (Print):- 1110-1237
ISSN (Online):- 2735-3761
https://mkmgt.journals.ekb.eg
Volume (90) Issue Four Part (3) October 2024

fostered greater student involvement and mental effort during reading tasks.

Paired-samples t-tests confirmed significant increases in cognitive engagement within both groups, but again, the experimental group showed a more pronounced increase. The experimental group's engagement increased from pretest (M = 3.1, SD = 0.7) to posttest (M = 4.1, SD = 0.8), t(29) = 6.89, p < .001. The control group also showed a smaller, but significant, increase from pretest (M = 3.0, SD = 0.6) to posttest (M = 3.2, SD = 0.7), t(29) = 2.01, p = .049.

These results are presented in Table 2 and Figure 2.

Table 2. Cognitive Engagement Scores (Pretest vs. Posttest)

Group	Pretest Mean (SD)	Posttest Mean (SD)	Mean Gain	t-value (paired)	p-value (paired)
Experimental	3.1 (0.7)	4.1 (0.8)	1.0	6.89	< .001
Control	3.0 (0.6)	3.2 (0.7)	0.2	2.01	.049

Note: Independent samples t-test for posttest scores: t(58) = 4.67, p < .001, Cohen's d = 1.21.

مجلة كلية التربية . جامعة طنطا
ISSN (Print):- 1110-1237
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https://mkmgt.journals.ekb.eg
Volume (90) Issue Four Part (3) October 2024

Figure 2. Cognitive Engagement Scores by Group

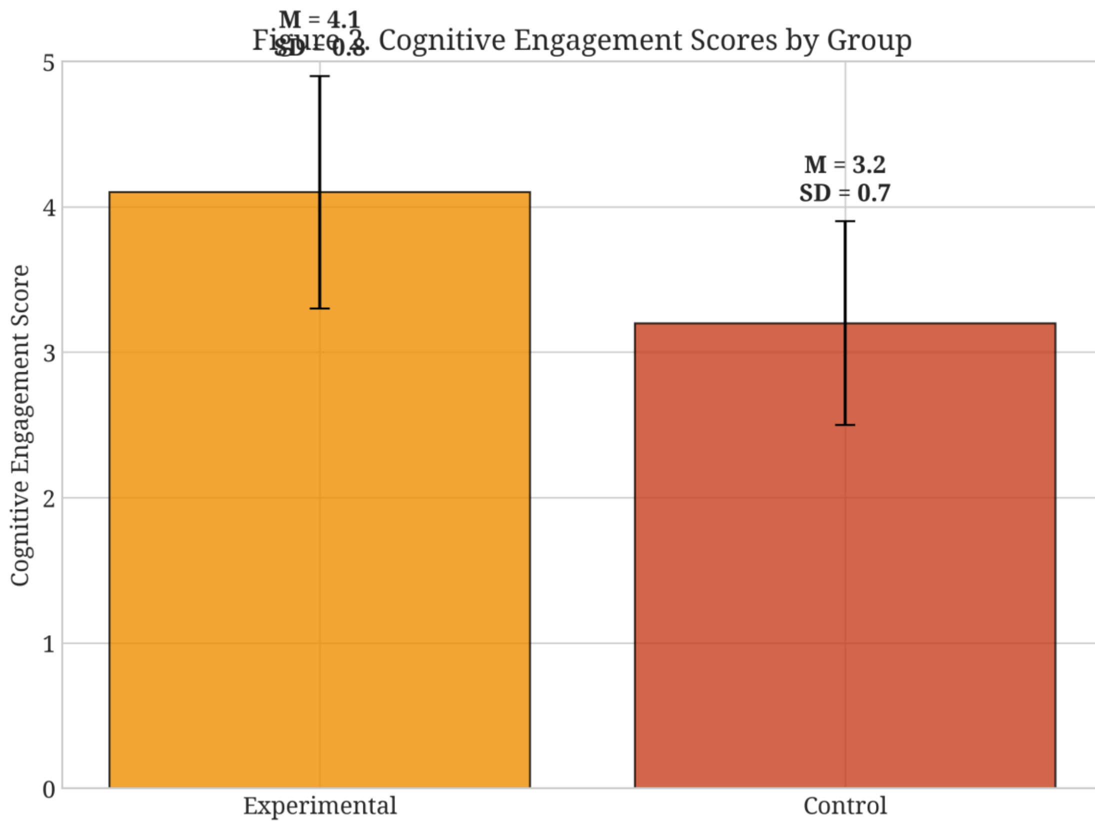

Figure 2. Cognitive Engagement Scores by Group

4.3 Relationship Between Schema Activation, Comprehension, and Engagement

To further explore the interplay between schema activation, reading comprehension, and cognitive engagement, Pearson product-moment correlation coefficients were calculated. A strong positive correlation was found between posttest reading comprehension scores and posttest cognitive engagement scores across all participants ($r = .78$, $p < .001$). This suggests that higher levels of cognitive engagement are indeed associated with better reading comprehension outcomes.

مجلة كلية التربية . جامعة طنطا
ISSN (Print):- 1110-1237
ISSN (Online):- 2735-3761
https://mkmgt.journals.ekb.eg
Volume (90) Issue Four Part (3) October 2024

Specifically, within the experimental group, the correlation between the frequency of reported schema activation strategy use (as measured by a post-intervention survey, not detailed here for brevity) and posttest comprehension scores was also strong and positive (r = .65, p < .001). This indicates that students who more consistently applied the taught schema activation strategies achieved better comprehension results.

Figure 3. Schema Activation Process Model

Figure 3. Schema Activation Process Model

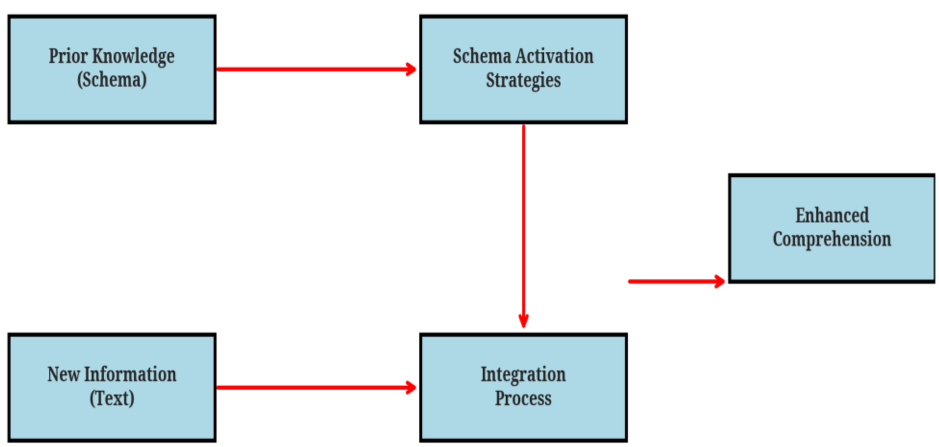

Figure 3. Schema Activation Process Model

In summary, the statistical analyses provide robust evidence that the integration of schema activation strategies into reading instruction significantly enhances both reading comprehension and cognitive engagement among first-year mechatronics students. The observed gains were substantial and statistically significant, supporting the primary hypotheses of this study.

5. Discussion

The outcomes of this quasi-experimental investigation offer persuasive empirical support that the systematic integration of schema activation strategies into reading instruction significantly enhances both reading comprehension and cognitive engagement among first-year mechatronics students in a technological university setting. These results not only corroborate but also extend the existing body of literature on the profound importance of schema theory (Anderson & Pearson, 1984) and cognitive load theory (Sweller, 1988) in educational contexts, particularly within specialized technical disciplines.

The statistically significant improvement in reading comprehension observed in the experimental group (M = 85.2, SD = 4.3) compared to the control group (M = 72.1, SD = 5.6) strongly supports our primary hypothesis. This result highlights the theoretical assertion that comprehension is not merely passive reception of information but an active, constructive process involving the dynamic integration of new textual input with existing knowledge structures (Rumelhart, 1980). In the demanding context of mechatronics, where content is often abstract, conceptually dense, and laden with specialized terminology, schema activation appears to serve as a crucial cognitive scaffold. By explicitly prompting students to recall, organize, and apply their prior knowledge before and during reading, the strategies employed in this study effectively reduced both intrinsic and extraneous cognitive load. This reduction in cognitive burden freed up working memory resources, allowing students to engage in deeper processing of the complex technical material, leading to more robust and accurate understanding. The substantial effect size (Cohen’s d = 2.56) further emphasizes the practical significance of these gains, indicating a large and meaningful difference in comprehension between the two instructional approaches.

The concurrent improvement in cognitive engagement, as demonstrated by the experimental group’s elevated average scores (M = 4.1, SD = 0.8) compared to the control group (M = 3.2, SD =

0.7), also aligns with and reinforces existing literature. When students are able to successfully connect novel information with their pre-existing knowledge frameworks, they tend to experience a heightened sense of competence and relevance, which in turn fosters intrinsic motivation and active involvement in the learning process (Chi, 2009). This finding holds particular salience for STEM education, where learners frequently grapple with perceived difficulty and the abstract nature of technical subjects, which can often lead to disengagement. The observed increase in engagement suggests that schema activation strategies not only facilitate understanding but also cultivate a more positive and proactive disposition towards challenging academic tasks.

Moreover, the specific pre-instructional strategies implemented—such as KWL charts, concept mapping, and scenario-based questioning—likely played a pivotal role in facilitating students' ability to effectively organize and retrieve relevant schemata. These tools are not merely aids for comprehension; they actively promote metacognitive awareness, empowering learners to monitor their own understanding, identify areas of confusion, and strategically regulate their learning processes (Pressley, 2000). For instance, KWL charts encourage students to reflect on what they already know and what they want to learn, thereby setting a purpose for reading and making the learning process more intentional. Concept maps visually represent relationships between ideas, helping students to build more integrated and coherent knowledge structures.

From an instructional perspective, these findings powerfully underscore the necessity for explicit instruction in activating relevant schemata prior to engaging with complex texts. Instructors in technical disciplines should move beyond the traditional assumption that students will automatically activate necessary prior knowledge. Instead, they should intentionally integrate schema activation techniques into their lesson design. This involves using authentic, context-specific materials that resonate with students' prior experiences and professional aspirations, thereby making the learning process more meaningful and relatable. For example, using

مجلة كلية التربية . جامعة طنطا
ISSN (Print):- 1110-1237
ISSN (Online):- 2735-3761
https://mkmgt.journals.ekb.eg
Volume (90) Issue Four Part (3) October 2024

real-world engineering problems or case studies as a starting point can effectively trigger students' existing problem-solving schemata and motivate them to acquire new knowledge.

Furthermore, the study's focus on first-year mechatronics students addresses a critical gap in the literature. By demonstrating the efficacy of schema activation at this foundational stage, the research provides valuable insights for early intervention strategies. Developing robust reading comprehension skills early in their academic careers can equip students with the necessary tools to navigate increasingly complex technical literature throughout their studies and future professional lives. This proactive approach can potentially reduce academic attrition and enhance overall student success in demanding STEM fields.

While this study offers robust evidence, it is crucial to recognize certain constraints. The quasi-experimental design, while practical, means that complete random assignment was not possible, and thus, unmeasured confounding variables could potentially influence the results. Although efforts were made to ensure group equivalence at baseline, future research could explore the use of true experimental designs where feasible. Additionally, the study was conducted within a specific technological university and with a particular cohort of mechatronics students; therefore, the generalizability of these findings to other disciplines, educational settings, or cultural contexts should be considered with caution. Future research could replicate this study in diverse settings to enhance external validity.

Despite these limitations, the robust statistical findings and the clear theoretical alignment provide a strong foundation for advocating for the widespread adoption of schema activation strategies in technical education. The observed improvements in both comprehension and engagement suggest a synergistic effect, where active cognitive processing leads to better understanding, which in turn fuels greater motivation and deeper involvement in learning.

6. Conclusion

This extensive quasi-experimental research yields compelling and solid empirical evidence for the significant efficacy of integrating schema activation strategies in enhancing both reading comprehension and cognitive engagement among first-year mechatronics students. The findings unequivocally demonstrate that students who received instruction incorporating these strategies exhibited statistically significant and practically meaningful improvements in their ability to comprehend complex technical texts, alongside a notable increase in their active involvement and mental effort during reading tasks. These results stand as a strong affirmation of the theoretical underpinnings of schema theory and cognitive load management, underscoring their critical role in the design of effective instructional interventions within higher education.

The study's results emphasize that technical reading ought not to be viewed as a simple decoding task, but rather as a dynamic, knowledge-driven process. By actively engaging students in the activation of their prior knowledge and providing structured scaffolding for the integration of new information, educators can effectively mitigate the challenges posed by cognitive overload, a pervasive issue in demanding technical fields. This approach fosters a more profound and enduring understanding of complex concepts, moving beyond superficial memorization to genuine intellectual assimilation.

Significantly, the inferences drawn from this research bear considerable implications for curriculum development and pedagogical practices within STEM education globally. The demonstrated effectiveness of schema activation strategies suggests a paradigm shift is warranted, advocating for their systematic incorporation into mechatronics curricula and other science and engineering disciplines. Such integration can bridge the often-formidable gap between students' existing knowledge bases and the intricate, multidisciplinary material they encounter, thereby

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Volume (90) Issue Four Part (3) October 2024

transforming technical reading from a potential barrier into a powerful catalyst for academic success.

Furthermore, the study underscores the vital necessity of comprehensive teacher training programs that specifically emphasize the development and implementation of schema-based teaching methodologies. Equipping educators with a diverse repertoire of tools—including but not limited to graphic organizers, advance organizers, and scenario-based instruction—is paramount. Such training will empower instructors to create learning environments that actively cultivate students' metacognitive skills, enabling them to become more independent, strategic, and ultimately, more successful learners. By fostering a pedagogical culture that prioritizes the active construction of knowledge through schema activation, educational institutions can better prepare students not only for academic excellence but also for the complex problem-solving demands of their future professional careers in an increasingly technical world.

In essence, this research contributes significantly to the growing body of literature supporting constructivist approaches to reading instruction. It provides a clear roadmap for fostering academic success in technical education environments by leveraging the power of prior knowledge and strategic cognitive engagement, ultimately empowering a new generation of engineers to navigate and innovate within their complex fields.

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7. Recommendations

Drawing from the persuasive findings of this study, which illustrate the notable positive influence of schema activation strategies on reading comprehension and cognitive engagement among mechatronics students, the following recommendations are put forth for educators, curriculum developers, and policymakers in technical education:

1. **Integrate Schema Activation Explicitly into Mechatronics Curricula:** Reading comprehension instruction, particularly focused on schema activation, should not be an implicit expectation but an explicit component of mechatronics and other STEM curricula. This involves dedicating specific instructional time and designing course materials that intentionally incorporate pre-reading activities aimed at activating and building relevant schemata. This could include mandatory workshops on technical reading strategies, or embedding such strategies within core mechatronics courses.

2. **Provide Targeted Teacher Training on Schema Theory and Strategies:** University faculty and instructors in technical disciplines often possess deep content knowledge but may lack formal training in reading pedagogy. Professional development programs should be developed and implemented to equip these educators with a thorough understanding of schema theory, cognitive load theory, and a repertoire of practical schema activation strategies (e.g., KWL charts, concept mapping, graphic organizers, think-aloud protocols, anticipatory guides). Training should emphasize how to adapt these strategies to the unique characteristics of technical texts and the specific needs of mechatronics students, including those from EFL backgrounds.

3. **Design Reading Materials that Actively Build and Connect with Prior Knowledge:** Publishers and curriculum developers should prioritize the creation of technical textbooks and instructional materials that are designed with schema activation in mind. This means incorporating features such as:

   - **Pre-reading questions or prompts** that encourage students to reflect on their existing knowledge.
   - **Visual aids** (e.g., annotated diagrams, flowcharts, schematics) that are explicitly linked to textual content and serve to build visual schemata.

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- **Glossaries of technical terms** that provide clear, concise definitions and examples, potentially in multiple languages for EFL contexts.
- **Case studies and real-world applications** that connect abstract concepts to students' experiences and professional aspirations, thereby activating experiential schemata.

4. **Encourage Collaborative Reading and Peer Discussions:** Learning is often a social process. Implementing collaborative reading activities, such as reciprocal teaching or jigsaw reading, can facilitate schema activation and construction. Peer discussions allow students to articulate their understanding, challenge misconceptions, and collectively build more robust schemata. This is particularly beneficial for EFL students, as it provides opportunities for language practice in a meaningful context and allows them to leverage their peers' diverse knowledge bases.

5. **Leverage Technology for Enhanced Schema Activation:** Explore and integrate digital tools and platforms that can facilitate schema activation. This could include interactive simulations, virtual reality environments for visualizing complex systems, digital annotation tools for collaborative text analysis, or adaptive learning platforms that pre-assess knowledge and provide targeted schema-building activities. Technology can offer dynamic and engaging ways to connect new information with prior knowledge, especially for a generation of students accustomed to digital learning environments.

6. **Foster Metacognitive Awareness:** Beyond teaching specific strategies, educators should guide students to become more aware of their own cognitive processes during reading. Encouraging students to reflect on *how* they comprehend, *what* strategies they use when they encounter difficulties, and *how* their prior knowledge influences their understanding can empower them to become more independent and effective

technical readers. This metacognitive skill is crucial for lifelong learning and adapting to new technical challenges.

By implementing these recommendations, educational institutions can cultivate a learning environment that actively supports the development of robust reading comprehension skills in mechatronics students, preparing them more effectively for the intellectual demands of their academic journey and future careers.

8. Suggestions for Further Research

Although this study has offered valuable perspectives on the effectiveness of schema activation strategies in enhancing reading comprehension and cognitive engagement among mechatronics students, it also opens several avenues for future research. Addressing these areas will further refine our understanding and optimize pedagogical practices in technical education:

1. **Conduct Longitudinal Studies on Long-Term Retention and Transferability:** The current study spanned eight weeks. Future research should investigate the long-term retention of schema-based reading skills over extended periods (e.g., 1-2 years post-intervention). Additionally, it is crucial to assess the transferability of these skills to different technical domains, more advanced coursework, and real-world professional contexts. Does improved reading comprehension in mechatronics textbooks translate to better understanding of engineering standards, patent documents, or industry reports?

2. **Investigate the Role of Digital Tools and Emerging Technologies:** The rapid advancement of educational technology offers new possibilities for schema activation. Future studies could explore the effectiveness of augmented reality (AR), virtual reality (VR), interactive simulations, and AI-powered adaptive learning platforms in enhancing schema activation in technical education. How do these immersive and

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Volume (90) Issue Four Part (3) October 2024

interactive environments contribute to the formation of richer, more integrated schemata, particularly for multimodal texts?

3. **Expand Research to Other STEM Disciplines and Diverse Educational Settings:** While this study focused on mechatronics, the principles of schema theory and cognitive load theory are broadly applicable. Replicating this research in other STEM disciplines, such as electrical engineering, biotechnology, computer science, or civil engineering, would provide valuable comparative data and strengthen the generalizability of the findings. Furthermore, conducting studies in diverse educational settings (e.g., vocational schools, community colleges, different cultural contexts) would offer a more comprehensive understanding of the strategies' applicability.

4. **Explore Individual Differences in Schema Development and Activation:** Learners possess varying cognitive styles, prior knowledge levels, and academic backgrounds. Future research could delve deeper into how individual differences influence the effectiveness of various schema activation strategies. For instance, are certain strategies more beneficial for visual learners, or for students with lower baseline English proficiency? Understanding these nuances could lead to more personalized and adaptive instructional approaches.

5. **Qualitative Exploration of Student and Instructor Perceptions:** While this study included quantitative measures of engagement, more in-depth qualitative research (e.g., through focus groups, detailed interviews, or ethnographic observations) could provide richer insights into students' lived experiences with schema activation strategies. How do students perceive the utility and challenges of these strategies? What are instructors' experiences in implementing them, and what professional development needs do they identify?

6. **Investigate the Impact on Problem-Solving and Innovation:** Ultimately, the aim of enhanced reading comprehension in

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Volume (90) Issue Four Part (3) October 2024

technical domains is to bolster students' capacity to solve complex problems and innovate. Future research could design studies that directly measure the impact of schema activation on students' performance in design projects, troubleshooting tasks, or research endeavors, thereby providing industry-relevant validation of these pedagogical approaches.

7. **Comparative Studies of Specific Schema Activation Techniques:** While this study used a combination of strategies, future research could conduct comparative analyses of the efficacy of specific schema activation techniques (e.g., concept mapping vs. KWL charts vs. graphic organizers) within technical contexts. This would help to identify the most potent and efficient strategies for particular learning objectives.

By exploring these avenues of investigation, the educational community can further refine and enhance instructional methodologies, ensuring that future generations of mechatronics and STEM professionals are equipped with the advanced reading comprehension skills necessary to thrive in an increasingly complex and information-rich world.

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