



Needs Analysis of Chemistry Content and Context for Metal Casting Technology Competency in Vocational High Schools

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Abstract: Need Analysis of Chemistry Content and Context for Metal Casting Technology Competency in Vocational High Schools. This research investigates the relevance of chemistry content and context for vocational high school students majoring in Metal Casting Technology to bridge the gap between the general science curriculum and practical industrial applications. Employing an evaluative approach with a qualitative research design, data were gathered through documentation studies, in-depth interviews, and expert reviews with four teachers at SMK Negeri 4 Kota Sukabumi. The collected data were analyzed using Mayring's Qualitative Content Analysis (QCA). The findings reveal a significant gap where the general science curriculum provides a foundational overlap but fails to address specific technical applications required in metal casting workshops. Through the analysis, 16 core chemistry topics were identified as highly essential for the industry but currently unaccommodated in the curriculum, such as precise material composition control, interfacial chemistry in mold coating, and the influence of alloy composition on metal microstructure. Based on these insights, a contextual teaching material outline was formulated to integrate chemical theory with practical metal casting processes across Pattern Making Techniques, Mold and Core Making Techniques, and Manual Casting Techniques. The study concludes that shifting the paradigm of chemistry learning from abstract theory to an essential instrument for solving technical problems is crucial. Recommendations emphasize the adoption of this structured outline and the implementation of problem-based learning and team-teaching strategies to enhance curriculum alignment and boost graduate workforce readiness.

Keywords: Needs Analysis, Chemistry Content, Metal Casting Technology, Evaluative Approach, Mayring's QCA.

Abstrak: Analisis Kebutuhan Konten dan Konteks Kimia Pada SMK Kompetensi Keahlian Teknik Pengecoran Logam. Penelitian ini mengkaji relevansi kebutuhan konten dan konteks materi kimia bagi siswa SMK Kompetensi Keahlian Teknik Pengecoran Logam guna mengatasi kesenjangan antara kurikulum sains umum dengan aplikasi riil di dunia industri. Menggunakan pendekatan evaluatif dengan desain penelitian kualitatif, pengumpulan data dilakukan melalui studi dokumentasi, wawancara mendalam, serta revidi pakar terhadap empat guru di SMK Negeri 4 Kota Sukabumi. Data yang diperoleh dianalisis menggunakan metode Qualitative Content

Analysis (QCA) Mayring. Hasil penelitian menunjukkan adanya kesenjangan signifikan, di mana kurikulum sains umum memberikan dasar yang relevan namun gagal mencakup aplikasi teknis spesifik yang dibutuhkan di bengkel pengecoran. Melalui analisis, diidentifikasi 16 topik kimia inti yang sangat krusial bagi industri namun belum terakomodasi dalam kurikulum saat ini, meliputi kontrol presisi komposisi material, kimia antarmuka pada mould coating, serta pengaruh komposisi terhadap mikrostruktur logam. Berdasarkan temuan tersebut, penelitian ini berhasil merumuskan sebuah outline bahan ajar kimia kontekstual yang mengintegrasikan teori dasar kimia dengan praktik pengecoran logam pada mata pelajaran Teknik Pembuatan Pola, Teknik Pembuatan Cetakan dan Inti, serta Teknik Pengecoran Manual. Studi ini menyimpulkan bahwa pergeseran paradigma pembelajaran kimia dari teori abstrak menjadi instrumen penting untuk memecahkan masalah teknis sangat diperlukan. Rekomendasi menekankan pentingnya adopsi outline terstruktur ini serta penerapan pembelajaran berbasis masalah dan strategi pengajaran tim untuk meningkatkan relevansi kurikulum dan kesiapan kerja lulusan.

Kata kunci: Analisis Kebutuhan, Konten Kimia, Teknik Pengecoran Logam, Pendekatan Evaluatif, QCA Mayring.

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▪ INTRODUCTION

Vocational education, particularly in Vocational High Schools (SMK), plays a vital role in preparing a skilled workforce. However, it faces significant challenges, such as high graduate unemployment due to curriculum misalignment, inadequate teacher competence, insufficient facilities, and weak industry partnerships (Wahid & Ratnasari, 2024). In the manufacturing sector, Metal Casting Technology (Teknik Pengecoran Logam) is a crucial competency that demands a profound understanding of metallurgical principles and material chemistry (Campbell, 2015). The implementation of the Merdeka Curriculum integrates Chemistry into the Science Project (Projek IPAS) and Basic Mechanical Engineering (DDTM) subjects. While understanding the chemical properties of materials is essential for metal casting, various studies consistently indicate a gap between the general chemistry taught and practical industrial applications, suggesting that the adaptation of chemistry into specific vocational curricula has not been optimal (Hartanto, 2026).

This gap is exacerbated because the chemistry content in Projek IPAS and DDTM is currently not fully aligned with the specific needs of Metal Casting Technology. Previous studies have highlighted the necessity of contextualizing chemistry for vocational programs. For instance, research on the Mechanical Engineering program (Pauline, 2022) and Analytical Testing Laboratory competencies (Visioni, 2025) successfully mapped essential chemistry elements. Furthermore, studies on Light Vehicle Body Technology (Fayruzzahra, 2025) and Industrial Chemical Engineering (Sari, 2023) emphasized that synchronizing chemistry materials with actual production processes significantly improves learning outcomes. Despite these efforts, there is a distinct lack of comprehensive research focusing specifically on the Metal Casting Technology competency. This represents a critical research gap, as the specific chemical requirements for casting processes—such as mold coating interfacial chemistry, alloy composition control, and thermal dynamics—differ substantially from other mechanical engineering fields.

The urgency of this research is underscored by the principles of Needs Analysis and Context-Based Learning. According to Hutchinson and Waters (1987), curriculum needs analysis must identify the target needs (necessities, lacks, and wants) to ensure the curriculum aligns with real-world demands. In the context of Metal Casting, students must master specific chemical concepts, such as redox reactions for metal melting, polymer bonding for mold making, and interfacial chemistry for coating applications, to transition from abstract theory to practical workshop skills (Anwar, 2023). The absence of a structured, contextualized chemistry outline forces students to rely on generalized science knowledge, which hinders their ability to troubleshoot complex metallurgical problems in the industry. Therefore, there is an urgent need to bridge this misalignment by deeply analyzing the relevant chemistry content and context.

To address this gap, this research offers a comprehensive needs analysis to formulate a relevant and contextual chemistry teaching material outline. The general objective of this research is to produce data on chemistry material needs in the form of a teaching material outline to improve the competence of vocational high school students in Metal Casting Technology. Specifically, this research aims to determine the suitability of chemistry material in the IPAS Project and DDTM, identify chemistry material that is not yet accommodated but supports competency, determine the scope of relevant chemistry material, and establish the chemistry content and context needed in vocational subjects. The novelty of this study lies in its specific focus on the Metal Casting Technology competency using an evaluative approach with Mayring's Qualitative Content Analysis (QCA), providing a structured blueprint for contextual chemistry learning that directly maps to the practical demands of the foundry industry.

▪ **METHOD**

This study adopts an evaluative approach to analyze the content and context needs of chemistry relevant to students of Vocational High Schools with Metal Casting Technology expertise. Evaluative research is a systematic process that follows scientific principles to measure the success, value, or benefit of an educational program or intervention (Arikunto, 2013; Stufflebeam, 2003). The evaluative approach was chosen to assess the effectiveness and relevance of the existing chemistry curriculum to the specific needs of the industrial world. Evaluative research allows for the identification of gaps between the implemented curriculum and the competencies required by the industry, as well as providing recommendations for the development of more contextual teaching materials (Hagenauer, 2020).

Research Design and Subjects

This study employs a qualitative research design to gain a deep understanding of the perceptions and needs of participants regarding chemistry material that supports Metal Casting Technology competency (Creswell & Poth, 2018; Sugiyono, 2022). The subjects of this research include the chemistry material found in the IPAS Project, DDTM, and vocational Metal Casting Technology subjects.

The research participants (informants) were selected using purposive sampling, based on their expertise and roles in the school. A total of four teachers participated in this study: one Project IPAS teacher, one DDTM teacher who also serves as a vocational teacher, and two vocational teachers specializing in Pattern Making Techniques (TPP), Mold and Core Making Techniques (TPCI), and Manual Casting Techniques (TPM). The research was conducted at SMK Negeri 4 Kota Sukabumi

Data Collection Techniques

Data collection in this study was carried out through three main integrated techniques:

1. Documentation Study: Collecting and analyzing official documents such as the Merdeka Curriculum, learning objectives (Capaian Pembelajaran), lesson plans, and existing teaching materials specifically used within the SMK Metal Casting Technology expertise to identify how chemistry content is currently integrated into Project IPAS and DDTM subjects.
2. In-depth Interviews: Conducted in both unstructured (preliminary study) and structured formats with the four selected teachers to gather qualitative data regarding their firsthand experiences, perspectives, and perceived needs for chemistry content in a vocational context.
3. Expert Review: Employing specialists in chemistry education and metal casting engineering to evaluate the research instruments and initial analysis results, ensuring the overall validity and academic rigor of the findings.

Data Analysis Techniques

The collected data were analyzed using QCA, a systematic approach that reduces qualitative data into relevant categories, identifies underlying patterns, and interprets their core meanings (Mayring, 2014; Schreier, 2012). The analytical process followed these steps:

1. Transcription and Organization: Interview data were transcribed, and review sheets were organized alongside curriculum documents.
2. Category Development and Coding: Using an iterative process, categories were developed inductively from the interview data and deductively from the curriculum framework. Each unit of data was coded into these established categories.
3. Mapping and Synthesis: The coded data were synthesized to map the taught chemistry content against the specific vocational competency needs of Metal Casting Engineering, pinpointing which concepts are already accommodated, which are missing, and which serve as essential prerequisites.

Data Trustworthiness

To ensure the validity and reliability of the findings, this study applied the trustworthiness criteria proposed by Lincoln and Guba (1985).

1. Credibility: Achieved through data triangulation, specifically source triangulation (comparing data from IPAS, DDTM, and vocational teachers) and methodological triangulation (comparing documentation, interviews, and expert reviews).
2. Transferability: Provided through thick description of the research context, participants, and findings.
3. Dependability: Ensured by documenting the systematic audit trail of the entire research process.
4. Confirmability: Achieved through member checking (discussing findings with participants) and expert reviews to confirm that the results were not solely based on researcher subjectivity.

Research Instruments

The instruments deployed in this research consist of structured interview guides and expert review sheets (checklists), designed to capture distinct and essential data points. Sample formats of the instruments used in this study are provided in the appendices

(Appendix A, Appendix B, and Appendix C). The interview guide serves as a tool for conducting in-depth interviews, aiming to explore unique perceptions regarding the relevance of existing chemistry content and the specific concepts required. Complementing this, the expert review sheets are utilized to gather critical feedback, evaluate the suitability of the chemistry content within Project IPAS in relation to vocational needs, and guide the development of the chemistry scope.

▪ RESULT AND DISCUSSION

RESULT

This section presents the results of the needs analysis of chemistry content and context in SMK Metal Casting Technology competency. The findings are divided into three main parts: the suitability of existing chemistry materials in general subjects, the identification of unaccommodated but essential chemistry materials, and the resulting scope and outline of the contextual teaching materials.

Suitability of Existing Chemistry Material in Projek IPAS and DDTM

In general, the research results indicate that the chemistry materials currently taught in the Projek IPAS and DDTM subjects under the Merdeka Curriculum possess a foundational relevance to support the basic needs of vocational competencies in Metal Casting Technology at SMK. Based on data triangulation from interviews, the majority of informants provided positive consensus on the role of basic chemistry materials as a necessary scientific foundation for students.

For instance, regarding the material on the Properties of Matter and Its Changes, one vocational teacher (TPCI) stated: *"Understanding the physical properties of molding sand and the phase changes during the solidification of the sand mixture is crucial. Students must be able to predict how the material behaves when heated in the oven or when the molten metal is poured."*

However, the qualitative data also revealed that the integration of chemistry into these general subjects causes the depth of the material to remain very general and focused primarily on broad scientific literacy rather than specific technical applications. The Projek IPAS teacher noted: *"The materials we teach cover the basic concepts of chemical changes and energy, but we do not go into the details of how this applies specifically to the metal casting process, such as calculating the exact enthalpy required for a specific casting."*

These findings indicate that while there is a foundational overlap, the currently available materials in Projek IPAS and DDTM do not fully address the specific technical aspects required in practical metal casting workshops. Consequently, material adjustments are necessary to optimally meet the technical needs in the main vocational subjects: TPP, TPCI, and TPM.

Unaccommodated Chemistry Materials Supporting TPL Competency

Through in-depth analysis of the vocational learning objectives and expert reviews, this research successfully identified 16 core chemistry topics that are highly needed but not specifically accommodated in the current general science curriculum of SMK. The coding results from the Mayring QCA process clearly mapped these gaps.

For example, in the aspect of material properties, understanding the precise control of material composition is crucial in the casting industry. The TPM teacher highlighted this during the interview: *"Students often fail to calculate the correct stoichiometry when adding alloying elements. They need to understand not just the theory of mixtures, but*

how to calculate the exact mass percentage to achieve the desired mechanical properties of the gray cast iron."

Furthermore, the use of mould coating to improve the surface quality of castings requires a deep understanding of interfacial chemistry. The expert review confirmed that concepts such as polymer bonding and colloidal dispersion are essential but currently missing from the standard SMK chemistry syllabus. Technical problems such as oxidation defects in gravity casting of aluminum alloys and the use of polyol ester-based biolubricants for machine maintenance were also identified as crucial chemistry content that must be taught.

These materials are systematically identified based on a needs analysis of each element of TPL vocational competency. The following table provides a complete breakdown of these 16 chemistry materials along with their specific application contexts in the metal casting industry:

Table 1. Details of Chemistry Topics and Application Contexts in Metal Casting Technology Competency

No.	Chemistry Material	Chemistry Content Details
1.	Classification of Matter	States of matter; pure substances & mixtures; mixture separation techniques.
2.	Properties of Matter and Its Changes	Physical/chemical properties; phase changes (melting, freezing).
3.	Hydrocarbon Compounds and Corrosion	Types of lubricants; viscosity; oxidation mechanisms & corrosion prevention.
4.	Stoichiometry	Calculation of mixture mass percentage; alloy element content.
5.	Solutions	Solution composition; gas solubility in liquids; chemical solvents.
6.	Gas Laws	Solution composition; gas solubility in liquids; chemical solvents.
7.	Kinetics and Reaction Rate	Rate factors; activation energy; role of catalysts.
8.	Organic Compounds and Macromolecules	Cellulose & lignin composition; thermal characteristics of wood.
9.	Chemical Bonds and Intermolecular Forces	Metallic bonds; adhesion & cohesion forces; refractory ceramic structure.
10.	Acids and Bases	Neutralization reaction principles; effect of pH on bonding strength.
11.	Chemical Reactions	Oxidation-reduction; carbonation reactions; reaction balancing.
12.	Colloidal Systems	Emulsion stability; dispersion systems; colloidal bonding strength.
13.	Electrochemistry	Electrolytic cell principles; electroplating process.

14.	Thermochemistry and Thermodynamics	Enthalpy; heat transfer; Fe-C equilibrium diagram.
15.	Element Chemistry	Periodic properties of elements; alloy chemistry; noble gas characteristics.
16.	Environmental Chemistry and OHS	GHS hazard identification; workshop B3 waste management.

Scope of Chemistry Material Supporting SMK Metal Casting Technology Competency

The scope of chemistry material supporting TPL competency is organized hierarchically. Basic chemistry material serves as a supporting pillar for vocational competency, allowing students to apply these theories concretely in various technical aspects of metal casting. The 16 materials identified above form a unified applied science curriculum specific to the TPL major.

The results of the material and application context identification are outlined in a structured teaching material outline. This outline is designed to bridge the gap between pure chemistry theory and industrial applications. By incorporating prerequisite materials (such as basic stoichiometry before moving into complex thermodynamic calculations), the outline ensures a systematic learning progression.

Integration of Chemistry Content and Context

The integration of chemistry content and context shows a strong correlation in each vocational subject. Table 2 details the mapping of chemistry content and context integrated comprehensively in TPP, TPCI, and TPM.

Table 2. Chemistry Content and Context in Vocational Subjects for Metal Casting Technology

No.	Chemistry Content	Details of Chemistry Content and Context
1.	Classification of Matter	Silica compound composition in molding sand (TPCI); silica structure in sand testing (TPCI); separation of residual sand mixer mixtures (TPCI); sieving & magnetic cleaning of castings (TPCI); slag separation via skimmer (TPM); filtration, decantation, & flotation furnace slag cleaning (TPM); refractory cement composition of furnace walls (TPM).
2.	Properties of Matter and Its Changes	Physical/chemical properties of metals on lathes, milling, drilling, & grinding machines (TPP); classification of hand tools (TPP); characteristics of wood for patterns (TPP); physical properties of molding sand (TPCI); density of matter in the mixer (TPCI); phase change of sand solidification (TPCI); liquid to solid phase change of metal solidification (TPM).

No.	Chemistry Content	Details of Chemistry Content and Context
3.	Hydrocarbon Compounds and Corrosion	Prevention of oxidation through mold coating (TPCI); mechanism of high-temperature oxidation in heat treatment (TPM); corrosion prevention of machine components (TPM); viscosity of machine maintenance oil (TPM).
4.	Stoichiometry	Mass percentage of sand mixer mixtures (TPCI); mass content of sand water & bentonite (TPCI); alloying element content of molten metal (TPM).
5.	Solutions	Chemical solvents for cleaning machine binder residues (TPCI); gas solubility in resin binders (TPCI).
6.	Gas Laws	Gas pressure in core cavities (TPCI); gas diffusion in core permeability (TPCI); air pressure of Core Blower machines (TPCI); molecular density of Jolt-Squeeze machines (TPCI); intermolecular forces in permeability testing equipment (TPM); gas partial pressure in molten metal degassing (TPM); atmosphere control of mold cavities (TPM); hydraulic systems of casting machines (TPM).
7.	Kinetics and Reaction Rates	Fluid flow against oxidation in pattern design (TPP); flow velocity gating ratio of channels (TPP); homogeneity of mixer mixtures (TPCI); gas catalyst for No-Bake core hardening (TPCI); chemical reactivity rate of furnace operations (TPM); metal solidification rate & quenching cooling speed (TPM).
8.	Organic Compounds and Macromolecules	Composition of cellulose & lignin in wood (TPP); wood fiber structure against frictional heat (TPP); pattern finishing protective layers (TPP).
9.	Chemical Bonds and Intermolecular Forces	Atomic strength of cutting tools & grinding machines (TPP); adhesion of pattern material surfaces (TPP); adhesion force in sand strength testing (TPCI); characterization of bentonite & cement binders (TPCI); graphite structure of crucibles & furnace lining refractory ceramics (TPM).
10.	Acids and Bases	Neutralization reaction in casting cleaning (TPCI); furnace molten metal residue slag cleaning (TPM); fettling neutralization reaction (TPM); influence of pH on sand binding strength (TPM); pickling of cast objects (TPM).

No.	Chemistry Content	Details of Chemistry Content and Context
11.	Chemical Reactions	Frictional heat oxidation of machines (TPP); interaction of molten metal with mold gases (TPP); oxidation of molten metal during pouring (TPCI); reaction of gas with sodium silicate (TPCI); slag formation & furnace iron ore reduction (TPM); furnace atmosphere reduction potential (TPM).
12.	Colloidal Systems	Machine coolant liquid emulsion (TPP); colloidal dispersion binding power of bentonite (TPCI); quenching cooling media emulsion (TPM); thermal stability of hydraulic lubricants (TPM).
13.	Electrochemistry	Electrolysis and electroplating processes for surface coating of castings (TPM).
14.	Thermochemistry and Thermodynamics	Shrinkage due to pattern design temperature (TPP); exothermic reaction of pattern shape design (TPP); melting point of molding sand (TPCI); thermal expansion coefficient of cores (TPCI); thermal decomposition of oven drying (TPCI); furnace heat efficiency & Fe-C equilibrium diagram (TPM).
15.	Element Chemistry	Metal hardness in machine operations (TPP); non-metallic inclusions in gating systems (TPP); melting point & atomic density of core dimensions (TPCI); carbon percentage of metal alloys (TPM); noble gases for machine protection (TPM).
16.	Environmental Chemistry and OHS	GHS aspects of pattern raw material handling (TPP); impact of mixer sand waste (TPCI); toxicity of machine operation chemical vapors (TPCI); toxic raw material handling in the furnace area (TPM).

DISCUSSION

This section provides a critical discussion of the findings, linking the results with broader theoretical contexts, previous research, and their implications for the development of vocational chemistry education.

The Gap Between General Chemistry and Vocational Competency

The findings of this study reveal a significant gap between the general chemistry taught in Projek IPAS and DDTM and the specific technical demands of the TPL competency. Although there is a foundational overlap — such as the basic concepts of matter classification and energy changes — these general subjects fail to delve into the specific technical applications required in the workshop. This aligns with previous

research indicating that vocational education often suffers from a curriculum misalignment where the science curriculum is not fully synchronized with the practical needs of the industry (Hartanto, 2026; Yonanda et al., 2023). This phenomenon is further supported by recent research, which indicates that vocational chemistry education faces significant challenges in aligning curricula with industry demands, and that active learning strategies are essential to bridge this gap between theoretical science and practical vocational applications (Qi et al., 2024).

The critical issue lies in the nature of the Merdeka Curriculum, which aims to streamline science education into broader thematic contexts. While this approach enhances general scientific literacy, it inadvertently strips away the highly specific, applied chemistry concepts necessary for specialized trades like metal casting. For instance, the general curriculum discusses "phase changes," but it does not explicitly cover the thermodynamic calculations required to predict the shrinkage of a casting or the microstructural changes in gray cast iron during cooling. Without this specific knowledge, students are forced to rely on generalized science knowledge, which severely hinders their ability to troubleshoot complex metallurgical problems in the industry.

This gap is fundamentally rooted in the structural design of the Merdeka Curriculum, which replaced the previous adaptive chemistry subject (*Kimia Adaptif*) with a more generalized science integration through *Projek IPAS* and *DDTM*. The shift from a discipline-specific approach to a thematic one, while beneficial for fostering general scientific literacy, has created a disconnect for students in highly technical fields. The curriculum no longer provides a dedicated space for chemistry concepts to be taught at a depth that matches the technical sophistication of modern foundry operations. As a result, vocational teachers are left to bridge this gap on their own, often without formal training in chemistry pedagogy.

The Importance of Context-Based Chemistry Learning

The identification of 16 essential chemistry topics that are currently unaccommodated in the curriculum underscores the urgent need for Context-Based Learning and Contextual Teaching and Learning approaches. This study confirms the principles of Needs Analysis, which posit that curriculum development must be driven by the target needs of the learners and the demands of the real world (Hutchinson & Waters, 1987). In the context of metal casting, this means that chemistry must be taught not as an abstract body of knowledge but as a set of tools that students can directly apply to solve production problems. This aligns with the findings of Ahdiat et al. (2026), who demonstrated that chemistry teaching modules based on basic concepts and practical applications are highly practical and effective in bridging abstract chemical concepts with real-world contexts. Furthermore, the application of context-based learning (CBL) in vocational high schools has been empirically shown to significantly improve students' chemical literacy, as demonstrated in a study where CBL was applied to petroleum topics in automotive engineering programs (Wiyarsi et al., 2020).

The integration of these specific chemistry topics directly addresses the practical requirements of the TPL major across its three core subjects. In TPP, understanding organic compounds and macromolecules is crucial for selecting the right type of wood for patterns and applying protective finishes that can withstand the frictional heat of machining. Without this knowledge, students cannot make informed decisions about material selection, which directly impacts the dimensional accuracy of the final casting.

In TPCI, knowledge of colloidal systems, gas laws, and acid-base chemistry is vital for understanding the binding power of bentonite, managing gas diffusion through core permeability, and controlling the pH of sand mixtures to ensure structural integrity. A failure to understand these concepts can lead to casting defects such as blowholes or mold collapse, which are costly and time-consuming to resolve in an industrial setting. In TPM, mastery of stoichiometry, thermochemistry, and element chemistry is indispensable for controlling the precise alloying of molten metal, managing the thermodynamics of the furnace, and preventing oxidation defects during pouring.

Theoretically, these findings support the concept that science education becomes significantly more meaningful when connected to the students' real-world experiences (Joshi, 2026). When students can see the direct relevance of a chemistry concept to their daily workshop activities, their motivation and engagement increase substantially. This is consistent with the findings of previous studies in other vocational fields, such as Light Vehicle Body Technology (Fayruzzahra, 2025) and Industrial Chemical Engineering (Sari, 2023), which demonstrated that contextualizing science education within vocational training significantly improves learning outcomes. Practically, this curriculum adjustment is crucial for enhancing the work readiness of TPL SMK graduates. By providing them with a robust, applied scientific foundation, they are better equipped to innovate and solve complex problems within industrial production processes (Kamaludin et al., 2024). These findings are consistent with a comprehensive thematic review of context-based chemistry curricula, which concluded that context-based approaches generally improve students' motivation, interest, and attitudes toward chemistry, and do not adversely affect their conceptual understanding (Ültay & Çalık, 2012).

Implications for Curriculum Development and Pedagogy

The findings of this study have profound implications for the development of the chemistry curriculum in vocational schools. The traditional paradigm of teaching chemistry as a purely theoretical, abstract subject must shift toward an instrument for solving technical problems in the casting industry. This shift requires a fundamental rethinking of how chemistry is integrated into vocational education. Rather than treating chemistry as a separate, standalone subject that students must "endure" before entering their vocational studies, it should be woven seamlessly into the fabric of their technical training.

To implement this, educators and curriculum developers must adopt the compiled teaching material outline as a structured blueprint for preparing more contextual teaching modules. The outline presented in this study ensures that every chemistry concept taught has a functional purpose in solving technical problems, thereby increasing efficiency and production quality. Furthermore, the development of adaptive learning modules is crucial. Since the Merdeka Curriculum has fixed time allocations, it may be difficult to add entirely new subjects without restructuring the entire curriculum. Therefore, the integration of these specific chemistry concepts should be done collaboratively between chemistry teachers and vocational teachers. This collaborative approach can take the form of team teaching, where a chemistry teacher and a vocational teacher jointly design and deliver lessons that blend theoretical knowledge with practical application. Research supports this approach, as context-based chemistry learning through Socio-Scientific Issues (SSI) has been consistently shown to improve students' chemical literacy across conceptual, epistemic, and affective dimensions (Nadapdap et al., 2026). Moreover, it is

essential to recognize that context-based chemistry education should draw from multiple domains of context, including the professional practice domain, where students are prepared for their future roles as workers in industrial settings (De Jong, 2008).

Additionally, the use of problem-based learning (PBL) approaches is highly recommended. By presenting students with real-world casting problems such as a recurring defect in a batch of castings or the failure of a mold under high temperature and asking them to use chemistry concepts to diagnose and solve the problem, educators can create a more engaging and effective learning experience. This approach not only deepens students' understanding of chemistry but also develops their critical thinking and problem-solving skills, which are essential qualities for success in the modern workforce.

In conclusion, while the Merdeka Curriculum provides a solid foundation for general science education, it falls short in addressing the specific chemistry needs of the TPL competency. The 16 chemistry topics identified in this study represent a critical gap that must be filled to ensure that SMK graduates are adequately prepared for the demands of the foundry industry. By adopting a more contextual and collaborative approach to chemistry education, vocational schools can produce graduates who are not only technically proficient but also scientifically grounded, enabling them to contribute meaningfully to the advancement of Indonesia's manufacturing sector.

▪ CONCLUSION

Based on the results of the needs analysis of chemistry content and context for vocational high school students with Metal Casting Technology competency, it can be concluded that although the current general science curriculum provides an initial foundation, there is a critical need to sharpen and integrate sixteen core chemistry materials that directly support technical operations in key vocational subjects. The innovation offered through this research lies in mapping a structured applied science curriculum that is no longer theoretical-abstract, but functional-applicative. Concepts such as metal thermodynamics, high-temperature reaction kinetics, and interfacial chemistry of molding sand have been identified as key pillars in building students' technical reasoning. These findings contribute new insights to vocational education by shifting the paradigm of chemistry learning from merely a supporting subject to an essential instrument for solving technical problems in the casting industry. As an applicative step, it is recommended for educators and curriculum developers to adopt the compiled teaching material outline as a guide in preparing more contextual teaching modules, and close collaboration between chemistry teachers and vocational teachers is highly recommended.

This study has several limitations. First, the research was conducted at a single vocational high school, limiting the generalizability of the findings to other schools with different regional characteristics, facilities, and industrial partnerships. Second, the informants were limited to four teachers, which may not capture the full spectrum of perspectives from industry practitioners, students, or curriculum developers. Third, this study focused solely on the needs analysis phase and did not proceed to the actual development and testing of the proposed teaching materials, so the effectiveness of the outlined chemistry materials in improving student competency remains to be empirically validated.

Future research is recommended in several directions. Researchers should consider expanding the study to multiple vocational high schools with Metal Casting Technology competencies across different regions and involving industry practitioners as additional

informants. Subsequent studies should also focus on the actual development and field testing of adaptive, context-based chemistry teaching modules based on the outline produced in this study, and explore the feasibility of implementing this chemistry outline within the time constraints of the Merdeka Curriculum through problem-based learning or team-teaching strategies.

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