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An Ontology-Driven Adaptive User Interface Framework for Indonesian Student Wellbeing

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Abstract— **Background**: The personalization of digital learning environments to support student wellbeing presents a significant challenge due to the need for integrating multi-dimensional contextual factors. Existing adaptive user interface (AUI) approaches often rely on ad-hoc rule-based systems or simpler adaptive mechanisms, lacking the formal semantic grounding required to handle the intricate interdependencies between diverse wellbeing dimensions and corresponding UI adaptations. **Objective**: This research aimed to design, develop, and formally validate a novel semantic framework for a context-aware AUI specifically tailored to provide a formal foundation for supporting multidimensional student wellbeing factors. **Methods**: The methodology involved creating a detailed "Context Mapping" table to establish relational scenarios between student contexts, wellbeing factors, and UI adaptations. Subsequently, a Semantic Taxonomy was engineered and implemented as a Web Ontology Language (OWL) model in Protégé. Its relational data retrieval capabilities were demonstrated via the SPARQL Protocol. The principal outcome of this investigation is the formal validation of the ontology using the HermiT reasoner. This study utilized a comprehensive literature review to formulate its context mapping, followed by a formal modeling and validation methodology. **Results:** Using the HermiT reasoner conclusively determined that the model is both coherent and consistent. The research successfully translated qualitative Indonesian student wellbeing requirements into a formal, computationally tractable semantic framework. **Conclusion**: The developed semantic framework provides a validated foundation for the deployment of intelligent, context-aware applications designed to enhance Indonesian student wellness in higher education. This research successfully multi-dimensional requirements for a context-aware student wellbeing application into a robust, and scalable framework.

Keywords—Adaptive User Interface; Context-Aware Computing; Ontology; Semantic Web; Student Wellbeing

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I. INTRODUCTION

The implementation of adaptive user interfaces (AUI) in higher education is primarily driven by their capacity to enhance usability and create personalized learning pathways. By dynamically adjusting to individual user preferences and contexts, AUIs facilitate more effective interactions with digital educational tools [1], [2]. This inherent adaptability not only improves student engagement but also directly contributes to better academic outcomes by ensuring resources are aligned with specific learning requirements [3]. Moreover, these interfaces play a crucial role in supporting diverse demographics; for instance, international students benefit significantly from intercultural designs that help bridge cultural divides and improve system usability [4]. Ultimately, prioritizing user-centered design principles ensures that digital learning environments remain inclusive and accessible for all [5].

In the specific context of Indonesia, student wellbeing is recognized as a multidimensional construct influenced by spiritual, psychological, social, and material dimensions[6]. Developing a balanced framework for self-growth requires a holistic approach that integrates religious, social, and academic values [7], [8]. Research indicates that pedagogical methods rooted in local culture can substantially boost student motivation and engagement[9]. Furthermore, the choice of language in an educational setting remains a vital factor in academic wellbeing [10], [11]. Technical infrastructure, including interactive media and the expertise of educational staff, also serves as a critical foundation for sustaining student academic involvement [12], [13], [14].

While Western models of wellbeing typically prioritize individual psychological and physical health, the Indonesian educational landscape necessitates a model where spiritual peace, social communalism, and regional identity are core pillars. This research captures these nuances by engineering a semantic framework where cultural and spiritual factors are not merely metadata but active ontological triggers. For instance, the framework facilitates 'empathetic' adaptations—such as regional visual motifs or spiritually timed alerts, designed to strengthen a student's sense of identity and academic resilience within a digital environment.

Smartphones have further revolutionized academia by providing students with constant access to educational content. Their widespread use is supported by their ability to offer personalized learning experiences and ubiquitous access to resources [15], [16]. Additionally, these devices foster inclusive environments through familiar interfaces that simplify collaboration between students and instructors [17], [18]. Despite the potential of AUIs, a significant challenge remains in formally integrating these complex wellbeing factors into a scalable framework. Current approaches often rely on ad-hoc rules that lack the formal semantic grounding necessary to handle intricate contextual interdependencies. This study addresses the gap by introducing a novel,

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formally validated semantic framework specifically designed to facilitate personalized wellbeing-sensitive adaptations in academic interfaces. By modeling diverse dimensions and employing rigorous formal reasoning, this research offers a robust and computationally tractable foundation for future intelligent, student-centric applications.

II. RESEARCH METHOD

The research methodology begins with a comprehensive literature review of scientific journals and online resources to gather information on Indonesian well-being factors, AUI design, and ontology technology. The primary objective of this review is to identify key elements influencing the well-being of Indonesian users in educational contexts and to understand how these can be integrated into an AUI.

The problem under study involves the need to dynamically adjust digital learning interfaces based on various student contextual factors (e.g., academic status, psychological state, cultural background, physical condition) to proactively support their multidimensional wellbeing (academic, social, psychological, cultural, spiritual, physical, material). This necessitates a formal representation of knowledge that can capture complex, often inferred, relationships between contexts, wellbeing factors, and appropriate UI adaptations, moving beyond simple rule-based systems that may struggle with scalability and logical consistency. The flowchart of this research is explained visually in Fig 1.

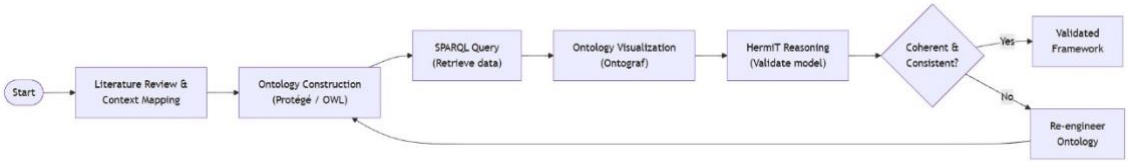

Fig 1. Research Flow for The Development and Formal Validation of The Semantic AUI Framework

The proposed method leverages semantic web technologies to create a formal, machine-readable knowledge base that can model these complex relationships. The core components of our methodology are as follows:

A. Literature Review and Context Mapping

A comprehensive review of scientific literature was conducted to identify key dimensions of Indonesian student wellbeing and relevant AUI design principles. This qualitative data was then structured into a detailed 'Context Mapping' table, establishing specific relational scenarios between identifiable student contexts (e.g., "Preparing for Approaching examinations"), their triggers (e.g., "exam dates in the academic calendar"), the affected wellbeing factors (e.g.,

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"Academic (stress management), Psychological (anxiety reduction)"), and the proposed responsive UI adaptations (e.g., "Adaptive 'Focus Mode'").

This initial phase formalizes the problem by systematically defining the domain's entities and their interrelationships, serving as the empirical basis for the ontology design, specifically tailored for the Indonesian educational landscape.

B. Ontology Model Construction using Protégé.

This phase involves building a formal knowledge representation of the identified Indonesian wellbeing factors and adaptive UI elements. We utilize Protégé[19], a widely used and robust ontology editor, to implement the ontology model as an Ontology Web Language (OWL) model. OWL was chosen for its expressivity (supporting complex relationships and logical axioms), its ability to enable robust reasoning, and its compatibility with logical reasoners. The ontology defines a comprehensive set of classes (e.g., StudentContext, WellbeingFactor, AdaptiveInterface, NotificationSettings, DisplaySettings, ModeSettings), properties (e.g., triggers, requiresAdaptation), and individuals, thereby creating a structured and organized knowledge base to support fine-grained AUI design [20], [21], [22].

This approach represents a state-of-the-art method for formalizing domain knowledge, allowing for sophisticated reasoning beyond simple keyword matching or predefined if-then rules, which often lack the flexibility and extensibility of an ontological model. This methodical construction directly contributes to the novelty by formalizing a complex domain specific to Indonesian student wellbeing that has not been addressed with this level of semantic rigor.

C. Semantic Data Retrieval using SPARQL Query

Upon completion of the ontology model, the SPARQL Protocol and RDF Query Language is used to establish semantic data connections, enabling the retrieval of specific information based on defined criteria. SPARQL's ability to traverse the semantic graph allows for inferential queries, retrieving not just explicitly stated facts but also knowledge that can be logically deduced from the ontology's axioms and relationships [23]. For instance, a query can infer all UI adaptations required when a student is in a specific stress context, by following the relationships defined in the ontology. This capability is crucial for dynamically identifying complex UI adaptations based on multiple interconnected contextual factors, ensuring that the system can make intelligent decisions about adaptations, thus demonstrating the practical application of our state-of-the-art semantic model.

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D. Ontology Visualization with Ontograf

Ontograf is employed to visualize the ontology model and the SPARQL Query analysis results. This provides a clear graphical representation of the model's structure and relationships, aiding in understanding and verifying the intricate connections within the semantic framework. Visualization is essential for debugging and communicating the complex architecture of the ontology.

E. Formal Validation using HermiT Reasoner

The final and most critical phase involves performing inference and reasoning on the model using HermiT [24], [25], a highly regarded OWL reasoner. HermiT performs a comprehensive diagnostic analysis of the ontology to verify its logical consistency and coherence. This includes detecting unsatisfiable classes (classes that cannot have any instances), identifying contradictory axioms (statements that conflict logically), and computing the inferred class hierarchy based on the defined properties. This formal validation step is paramount; it ensures the logical soundness and robustness of the model, a level of rigor often missing in less formal adaptive systems. The successful demonstration of coherence and consistency proves that the complex qualitative requirements of student wellbeing can be successfully formalized into a logically robust framework, thereby significantly contributing to the novelty and reliability of this research, offering a new benchmark for AUI framework development.

This comprehensive methodology, integrating systematic context mapping rooted in Indonesian wellbeing nuances, robust ontology engineering with OWL, inferential querying with SPARQL, and rigorous formal validation with HermiT, ensures that the adaptive UI framework is not merely a collection of rules but a logically consistent, semantically rich, and validated system capable of intelligent context-aware adaptation for student wellbeing. This integrated approach represents a significant contribution to knowledge in the design and implementation of adaptive educational technologies.

III. RESULT AND DISCUSSION

Following the comprehensive review of student wellbeing and adaptive user interface design, the subsequent sections detail the results of our research, presenting the core components of the proposed semantic framework for context-aware adaptive user interfaces designed to enhance student wellbeing.

A. Context Mapping and Adaptive Scenarios

The context mapping serves as a practical framework for implementation, designed to translate identified multidimensional wellbeing factors into tangible, adaptive features on a smartphone

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interface. This mapping systematically delineates specific student contexts, identifies their triggers, links them to corresponding wellbeing factors, and proposes responsive UI adaptations. This approach aims to illustrate how a thoughtfully designed digital environment can proactively address student needs, mitigate stress, foster a sense of belonging, and ultimately enhance both academic performance and overall wellbeing.

This comprehensive mapping is conceptually represented in Table 1. Context Mapping for Student Wellbeing with Smartphone Interface. For instance, when a student is preparing for examinations (triggered by approaching exam dates or self-reported stress levels), the primary wellbeing factors affected are academic stress management and psychological anxiety reduction. The proposed UI adaptations include an "Adaptive Focus Mode" that limits non-essential notifications and proactive pop-ups with links to guided meditation or breathing exercises. The expected outcome is reduced academic stress, improved focus, and enhanced mental clarity for exams.

Table 1. Context Mapping for Student Wellbeing with Smartphone Interface

ID	Context	Context Details (Trigger & Factors)	Smartphone Interface (AUI)	Expected Outcome
AC01	Exam Prep	Exam dates; Academic stress	Focus Mode; Meditation pop-ups; Counseling link	Improved focus & mental clarity
SO01/ CU01	Social and Cultural	1st semester; Intl status; Sense of belonging	Club alerts; Mentor links; Local customs cards; Buddy system	Social integration; Reduced isolation
SP01/ SP02	Spiritual	Inactivity; Profile: Muslim; Purpose/Peace	Goal-tracker; Prayer alerts (orange theme); Reflective videos	Renewed purpose; Religious balance
PH01	Physical Fatigue	Night usage; Physical health/Burnout	Break reminders; Night Mode (blue filter); Fitness app sync	Reduced strain; Healthier study habits
MA01	Financial	Aid searches; Material/Anxiety	Budget tool; Scholarship alerts; Literacy resources	Financial stability; Reduced anxiety
LA01	Language	Dictionary use; Academic skills	Bilingual quizzes; Dual-language terms; Exchange forum	Improved communication & confidence
AP01	Progress	Semester updates; Progress tracking	Achievement Bar (Green/Yellow/Red status based on GPA)	Visualized progress; Early warning system
CU02	Cultural Identity	Home region settings; Sense of identity	Regional ornamental background (ukiran)	Strengthened sense of belonging
DB01	Academic Calendar	GPA; Payment; Library; Task awareness	Dynamic buttons (Color-coded: Green/Pink/Yellow/Red)	Cognitive load reduction; Intuitive status

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The mapping strategy, as detailed in Table 1, translates qualitative multidimensional wellbeing requirements into tangible, computationally tractable smartphone interface features. This framework proactively addresses a broad spectrum of student needs by linking specific triggers to responsive UI adaptations.

For instance, academic and psychological stress during critical periods like examinations is mitigated through functional changes such as an "Adaptive Focus Mode" and proactive wellness prompts. To foster social integration and cultural belonging, especially for first-semester or international students, the system triggers personalized content like mentor connectivity, local custom guidance, and regional ornamental backgrounds (batik).

Furthermore, the framework supports spiritual and physical health by integrating time-sensitive prayer notifications and health-centric features like "Night Mode" and break reminders based on usage patterns. Visual cues, such as a color-coded achievement bar and dynamic button backgrounds, are also employed to reduce cognitive load and provide intuitive updates on academic progress. Unlike static interfaces, this empathetic approach allows the digital environment to evolve alongside the student's dynamic context, effectively strengthening their sense of identity and academic resilience.

This comprehensive context mapping strategically addresses the multidimensional needs of Indonesian students, encompassing academic, social, psychological, cultural, and spiritual dimensions. This adaptive approach is superior to static interfaces due to its ability to proactively respond to dynamic student conditions, thereby creating a supportive and empathetic digital learning environment. Adaptations, such as culturally relevant background changes, not only enhance user experience but also significantly strengthen a student's sense of identity and belonging, which are critical dimensions of overall wellbeing. The integration of these culturally specific factors directly addresses a gap in the existing state-of-the-art for AUI design.

B. Adaptive System Interaction Flow and Relational Modelling

The system's interaction flow illustrates how various components collaborate to provide context-aware UI adaptations. This flow begins with the student opening and using the application, which initiates a continuous context sensing loop. In this loop, the system provides context data, such as time (e.g., 2 AM), location (e.g., Library), and activity (e.g., Studying). This overall process of context-aware UI adaptation driven by student wellbeing factors is conceptually depicted in Fig 2. A relational diagram of the use case, showing context-aware UI adaptation based on student well-being factors.

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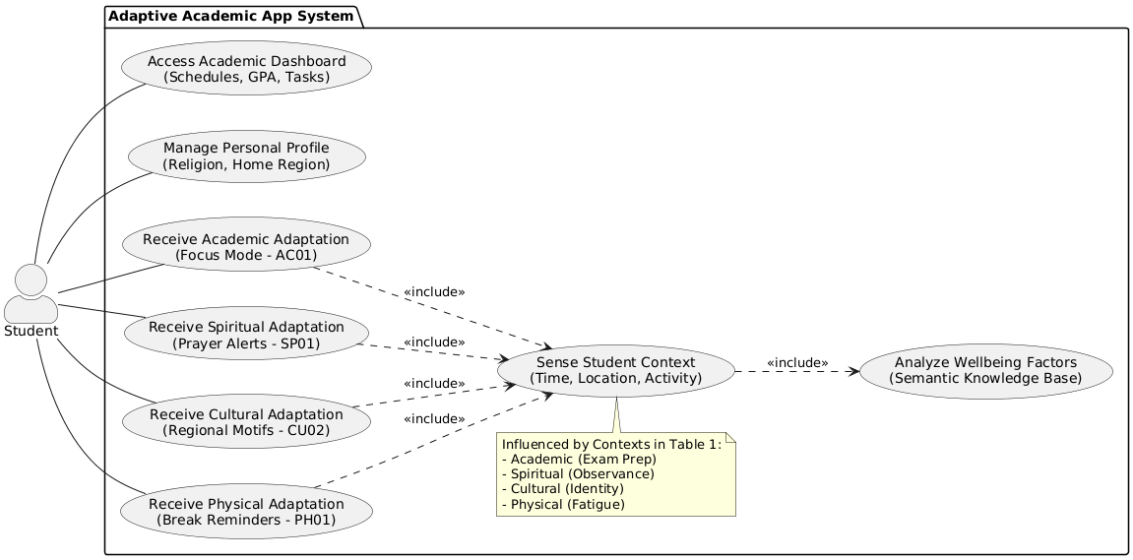

Fig 2. A Relational Diagram of The Use Case, Showing Context-Aware UI Adaptation Based on Students Well-Being Factors

The contextual data gathered is then fed into the "Wellbeing Factor Analysis" component, which identifies relevant wellbeing factors that might be affected by the current context (e.g., Physical Health, Psychological Burnout). Based on this analysis, the system commands the "Adaptive UI" to perform specific adaptations. Subsequently, these adaptive changes are displayed to the student.

For example, as illustrated in Fig 3. Sequence diagram for context aware UI adaptation, if the system detects that a student is studying in a library late at night (2 AM), the "Wellbeing Factor Analysis" component infers a potential impact on "Physical Health" and a risk of "Psychological Burnout". This inference then triggers the "Adaptive UI" to switch the screen to 'Night Mode' and deliver a "Take a Break" notification. This scenario highlights how the system intelligently deduces potential wellbeing needs from environmental and activity cues, providing timely and appropriate support that extends beyond simple, predefined rules. This student-centric approach allows the system to "understand" student needs holistically by connecting contextual conditions with desired wellbeing outcomes through intelligent UI adaptations, thereby contributing to the novelty of context-aware system design.

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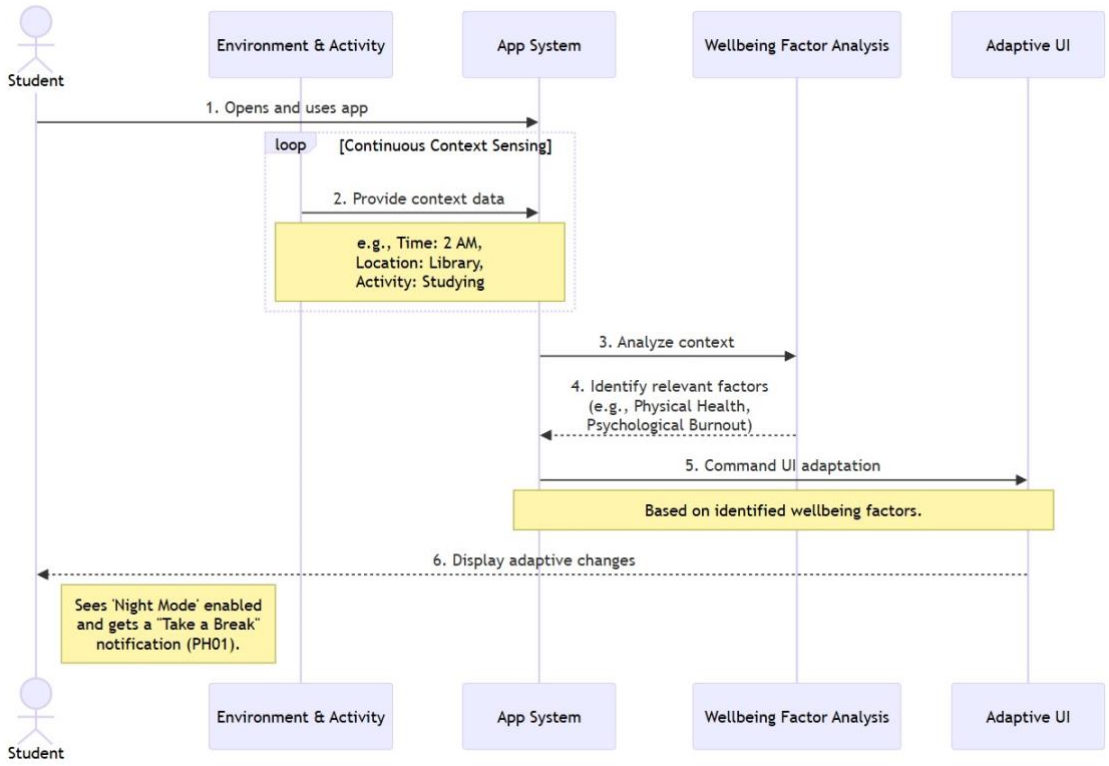

Fig 3. Sequence Diagram for Context Aware UI Adaptation

C. Semantic Taxonomy and Ontology Structure

The designed semantic taxonomy, built using Protégé, illustrates the structured knowledge representation that underpins the adaptive user interface within the academic smartphone application. Adaptive user interface is structured within the academic smartphone application. At the core of this taxonomy is the abstract class "AdaptiveInterface," which establishes the foundational methods for adjusting the interface. Three specific setting categories are derived from this class: *NotificationSettings*, *DisplaySettings*, and *ModeSettings*. Each category is designed to manage distinct aspects of the user experience by responding to specific contexts identified in our research.

NotificationSettings is responsible for modulating the frequency and type of alerts. For instance, based on the context mapping, this includes sending orange-backgrounded prayer time alerts for Muslim students, pushing notifications about scholarship deadlines to address financial anxiety, or providing "take a break" reminders during long study sessions to prevent burnout. The structured relationships within the ontology ensure that these notifications are triggered contextually and appropriately. This structure is conceptually presented in Fig 4.

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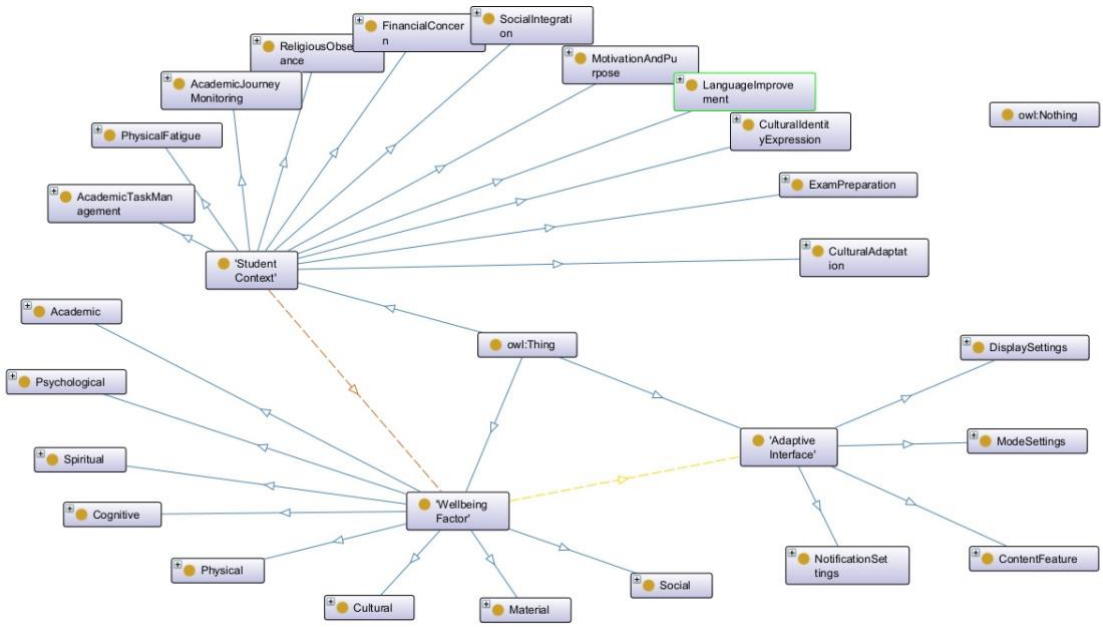

Fig 4. Adaptive User Interface is Structured within The Academic Smartphone Application

DisplaySettings manages the visual presentation to enhance comfort and convey information intuitively. This goes beyond simple brightness and includes dynamically changing button backgrounds, such as a "Transcript" button turning red for a low GPA, and adapting the entire app background with cultural ornaments based on the student's home region. It also governs the visual state of the "Achievement Bar" to reflect academic progress. These adaptations are directly linked to wellbeing factors through explicit ontological relationships, ensuring visual cues are always relevant to the student's state.

ModeSettings allows the application to switch between operational modes tailored to the student's activity. This includes activating a "Focus Mode" during exam periods to minimize distractions and support concentration, or a potential "Relaxation Mode" that could present calming visuals and link to meditation resources when a student reports high stress levels. The logical consistency of mode transitions is maintained by the ontology, preventing conflicting adaptations.

Specific context classes, such as *ExamPeriod*, *FinancialStrain*, and *CulturalIdentity*, link directly to these settings via object properties. For example, the *ExamPeriod* context triggers adaptations in all three categories: *ModeSettings* activates study mode, *DisplaySettings* might dim the screen, and *NotificationSettings* will silence non-essential alerts. This multi-faceted approach ensures the application dynamically adjusts to support the student's holistic needs, creating a responsive digital environment that actively contributes to their wellbeing. The formal definition of these classes and properties in OWL enables sophisticated reasoning about how different

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contexts necessitate specific combinations of UI adaptations, ensuring the coherence and consistency of the overall adaptive behavior, thereby showcasing a state-of-the-art method for structuring knowledge in adaptive systems.

The formal validation of the ontology using the HermiT reasoner represents a pivotal contribution to knowledge of this research. This conclusively confirms that the model is both "coherent and consistent," as demonstrated by the validation output in Fig 5.

Fig 5. Context Ontology Validation for Adaptive User Interface

D. Discussions and Key Finding

The operational framework of this system is centered on a Semantic Taxonomy that formalizes qualitative wellbeing requirements into a machine-readable knowledge base. Unlike the context-driven interfaces proposed by Ali et al.[1] or the preference-based policies [2], in which often rely on manual declarative rules [26], our framework utilizes a semantic reasoner to automate complex interdependencies. The retrieval process utilizes SPARQL to infer nuanced relationships rather than simple data lookups, aligning the study with modern advancements in knowledge graph integration and context-aware messaging [27]. By moving beyond these rigid structures, the proposed framework overcomes the maintenance and scalability issues typically associated with rule-based systems [28].

A pivotal contribution of this research is the formal validation conducted using the HermiT reasoner, which guarantees a consistent and contradiction-free model. This level of rigor addresses a common gap in adaptive system design, where explicit and rigorous formal validation is not always documented to the same degree [29], [30]. Such transparency is essential for the ethical deployment of AI in sensitive areas like student wellbeing, where current reviews highlight persistent challenges in interpretability and ethical considerations [31], [32]. While many platforms in the literature review, such as the one by Thuan et al. [33], prioritize only academic performance or basic user preferences, our framework extends the state-of-the-art by integrating the multidimensional wellbeing factors (spiritual and cultural) identified by Zuhdi and Syarief [6].

Despite these contributions, the current study is limited to the conceptual and formal logical validation of the ontology. While the HermiT reasoner proves the model is free of logical contradictions, it is crucial to acknowledge that logical consistency does not automatically

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guarantee user effectiveness in practice. Future research must prioritize integrating this framework into a live mobile application to evaluate its real-world psychological impact. Specifically, longitudinal studies and User Experience (UX) testing with real Indonesian students are necessary to empirically validate whether these UI adaptations (such as triggering 'Focus Mode') genuinely reduce academic stress and improve subjective wellbeing. Additionally, incorporating more granular biometric or environmental data could further refine the system's personalization capabilities.

IV. CONCLUSION

This research successfully achieved its objective of systematically translating qualitative Indonesian student wellbeing requirements into a formal, computationally tractable semantic framework. The methodology involved the development of a detailed "Context Mapping" table to establish relational scenarios, followed by the engineering of a Semantic Taxonomy using the Web Ontology Language (OWL) to formalize these relationships into a class hierarchy with defined object properties. The resulting knowledge graph was made explicitly queryable via the SPARQL Protocol, allowing for relational data retrieval. The culminating phase of this investigation was the formal validation using the HermiT reasoner within Protégé, which confirmed that the developed Context Ontology is both coherent and consistent. This outcome substantiates that the complex, multi-dimensional requirements for a context-aware student wellbeing application have been successfully modelled into a logically sound, robust, and scalable framework, thereby validating its suitability for deployment in a live system and advancing the field of adaptive user interfaces for wellbeing, especially within the Indonesian educational context. Furthermore, future implementation must address potential computational overheads on mobile devices by optimizing OWL reasoning or adopting cloud-based SPARQL processing to ensure real-time responsiveness without compromising smartphone resources.

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All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare that there is no conflict of interest between the authors or with the research object in this paper.

Data Availability: The semantic taxonomy data, OWL ontology models, and SPARQL queries generated during this study are available from the corresponding author upon reasonable request to support further research and reproduction of the results.

Informed Consent: There were no human subjects involved in the formal modeling and reasoning phases of this study.

Animal Subjects: There were no animal subjects involved in this research.

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