A Data-Driven Design Module Development for Enhancing Multi-Attribute Decision-Making (MADM) Efficacy

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***Abstract*—The development of decision-making modules that leverage data-driven design principles is crucial for enhancing the efficacy of multi-attribute decision-making (MADM) systems. This paper discussed modules, focusing on the integration of diverse attributes into the decision-making process. Five distinct modules are proposed within this framework, each tailored to address specific aspects of MADM, thereby offering a comprehensive approach to decision support. The proposed modules are conceptualized based on a thorough analysis of existing data-driven design methodologies and MADM theories, ensuring their relevance and applicability to real-world decision-making scenarios. The effectiveness and validity of the proposed framework and its modules are assessed through expert reviews. These reviews involve subject matter experts evaluating the content structure, usability, and applicability of the modules in various decision-making contexts. The feedback obtained from these reviews is integral to refining the modules, ensuring their alignment with the needs and expectations of end-users. For practitioners, the framework provides a structured approach to developing decision-making modules that are both robust and adaptable, capable of accommodating a wide range of decision attributes. For researchers, it offers a conceptual and methodological foundation for further exploration into data-driven design and its application in MADM. This paper contributes to the evolving field of decision support systems, highlighting the importance of structured content development in enhancing the decision-making capabilities of organizations and individuals alike.**

***Index Terms*—Data-Driven Design, Engineering Education, MADM, Decision Making, Module Development**

I. Introduction

In the contemporary landscape, the acquisition and refinement of decision-making skills are paramount for individuals and organizations alike. Industries across the spectrum, from business and technology to healthcare and beyond, require professionals who can navigate complex scenarios and make informed choices to drive success [1]. Traditional decision-making approaches often fall short when confronted with situations involving multiple attributes, such as cost, quality, time, and risk [2]. Recognizing the evolving demands of various sectors, it becomes imperative for students to cultivate skills in multi-attribute decision-making, especially in fields like product design [3]. The intricate nature of product design involves juggling numerous factors, including functionality, aesthetics, and sustainability. Therefore, empowering students with the ability to employ multi-attribute decision-making methodologies not only aligns with industry needs but also equips them with a strategic advantage in navigating the complexities inherent in modern design challenges.

This paper aims to offer an overview of the design and development of a data-driven design module, emphasizing the significance of data-driven design and the students' ability to make decisions amidst uncertain design attributes. The remainder of the paper is structured as follows: Section II introduces our literature review on data-driven design. In Section III, the overview of the design and development of our module. Finally, Section IV presents the findings from expert validation, focusing on the criteria used to develop an appropriate teaching module.

II. Literature Review: Data Driven Design

Data-driven design is important because it allows UX designers to make more accurate predictions about user preferences based on past trends [4]. It also helps in identifying unforeseen competitive advantages and tailoring products and services to meet customer needs, thereby enhancing customer experiences [5]. Data-driven design can also help in mitigating risks by detecting anomalies in user satisfaction before they become unmanageable [6]. Additionally, data-driven design enables the generation of design solutions, optimization, evaluation, and retrieval by utilizing deep learning algorithms and historical design process data. It supports intelligent and innovative design activities and has the potential to create new or improved products and services, build customer relationships, adapt to business reconfiguration, and address societal challenges . Furthermore, data-driven design in molecular docking facilitates large-scale screening of associations between small organic molecules and protein targets, leading to the development of practical applications in rational drug design. Finally, data-driven design allows for the engineering

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of new protein-protein interactions with controlled specificity and selectivity, enabling the design of new interacting protein pairs .

III. Instructional Framework for MADM in Data-Driven Product Design

This module is an expansive extension of the core concepts presented in the book "Optimizing Product-Service Bundle Design: A Guide to Design Analysis and Decision Making." [7]. The module enriches the fundamental ideas of the book by offering a structured, in-depth educational experience that immerses students in the practical aspects of data-driven decision-making in product design. Drawing upon the book's thorough exploration of optimizing product-service bundles through analytical and decision-making strategies, the module expands these concepts into a comprehensive curriculum. It is meticulously crafted to not only convey theoretical knowledge but to also provide hands-on application through real-world case studies, practical exercises, and the use of modern statistical tools and software. This module is ideal for undergraduate students, especially those in fields related to product design, engineering, and business, this module also serves as an excellent foundation for capstone projects where students can apply MADM methodologies to real-world problems. The course's practical orientation ensures that students not only grasp theoretical concepts but also develop the ability to apply these concepts in practical scenarios, a skill highly valued in the professional world.

A. Description of Proposed Modules

This module consists of five separate but interconnected sections that provide a comprehensive examination of MADM principles and their practical implementations in product design and analysis. The training is divided into seven weeks to ensure a comprehensive understanding of each component of MADM. The following presented the description of content for each modules:

i. **Module 1: Introduction to MADM and Data-Driven Design**

This module provides a foundational overview of MADM and its pivotal role in decision-making processes within product development. This module is designed to familiarize students with the fundamental concepts of MADM, a decision-making framework that evaluates multiple criteria to make informed choices, especially relevant in complex scenarios such as product design.The module begins by detailing the principles of MADM, highlighting how it allows for a structured approach to decision-making by considering various attributes and criteria. This methodical process is essential in evaluating complex products where multiple factors must be weighed simultaneously. The instruction then shifts to the concept of data-driven design, an approach that relies heavily on data analysis and empirical evidence to guide design decisions. This part of the module demonstrates how data-driven design leads to more effective, user-centered products, as it bases design choices on actual user needs and preferences derived from data. Overall, this introductory module sets the stage for a deeper understanding of how MADM can be applied in the realm of product design and development. It underscores the transition from intuition-based to data-driven methodologies, showing how these modern approaches lead to more efficient, effective, and user- friendly products. The learning outcome for this module involve,
(i) Understand the basic principles of MADM
(ii) Recognize the role of MADM in making informed design decisions. (iii) Appreciate the importance of a data-driven approach in product design.

ii. **Module 2: Understanding Attributes and Criteria**

This module is specifically designed to equip students with the knowledge and skills necessary to identify and understand the various attributes and criteria that are essential in evaluating and comparing different products. The module starts by providing clear definitions and examples of what constitutes an attribute and a criterion in the realm of product analysis. Attributes are the different features, characteristics, or aspects of a product that can be measured or assessed, such as durability, cost, efficiency, or aesthetic appeal. Criteria, on the other hand, refer to the standards or benchmarks used to evaluate these attributes, which can vary depending on the product's intended use, target market, or specific requirements. Students are then guided on how to select the most relevant attributes for different types of products. This involves understanding the product's purpose, the needs and preferences of its intended users, and the context in which the product will be used. The module emphasizes the importance of choosing attributes that are significant and meaningful to the product's overall performance and appeal, ensuring that the MADM process is both effective and relevant. Through this module, students gain a comprehensive understanding of how to critically analyze and select attributes and criteria, a foundational skill in applying MADM for product evaluation and decision-making. This knowledge is crucial for making informed and objective assessments of products, leading to better design and development outcomes.

iii. **Module 3: Data Collection Methods**

This module is designed to provide students with comprehensive insights into various data collection methods and to underscore the importance of quality and relevance in the data collected. The module begins by instructing students on a range of data collection techniques, each crucial for gathering the

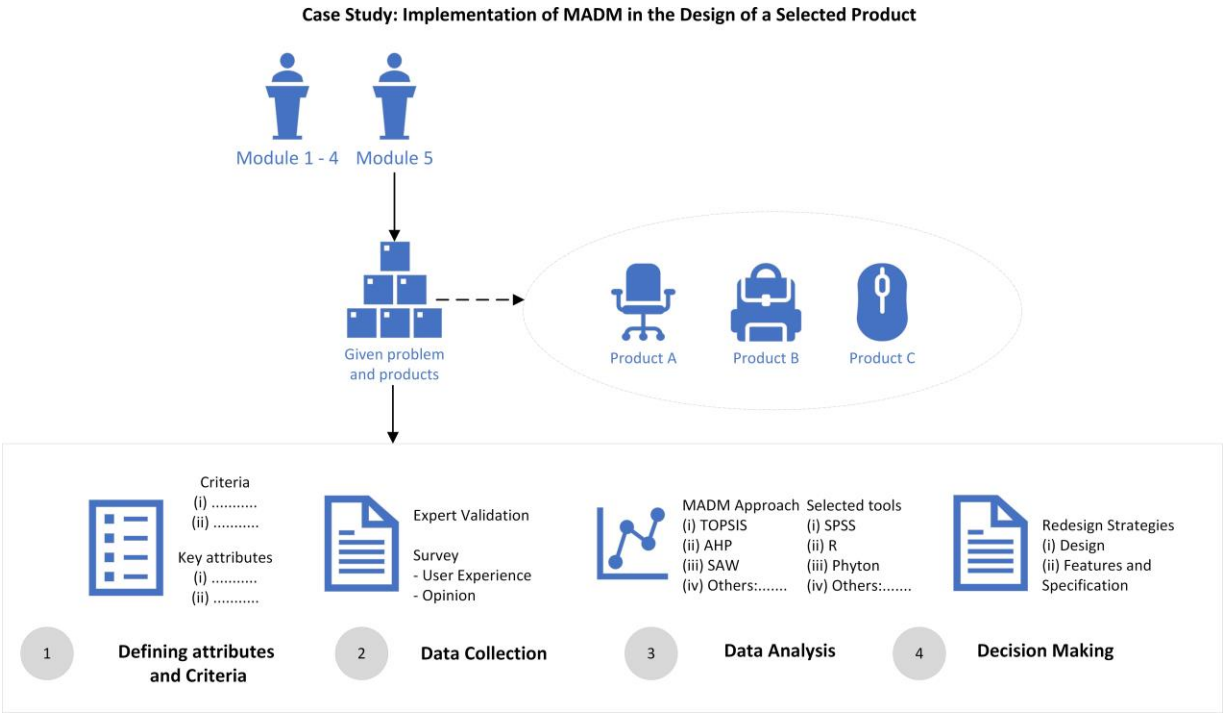

Fig. 1. The overview of methodology for the case study implementation

information necessary to make informed decisions in MADM processes. Key methods covered include surveys, which are useful for collecting quantitative data from a large audience; focus groups, which provide qualitative insights and in-depth discussions; and A/B testing, a method particularly effective in comparing two versions of a product to determine which performs better among the target audience. Other methods such as interviews, observational studies, and user testing may also be explored to provide a broad perspective on data collection. An essential focus of this module is on the importance of data quality and relevance. Students learn that the reliability of MADM outcomes heavily depends on the accuracy, consistency, and pertinence of the data collected. Quality data ensures that the decision-making process is based on sound, verifiable information, while the relevance of data ensures that the attributes and criteria being evaluated are directly aligned with the product's goals and user needs. Throughout the module, students engage in practical exercises and case studies, applying different data collection methods in simulated product evaluation scenarios. This hands-on approach not only reinforces theoretical knowledge but also hones the practical skills necessary for effective data gathering in real-world situations.

iv. **Module 4: Data Analysis Techniques**

This module aims to introduce students to the various statistical tools and software used in data analysis, and to provide practical experience in analyzing data to extract meaningful insights, particularly focusing on product attributes. The module begins with an overview of statistical concepts and techniques essential for data analysis in the context of product evaluation. This includes fundamental statistical measures like mean, median, mode, variance, and standard deviation, along with more advanced concepts such as regression analysis, hypothesis testing, and correlation analysis. Students are also introduced to statistical software and tools commonly used in data analysis, such as SPSS, SAS, R, Python, and Excel. However, the module will provide demonstration of how R tool can be used to process and analyze data effectively. A significant part of the module is dedicated to practical exercises where students apply these statistical techniques to real or simulated data sets. These exercises are designed to help students understand how to interpret data, identify patterns and trends, and make inferences about product attributes and user preferences. For instance, students might analyze survey data to determine the most valued features in a product or use A/B testing results to decide which product version is more effective. The module also emphasizes the importance of drawing meaningful and actionable insights from data analysis. Students learn to go beyond mere number-crunching, understanding how to translate statistical findings into practical recommendations for product design and improvement. This involves learning how to effectively communicate these insights, both in written and visual formats, making the data

understandable and compelling for different stakeholders.

v. **Module 5: Case Study Analysis**

This module is structured to provide students with a deep dive into various case studies where MADM principles have been successfully applied, giving them insights into practical, data-driven decision-making processes in product design. The primary objective of this module is to present a series of real-world case studies that illustrate the use of MADM in the context of product design. These case studies are selected from diverse industries to showcase a wide range of applications and complexities involved in product design decisions. Through these cases, students are exposed to the nuances of how attributes and criteria are identified, weighted, and analyzed to make informed decisions in the design and development of products. A critical component of the module is the analysis of the decision-making process detailed in each case study. Students are guided through a thorough examination of how data was collected, analyzed, and utilized to influence design choices. This includes understanding how different attributes were prioritized, the challenges encountered in the decision-making process, and the outcomes of these decisions. By analyzing these real-world applications, students gain a practical understanding of how MADM tools and techniques are applied in professional settings. They learn to appreciate the role of data in making informed decisions and how a structured approach like MADM can lead to better design outcomes. This module not only reinforces the theoretical knowledge gained in earlier modules but also enhances students' analytical and critical thinking skills, preparing them for real-world challenges in product design and development.

B. Assessment for the Proposed Modules

This modules incorporates a comprehensive evaluation strategy to assess student understanding and proficiency across various modules. Each module is designed with specific evaluation methods to effectively gauge the students' grasp of the course material, their practical application skills, and their analytical abilities. This approach ensures that students are not only tested on their theoretical knowledge but are also evaluated on their ability to apply these concepts in real-world scenarios.

TABLE I
ASSESSMENT FOR THE PROPOSED MODULES

Module	Assessment Methods
Module 1: Introduction to MADM and Data-Driven Design	Quizzes on key concepts; Reflection paper on the importance of data-driven decision-making.
Module 2: Understanding Attributes and Criteria	Case study analysis to identify key attributes; Participation in class discussions.
Module 3: Data Collection Methods	Practical exercise on conducting surveys; Presentation on data collection strategy.
Module 4: Data Analysis Techniques	Lab assignments using statistical software; Data analysis report on a given data set.
Module 5: Case Study Analysis	Group project on analyzing a real-world case study; Peer evaluation of group project contributions.

C. Overall Skills Gained in Data-Driven Design

This is designed to equip students with a suite of crucial data-driven skills, each module targeting specific competencies integral to modern product design and analysis. Table II presented the expected outcome for each of the module. The course's structure – from theoretical foundations to practical application – is meticulously designed to equip students with a comprehensive skill set in data-driven design. This approach is not only relevant but essential in a world where data is increasingly the cornerstone of innovation, efficiency, and market responsiveness in product development. The course ensures that students are not merely consumers of data but are adept at harnessing it to drive forward-thinking, evidence-based decisions in product design.

TABLE II
EXPECTED OUTCOMES OF MADM IN PRODUCT DESIGN MODULES

Module	Expected Outcomes
Module 1: Introduction to MADM and Data-Driven Design	- Understanding of MADM Concepts: Fundamental grasp of MADM and its application in decision-making. - Appreciation of Data-Driven Design: Recognition of how data-driven decisions enhance product quality and user satisfaction.
Module 2: Understanding Attributes and Criteria	- Identification of Attributes and Criteria: Ability to define and exemplify relevant attributes and criteria. - Attribute Selection Skills: Skill to select pertinent attributes for various products.
Module 3: Data Collection Methods	- Proficiency in Data Collection: Knowledge of diverse data collection methods. - Understanding Data Quality and Relevance: Ability to assess the quality and relevance of collected data.
Module 4: Data Analysis Techniques	- Data Analysis Skills: Proficiency in using statistical tools and software for data analysis. - Insight Extraction Ability: Capability to analyze data and extract meaningful insights.
Module 5: Case Study Analysis	- Application of MADM in Real-World Scenarios: Understanding of applying MADM in real-world product design. - Analytical and Critical Thinking: Enhanced skills in analyzing decision-making processes and understanding the role of data.

In the conclusion, the key competencies emphasized in the curriculum are designed to empower professionals with a comprehensive skill set. This includes Strategic Decision-Making, where individuals gain the ability to make informed and strategic decisions in product design. Data Literacy is another crucial area, focusing on developing proficiency in interpreting and analyzing data effectively. The curriculum also emphasizes the importance of Critical Evaluation, equipping learners with the skills needed to critically evaluate various design alternatives. Problem-Solving is addressed through

enhanced abilities to utilize data-driven insights for effective resolution of complex issues. Effective Communication is another focal point, enabling individuals to clearly articulate their data analysis findings and the rationale behind their decisions. Lastly, Adaptability is highlighted as a key skill, fostering flexibility in professionals to adeptly adapt to a range of data-driven tools and methodologies. This comprehensive approach ensures a well-rounded development of essential skills for modern professionals.

IV. Content Structure Validation

The content structure validation for the module was conducted through an expert review process involving five distinguished professionals. This panel was carefully chosen to encompass a broad range of relevant expertise and perspectives. It included two mechanical engineering lecturers, renowned for their extensive knowledge and practical experience in data-driven design and decision-making within the engineering field. Their academic and research backgrounds provided invaluable insights into the theoretical and applied aspects of the module. Additionally, a seasoned product designer was part of the panel, bringing a hands-on perspective on how multi-attribute decision-making is integral in real-world design processes. This professional's input was crucial in ensuring that the content was not only academically sound but also practically relevant. Completing the panel were two educational instructors, specialists in curriculum development and pedagogical strategies. Their expertise was essential in evaluating the module's educational structure, ensuring that the content was effectively organized and pedagogically sound for learners. Together, these experts engaged in a comprehensive review process, providing detailed feedback and recommendations to refine the module, thereby enhancing its accuracy, relevance, and educational value.

TABLE III
Consensus for Reaction

No	Reaction	Mean	SD
1	The content structure appears logically organized and coherent.	3.8	0.84
2	The proposed module is visually and aesthetically well-presented.	3.8	0.84
3	The content seems relevant and applicable to the field of data-driven design.	3.6	0.89
4	Case studies and examples provided are appropriate and enhance understanding.	3.8	0.84

Within the domain of educational modules for data-driven design, a meticulous analysis of the 'Learning' dimension has yielded notable results as shown in Table IV. The module's comprehensive coverage of essential concepts related to multi-attribute decision-making is acknowledged with an average rating of 4.0, and a standard deviation of 0.71, reflecting a high level of agreement on its breadth and relevance. Parallel to this, the module's effectiveness in providing a thorough and clear understanding of the subject matter is also recognized with a mean score of 4.0, paired with a standard deviation of 0.71, which further attests to the module's clarity and pedagogical soundness. Importantly, the elucidation of key concepts with adequate depth was uniformly rated, achieving a mean of 4.0 and a standard deviation of 0.71, reinforcing the notion that the module successfully imparts critical knowledge with precision. Moreover, the module's content structure, particularly in facilitating ease of navigation and learning, stood out with a higher mean score of 4.6 and a lower standard deviation of 0.55, indicating a strong consensus on its user-friendly design and its role in enhancing the learning experience. These findings collectively suggest that the module is highly effective in fostering learning, with a consistently positive reception across varied pedagogical facets, making it a significant contribution to educational resources in the field of data-driven design.

TABLE IV
Consensus for Learning

No	Learning	Mean	SD
1	The proposed module covers all essential concepts of multi-attribute decision-making in a data-driven design context.	4.0	0.71
2	It provides a thorough and clear understanding of the subject matter.	4.0	0.71
3	Key concepts are well-defined and explained with sufficient depth.	4.0	0.71
4	The content structure facilitates easy navigation and learning.	4.6	0.55

In a critical assessment of a pedagogical module aimed at enhancing data-driven design practices, the evaluative data reflects a positive reception in the behavior category as shown in Table V. Participants rated the module's potential to influence best practices highly, with a mean score of 4.4 and a standard deviation of 0.89, highlighting a strong but varied recognition of its impact. The encouragement of practical application of theoretical concepts garnered a mean score of 4.2, with a lower standard deviation of 0.71, indicating a more unified agreement on its effectiveness in real-world applications. Notably, the module's integration with existing methodologies and tools was met with the highest approval, receiving a mean score of 4.6 and the lowest standard deviation of 0.55, underscoring a widespread consensus on its seamless fit within the current professional ecosystem. However, the module's role in promoting critical thinking and innovation in decision-making received a somewhat moderate mean score of 3.6, with the standard deviation 0.89, suggesting a need for further investigation into this aspect.

The data collectively suggest that the module is well-received for its practical utility and integration within the existing framework of the field, with room for enhancing its influence on critical thinking and innovative practices as observed in the feedback. This feedback is pivotal for the continuous refinement of the module to ensure it not only aligns with industry standards but also fosters a progressive learning environment for professionals in the field. The consensus among participants indicates a strong endorsement of the module's effectiveness across various dimensions critical to educational success in data-driven design. The standard deviation values reflect a moderate agreement among the respondents on the

module's benefits, with the highest consistency observed in its ability to integrate with existing methodologies (SD = 0.55). The variation in scores, especially the higher standard deviation seen in the module's influence on best practices and its promotion of critical thinking (SD = 0.89), suggests areas for further refinement and investigation. The relatively lower mean score for promoting critical thinking highlights an opportunity for enhancing this aspect to foster more innovative approaches in decision-making.

TABLE V
CONSENSUS FOR BEHAVIOUR

No	Behaviour	Mean	SD
1	The proposed module seems likely to influence best practices in data-driven design.	4.4	0.89
2	It encourages the practical application of concepts in real-world scenarios.	4.2	0.71
3	The content appears to integrate well with existing methodologies and tools in the field.	4.6	0.55
4	It promotes critical thinking and innovative approaches in decision-making.	3.6	0.89

In the recent evaluation of a novel educational module aimed at enhancing professional practices within the realm of data-driven design, the aggregated feedback from various respondents has yielded promising insights as presented in Table VI. The module's potential to substantially influence professional practices garnered a mean score of 4.0, indicative of a strong consensus on its impactful nature, although the standard deviation of 1.0 reflects a broader dispersion of opinions. More strikingly, the likelihood of the module to foster improved decision-making outcomes was received more favorably, with a mean score of 4.4 and a marginally lower standard deviation of 0.89, signaling a robust confidence in its efficacy. Furthermore, the module's structure was commended for its conduciveness to continuous learning and adaptability in the field, achieving a mean score of 3.8 and a standard deviation of 0.84. Finally, it was perceived as a significant addition to the existing literature and resources in the domain, with a mean score of 3.6 and the smallest standard deviation of 0.55, underlining the highest level of agreement among the respondents. Collectively, these metrics not only underscore the module's anticipated positive impact but also highlight its role as a catalyst for ongoing professional development and enhancement of data-driven methodologies.

TABLE VI
CONSENSUS FOR RESULTS

No	Results	Mean	SD
1	The proposed module has the potential to significantly impact professional practices in data-driven design.	4.0	1.0
2	It is likely to contribute to improved decision-making outcomes.	4.4	0.89
3	The structure is conducive to ongoing learning and adaptation in the field.	3.8	0.84
4	This content structure is a valuable addition to the existing literature and resources in data-driven design	3.6	0.55

V. CONCLUSION

In conclusion, the development and implementation of the data-driven design module, bridges the gap between theoretical knowledge and practical application, providing students with an immersive educational experience that emphasizes the importance of data-driven decision-making in the modern design landscape. Expert reviews have highlighted the module's comprehensive curriculum, which effectively integrates theoretical insights with practical application through case studies, exercises, and the use of advanced statistical tools. However, they also suggest areas for improvement, particularly in enhancing the module's adaptability to rapidly evolving design technologies and methodologies. Addressing these feedback points is essential for ensuring that the module remains relevant and continues to meet the changing needs of the industry and student body. The implications of this module for the product design industry are profound. By equipping students with the skills to apply multi-attribute decision-making methodologies effectively, the module contributes to the cultivation of a new generation of designers who are not only technically proficient but also adept at making informed, strategic decisions in complex scenarios. This shift is likely to drive innovation and efficiency in product design and development processes, ultimately benefiting the industry at large.

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