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Scientific Creativity in TVET Product Design: Integrating Scientific Knowledge and Imagination

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Abstract

Technical and Vocational Education and Training (TVET) faces a pressing need to adapt its curriculum to the demands of Industry 4.0, particularly in product design. While creativity is recognized as a crucial skill, there remains a gap in the literature regarding validating instruments for measuring scientific creativity in this context. This study aims to address this gap by developing and validating an instrument to measure scientific creativity by integrating scientific knowledge and imagination in product design for TVET teachers in Malaysia. The instrument was then subjected to content validation by eight experts. The item content validity index (I-CVI) and the scale content validity index (S-CVI) were used to determine content validity. Findings indicate strong content validity for both constructs and scientific creativity with high levels of agreement among experts. The item's content validity index (I-CVI) ranged from 0.99 to 0.96 and the scale content validity index (S-CVI/AV) for each construct was 0.99 for the scientific knowledge construct, and 0.96 for the imagination construct. This range is valid and appropriate for developing the instruments. However, some items required refinement to enhance content validity further. This study contributes to the literature by providing a reliable instrument developed to the specific needs of TVET teachers in Malaysia, thereby filling a critical gap in the assessment of scientific creativity in product design.

1. Introduction

The advent of Industry 4.0 (I4.0) necessitates a reevaluation of the skills and competencies taught in Technical and Vocational Education and Training (TVET), particularly in the field of product design (Ismail & Hassan, 2019). With ongoing technological advancements and the increasing impact of globalization, product design has transformed from merely an art and craft activity into a comprehensive innovation process that incorporates interdisciplinary knowledge from fields like computer science, mathematics, and physics (Wang & Yao, 2024). As product designs become increasingly essential to fulfilling human needs and gaining widespread growth worldwide (Saleh et al.,2020), it is crucial to incorporate skills such as adaptability, critical thinking, problem-solving, and digital literacy into the TVET curriculum (Adnan et al, 2021) to provide students for dynamic industries and future technological advancements.

Furthermore, educators must emphasize creativity skills, as creativity is a crucial 21st-century attribute essential for innovation and holistic development in TVET (Madar et al., 2019; Zhao, 2019). In the context of product design, creativity can be developed into scientific creativity if it involves specific domains such as science, mathematics, engineering, and so on (Tran et al., 2021). Thus, scientific creativity is pertinent to the development of product design (Chen et al., 2023; Cheng et al., 2022; Gök & Sürmeli, 2022). By fostering scientific creativity in TVET programs, educators can equip students with the skills needed for I4.0, helping them design innovative and user-focused products that address complex challenges. This method ensures that students are not merely passive learners; instead, they are active designers who possess the ability to make beneficial contributions to dynamic industries that are heavily impacted by technology.

However, TVET product-design learning often treats creativity as a generic skill rather than as scientific creativity that intentionally integrates disciplinary knowledge (science, mathematics, engineering) with imagination. This misalignment results in a poor transfer of scientific principles to design requirements, restricts independent ideation and problem-solving, and yields product outcomes that fall below standards or lack sufficient innovation. In Malaysia, integrating scientific creativity into TVET curricula remains challenging. According to Uyub et al. (2021), students' product design in Design and Technology (D&T) was often incomplete or below standard due to insufficient knowledge and application skills, which in turn restricts problem-solving and independent idea generation. This constraint, combined with an inability to apply scientific knowledge, limited creativity and led to less engaging and innovative product solutions. Similarly, Hashim et al. (2021) observed that students, especially those with weaker academic backgrounds, often faced challenges when attempting to use their scientific knowledge in product design. These issues mostly came from their failure to comprehend design requirements and effectively incorporate scientific concepts. Moreover, Tze Kiong et al. (2020) highlighted that many D&T teachers in Malaysia reported a lack of confidence in teaching imagination techniques, which is crucial for fostering creative thinking in students. Consequently, students' imaginative capacity, especially the ability to generate scientifically coherent, novel ideas connected to everyday contexts, remains underdeveloped, hindering their performance in product design learning.

International studies highlight significant challenges in fostering scientific creativity in TVET product design. In Indonesia, Hamdani & Suherman (2021) discovered that vocational students faced challenges due to a lack of adequate scientific knowledge. This resulted in project delays and failures, highlighting the necessity for implementing a more systematic approach to project-based learning to improve problem-solving and design abilities. Similarly, Oyebola et al. (2018) observed that Nigerian students relied more on practical experience and intuition rather than creative brainstorming and scientific investigation. This preference hinders creativity and restricts the possibility of making substantial advancements. The study highlights the importance of incorporating scientific knowledge into curricula to foster scientific creativity. According to Chystiakova (2017), in Ukraine, students' ability to effectively apply scientific knowledge in design projects was frequently hindered by teachers' insufficient methodological expertise. This emphasizes the crucial importance of teacher training in fostering scientific creativity. In addition, Atamtajani et al. (2020) observed that traditional instruction methods in Indonesia frequently resulted in passive learning, where students simply followed instructions without actively using their imagination to generate ideas or solve problems. This hindered innovation and led to less effective product designs. These challenges highlight the importance of combining scientific knowledge and imagination, particularly in the context of Industry 4.0 to ensure that TVET students have the skills necessary to compete in an increasingly complex and technologically advanced global marketplace.

Effective product design necessitates a blend of scientific creativity, drawing upon a foundation of scientific knowledge (Yu et al., 2020), with the boundless possibilities of imagination (Sica et al.,2023). By combining scientific knowledge with imagination, designers have the power to create products that not only meet the needs of society but also anticipate future demands (Hui et al.,2020). This approach equips students with the capacity to envision and implement novel ideas, leveraging their understanding of scientific principles to develop practical solutions. Students are typically encouraged to design solutions to various problems (Omar et al.,2018) to enhance their creativity and problem-solving skills. Moreover, the ability to think outside the box and explore unconventional approaches is instrumental in generating breakthrough designs that potentially revolutionize various industries (Pedota & Piscitello, 2022) as it stimulates creativity by challenging norms and broadening the range of possibilities.

Although scientific creativity is such a complex skill and is often ignored by teachers during teaching activities (Rasul et al.,2018), fostering it among teachers cannot be underestimated (Rosa & Mujiarto, 2020). Teachers play a crucial role in cultivating creativity among students, as well as promoting innovation and problem-solving skills necessary for their future careers (Částková & Kropáč, 2020). Teachers in TVET need to embrace innovative teaching methods and create a conducive environment that encourages students to think creatively, explore new ideas, and develop innovative solutions (Asykin et al., 2019). By incorporating various sources of inspiration, such as real-world examples, practical projects, and collaborative learning experiences, teachers can ignite the creative spark in their students (Hero & Lindfors, 2019) to apply their knowledge and skills in a novel way. Teachers must be well-prepared to foster scientific creativity in product design. They need to promote imaginative thinking while applying scientific knowledge in the classroom. Thus, instruments serve as a measurement tool and enable researchers to collect data and information systematically and objectively (Sturm & Ash, 2005).

However, among the problems that existed with the instrument before are i) available instruments were not yet well established; as an indication that scientific creativity was a relatively new and exciting topic for further study (Wiyanto et al., 2020) and most of the instruments that are developed only focus on the instrument's reliability value instead of content validity which is one of the main validity in developing instruments (Connell et al., 2018). Although content validation calculation is important, few articles conduct this process (DeVellis, 2021; Hadzaman et al., 2018; Zamanzadeh et al., 2015). Consequently, this study aims to develop and validate a reliable instrument to measure scientific creativity by integrating scientific knowledge and imagination in product design for TVET teachers and report the steps of content validity calculation. In addition, the significance of this research is to ensure the instruments developed can serve the purpose and measure the intention of the TVET teachers for the adoption of scientific creativity in product design.

2. Literature Review

2.1 Content Validation

Content validation is a crucial process that evaluates the degree to which the elements of an assessment instrument accurately represent and are relevant to the targeted construct or concept being measured (Haynes et al., 1995; Cook & Beckman, 2006). Higher levels of content validity in an instrument indicate greater precision in measuring the intended construct (Devon et al., 2007). For an instrument to be considered valid, it must be simple, affordable, unbiased, appropriate for the problem under study, have clearly defined dimensions, and adequately reflect the concept it intends to measure (Luque-Vara et al., 2020).

Content validation is an important step in the assessment process that ensures the instrument is valid, equitable, and effectively measures the intended construct (Talaee et al., 2022). By validating the content, researchers can confirm that the items in the instrument align with the constructs they intend to measure (Mohamad et al., 2015). According to Ranganathan et al. (2024), this process involves a comprehensive review and validation of each item to guarantee they accurately represent the study's intended objectives. Content validation is important to ensure an instrument is valid, equitable, and effectively measures the intended construct.

The standard procedure for assessing content validity involves consulting experts in the relevant field (Sireci, 1998). Expert judgment refers to the well-informed opinions of individuals recognized as qualified experts in their field, who can offer valuable information, evidence, judgments, and assessments (Shrotryia & Dhanda, 2019). This technique calculates a content validity index (CVI) using rigorous statistical methods and an appropriate methodology (Sireci, 1998), ensuring the instrument can be used for its intended purpose.

An instrument must undergo content validation to ensure it contains a suitable selection of items for evaluating the content validity index (CVI) (DeVellis, 2021). The CVI is divided into two types: the I-CVI, which measures the content validity of individual items, and the S-CVI, which calculates the content validity of the overall scale (Hadi et al., 2023). The content validation process involves several steps, including preparing the content validation form, selecting a review panel of experts, conducting the validation, reviewing constructs and items, providing scores for each item, and calculating the CVI (Yusoff, 2019).

Consequently, content validity serves as the primary indicator of how well the content is developed (Polit & Beck, 2006). Good content validity implies that the instruments are well-developed and align with current evidence and best practices (Yusoff, 2019). In this study, by ensuring content validity, teachers can have confidence that the instrument comprehensively and accurately covers the intended topics, laying a solid foundation for effective learning and knowledge acquisition.

2.2 Scientific Creativity in Product Design

Traditionally, TVET has focused on teaching foundational skills and knowledge specific to a particular trade or industry (Ramamuruthy et al., 2020). However, with the emergence of I4.0, which emphasizes the integration of humans and technology, there is a need for a more holistic approach to product design education (Fotouhi & Sorooshian, 2020). Designing products in TVET entails not only the application of technical skills (Terzioğlu & Wever, 2021) but also the cultivation of imagination (Hanafiah et al., 2020; Sejal et al., 2022), and innovative problem-solving abilities by applying scientific knowledge (Ghazali & Zbiec, 2022). As Zhang et al. (2024) highlighted, the ability to design products is related to scientific creativity.

Scientific knowledge is a construct combining the product dimension of scientific knowledge from the Scientific Creativity Structure Model (SCSM) (Hu & Adey, 2002) and the Model of Scientific Creativity (MSC) (Park, 2004), which forms the construct of "Scientific Knowledge". Scientific knowledge is creative thinking that depends on aspects of scientific content knowledge, such as biology, physics, or even chemistry, as highlighted by MSC. According to Yu et al. (2020), it is the basic concepts of technology, engineering, and mathematics. In the context of scientific knowledge in product design, physics provides fundamental principles and an understanding of how different materials and forces interact (Zhang & Chen, 2016). While biology and chemistry are relevant, their direct applicability may not be as apparent (Shenvi, 2024). Hence, in this study, scientific knowledge refers to the application of physics, engineering, mathematics, and technology in product design. The construct "Imagination" from the process dimension, which is imagination from SSCM, refers to mental activity that involves the creation of new ideas that are consistent with scientific principles linked to daily life experiences (Zhu et al., 2023; Cheng et al., 2022; Wang et al., 2015; Chen, 2013).

Scientific knowledge is essential to produce a good design (Cheng et al., 2022; Gök & Sürmeli, 2022; Yu et al., 2020). Research has consistently highlighted the critical role of scientific knowledge in effective product design. A study by Ergül and Çalış (2021) emphasizes the necessity of scientific knowledge for realistic product design, which involves understanding material reactions and applying real-life problem-solving skills, requiring mathematical thinking beyond classroom teachings, accurate calculations, and proportional planning. Research by Lino Alves and Duarte (2023) further stresses the essential role of foundational knowledge in science, mathematics, and engineering, alongside material selection sensitivity, in crafting effective product designs with potential applications in engineering solutions (Kuppuswamy & Mhakure, 2020). However, product design is not merely a matter of scientific knowledge; imagination intertwines with scientific knowledge and experience, integrating emotional awareness, to creatively generate solutions and address challenges (Mun et al., 2015; Siew, 2017).

A study by Demetriou and Nicholl (2022) investigating the Designing Our Tomorrow (DOT) challenge, centered on crafting respirators for paediatric asthma patients, found that adopting a patient's perspective fosters imaginative, empathetic design solutions. Similarly, Chung et al. (2022) found that imagination contributes to enhancing students' abilities in designing wearable devices for pets, as evidenced by a study involving 40 third-year electronic science students in a technology-focused high school who utilized imagination in product design. Thus, effective product design requires a harmonious blend of scientific knowledge and imagination, enabling students to create innovative solutions that address real-world problems and meet the evolving needs of society.

Through literature review, it is evident that researchers have employed a combination of theoretical perspectives and experimental studies to gain a broader understanding of the implementation of scientific creativity by integrating scientific knowledge and imagination in product design. This implies that for a better understanding of fostering scientific creativity in product design, it is necessary to employ a comprehensive research context and relevant variables, following the proposed construct of scientific creativity for adoption. To achieve this, systematic methodological steps must be followed, as explained by Creswell and Creswell (2017) for quantitative research.

3. Methodology

3.1 Instrument Development

Scientific Creativity in Product Design for the TVET instrument was developed to measure two constructs: scientific knowledge and imagination. It consists of 24 items across these two constructs, scientific knowledge, and imagination, with 12 items each. The instrument was developed in the Malay language after conducting a systematic literature review on scientific creativity in product design. The instrument is specifically developed for the specific demographic of TVET teachers in Malaysia by being presented in the Malay language, which is the national language of this nation. This ensures that it effectively connects with the intended population and addresses a significant gap in existing literature. While other scales have broader applications, this instrument specifically focuses on the specific challenges encountered by TVET teachers in Malaysia. It provides an accurate instrument for assessing scientific knowledge and imagination in the context of product design.

To develop the instrument and combine the model, the researchers have conducted a systematic literature review on scientific creativity product design, especially in education. Exploring relevant literature involved searching through sources from Scopus, Web of Science (WOS), and Google Scholar using keywords including "engineering", "physics", "mathematics", "technology", “imagination”, “product design", "creativity" and "education". Rather than having predefined inclusion and exclusion criteria, the aim was to broadly understand questionnaires related to scientific creativity in product design, especially within education. This exploratory approach prioritized gaining a comprehensive overview instead of an exhaustive systematic review. Nonetheless, the search results significantly influenced the conceptualization of scientific creativity by providing critical insights into the relevant constructs for product design.

The procedure began by adopting and adapting existing instruments as the first step which are the Scientific Creativity Test (SCT), originally developed by Hu and Adey, then, the Creative Scientific Ability Test (C-SAT) by Ayas and Sak, the Scientific Imagination Inventory by Mun et al (2015) and scientific imagination instrument by Wang et al (2015) and Siew (2017). Then, items are also constructed through past studies associated with the construct. The researchers created an instrument specification plan to produce a questionnaire instrument based on the identified constructs. Additionally, some existing questionnaires were adjusted to match the specific items and elements utilized in the study. To minimize ambiguity, each item was tied to an operational definition (scientific knowledge or imagination) and wording was refined to reflect the action expected in product-design tasks (e.g., selecting materials, translating principles to requirements).

Table 1 shows the distribution of the constructs used for the instrument. This resulted in 12 items representing the construct of scientific knowledge (K1-K12), which can apply basic knowledge in mathematics, physics, engineering, and technology. Meanwhile, the construct of Imagination (I13-I24) consists of three stages: (1) initiation, (2) dynamic adjustment, and (3) virtual implementation.

Table 1 *Distribution of the construct*

Construct	Number of Items	Item Code	Summary of Items
Scientific knowledge	12 (K1-K2)	K1 – K4	Application of mathematics, including measuring the dimensions, such as length, width, and height, accounting for weight, estimating cost, and calculating the structural stability of the design
		K5	Application of concepts, theories, laws, and principles in physics
		K6 – K10	Application of engineering knowledge, including selecting materials based on their properties and performance, considering manufacturing constraints, assembling components into a functional whole, meeting all functional requirements, and analyzing intended operational movement.
		K11 – K12	Application of technology such as artificial intelligence (AI), Virtual reality (VR), and 3D printing.
Imagination	12 (I13-124)	I1-I4	Application of the initial stage, including brainstorming a wide range of potential problems related to the given situation, connecting those problems to real-life experiences, and generating new ideas by combining existing knowledge with guidance from experienced mentors, forms the foundation of an effective product design process.
		I5 – I8	Application of dynamic adjustment, including proposing numerous potential solutions through brainstorming, carefully selecting the most suitable physical features and functions to address the core issue, and then reorganizing and refining these elements to create an optimal and visually appealing product design.
		I9 – I12	Application of virtual implementation, including translating the product design concept into detailed sketches, improving those designs iteratively, and then creating, testing, and assessing the actual prototypes based on the sketches.

The instrument is considered an essential tool in quantitative research; thus, a series of processes must be performed to establish the instrument's validity, ensuring that the questionnaire's items comprehensively and accurately represent every aspect of their respective constructs. Content validity is one of the essential steps, ensuring that the items measure the intended content (Ismail et al., 2023). The next topic focuses on instrument validation as a methodological approach to establish the content validity of the questionnaire items for assessing scientific creativity in product design within TVET.

3.2 Steps of Content Validation

Since this research employed a quantitative approach utilizing a questionnaire as the instrument, the researchers adhered to the content validity procedure proposed by Yusoff (2019). This procedure was (i) preparing the content validation form, (ii) selecting a review panel of experts, (iii) conducting content validation, (iv) reviewing construct and items, (v) providing a score on each item, and (vi) calculating on CVI. The subsequent paragraphs will elaborate on each step in detail.

3.2.1 Step 1: Preparing Content Validation Form

The first phase of content validation involves the preparation of a content validation form, which aims to establish clear expectations and understanding among the review panel of experts regarding the task given. Before conducting the content validation, the content validation form was prepared, incorporating a list of items and a rating scale (Baharuddin et al., 2024). This form was developed to assess the relevancy of each item in the scale to the intended construct, i.e., scientific knowledge, divergent thinking, and imagination. Each indicator corresponded to an item from the form, allowing the experts to make their judgment based on the relevance and pertinence measured (Baheiraei et al., 2013) with a rating scale ranging from 1 to 4 (David, 1992; Soriano, 2021), with 1 being not relevant and 4 representing highly relevant in Fig. 1.

Instruction: Please tick (√) on the appropriate items based on the following scale.

Degree of relevance	
1	The item is not relevant to the measured domain
2	The item is somewhat relevant to the measured domain
3	The item is quite relevant to the measured domain
4	The item is highly relevant to the measured domain

B1: Scientific Knowledge
Definition: The application of knowledge in the areas of mathematics, physics, engineering, and technologies for product design.

No.	Item	How appropriate is this item to measure constructs to apply scientific creativity in designing the product?				**Expert Comment**
		1	**2**	**3**	**4**	
K1	**Calculate the structural stability:** Calculating the structural stability of the product design.					
K2	**Measurement of the dimensions:** Measuring the dimensions of the product design, including length, width, and height.					

Fig. 1 *Layout for content validation form with domain, its definition, and items represent (English version)*

3.2.2 Step 2: Selecting a Review Panel of Experts

The selection of experts to review and critique an assessment tool such as questionnaires, is typically based on their subject-area expertise (Alqahtani et al., 2023). Before choosing a panel of experts, identifying the population involved in a study is important to gather all the elements studied that allow conclusions to be drawn (Degtiar et al., 2023). Meanwhile, sampling is representative of the population, and is a critical component of the research, as it shows inferences as a generalization (Casteel et al., 2021). Thus, in this study, the population consists of experts with experience in the field of TVET, especially involving the development of creativity, measurement and evaluation, and product design to validate the content of this instrument. These experts consist of TVET lecturers from universities, community colleges, polytechnics, and teaching institutes. The selection of suitable experts for the study has the potential to affect the validation of the study. Since the purposive sampling technique targets participants based on specific criteria relevant to the research objectives (Campbell et al., 2020), the researchers chose this technique because it can provide the most significant and insightful data.

The following recommendations by Polit et al. (2007) and Polit and Beck (2006) suggested involving at least six and up to ten experts for content validity. As Said (2022) recommended, for this study, the researchers have chosen eight experts with the abilities and expertise required in the related field. According to Lynn (1986) and Berliner (2004), the experts include professional and field experts. Professional experts usually possess knowledge of the research field, have published articles on the subject, presented at national or international seminars, and possess relevant work experience and expertise to contribute to the study (Davis, 1992), meanwhile, the field experts refer to individuals related to the field of research and the topic being measured (Rubio et al., 2003). In this study, the criteria used to select the professional experts were:

(a) academic qualifications (i.e., having a doctorate in the field of expertise)
(b) at least ten years of experience in the area
(c) still working
(d) actively teaching or publishing in the related area
(e) the expert's consent to engage and commit to this study.

Meanwhile, in the field expert criteria, the researchers set:

(a) experience of more than 5 years and above
(b) still serving in the same field in the public or private sector
(c) recommendation from the Ministry of Education
(d) approval from experts.

Five professional experts were appointed from academicians who are actively engaged in teaching at universities and teaching institutes or publishing in the field of creativity and product design. These experts possess diverse backgrounds encompassing creativity, product development, TVET, and psychometric areas. Each expert has a minimum of 15 years of experience and holds a doctorate qualification. Additionally, two lecturers from teaching institutes specializing in TVET implementation in education who teach product design, as field experts. Both experts have extensive experience, with 25 years and 22 years respectively, and are currently serving in public organizations. They have been endorsed by the Ministry of Education. All the experts have agreed to participate and fully commit to this study (Table 2).

Table 2 *List of experts*

No.	Experts	Qualification	Expertise	Year of Experience	Organization
1.	Professor	Doctoral Degree	Scientific Creativity, Engineering Education	21 years	Universiti Teknologi Malaysia
2.	Associate Professor	Doctoral Degree	Creativity development	22 years	Universiti Teknologi Malaysia
3.	Associate Professor	Doctoral Degree	TVET	15 years	Universiti Putra Malaysia
4.	Senior Lecturer	Doctoral Degree	Product development, TVET	25 years	Universiti Tun Hussein Onn Malaysia
5.	Senior Lecturer	Doctoral Degree	Product design and design development, Manufacturing Engineering	16 years	Universiti Tun Hussein Onn Malaysia
6.	Senior Lecturer	Doctoral Degree	Measurement and evaluation, TVET	21 years	Universiti Tun Hussein Onn Malaysia
7.	Lecturer	Doctoral Degree	Product design, TVET	22 years	Institut Pendidikan Guru
8.	Lecturer	Doctoral Degree	Product design, TVET	25 years	Institut Pendidikan Guru

Considering eight experts are engaged, a value of 0.86 for the I-CVI is deemed acceptable (Lynn, 1986), as shown in Table 3. Consequently, to ensure a robust validation process for the instrument, it becomes imperative to exclude items with lower I-CVI scores, as suggested (Hadi et al., 2023). This careful curation of items based on expert evaluation contributes to the overall validity of the instrument. Panel size was set a priori at eight to exceed the minimum acceptable I-CVI threshold (0.86) and to balance breadth of expertise with feasibility; composition covered professional experts in creativity, TVET, product design, and field experts actively teaching D&T.

Table 3 *The number of experts and its implication on the acceptable cut-off score of CVI*

Number of Experts	Acceptance I-CVI values	Sources of recommendation
2 experts	0.80	Davis (1992)
3 – 5 experts	1.00	Polit & Beck (2006), Polit et al., (2007)
At least 6 experts	0.86	Polit & Beck (2006), Polit et al., (2007)
6 – 8 experts	0.86	Lynn (1986)
At least 9 experts	0.78	Lynn (1986)

3.2.3 Step 3: Conducting Content Validation

Content validation can be conducted via either a face-to-face or non-face-to-face approach (Almanasreh et al., 2019). For the face-to-face approach, an expert meeting is organized to gain the experts' permission to be involved in the study and given a certain period to evaluate the instrument (Said et al., 2022). Conversely, in the non-face-to-face approach, experts are typically supplied with an online form for content validation, accompanied by comprehensive instructions (see Step 1), streamlining the process from Step 4 to Step 5 (Roy & Sahu, 2024).

The critical assessment of content validation necessitates scrutiny of various factors such as cost, time constraints, and response rates (Roy & Sahu, 2024). While potentially yielding a high response rate, the face-to-face approach faces significant challenges due to the logistical complexities of gathering all experts. Conversely, even though conducting content validation by a non-face-to-face approach presents considerable drawbacks including delayed responses and the risk of non-responses, which can compromise the validity of the instruments, its primary advantage lies in cost savings (Yusoff, 2019). Hence, choosing between face-to-face and non-face-to-face approaches for content validation involves weighing their respective challenges and benefits, including response rates, logistical issues, and cost considerations.

Following this context, the researchers opted for the non-face-to-face approach due to its effectiveness, particularly when accompanied by a systematic follow-up strategy aimed at improving both response rates and response times (Yusoff, 2019). The content validation form is predominantly distributed to experts online via email, accompanied by detailed instructions to facilitate the execution of the validation process. Additionally, content validation can be executed via either qualitative or quantitative methods. In the qualitative approach, experts and the target group analyze the content, providing feedback on grammar, usage of appropriate wording, proper word order, and suitable scoring for each item (Safikhani et al., 2013). While experts may encounter challenges in seeking clarification on developed items, they often communicate with researchers through phone calls, text messages, and video discussions, which proves to be a more efficient and systematic method, while also saving on transportation and postage costs. An appointment with an expert is scheduled two days before the discussion, and researchers maintain continuous contact to incorporate any revised information. Experts rated item relevance on a 4-point scale (1 = not relevant to 4 = highly relevant). Open-ended justifications were required for low ratings and encouraged for all items; comments directly informed wording edits and alignment to operational definitions.

3.2.4 Step 4: Reviewing Construct and Items

This step involves conceptualization, aiming to specify the content domain and its items, aligning with the guidance provided by Benz, Ridenour, and Newman (Crain-Dorough, 2009). The first step involves determining the content domain of the construct within the instrument, which represents the targeted area for measurement, typically identified through literature review or expert interviews, and achieved by precisely defining the construct's attributes to obtain a comprehensive understanding of its dimensions, boundaries, and components (Zamanzadeh et al., 2015). Following this context, items for measuring the variables were retrieved by the researchers through a meticulous search of reputable publications within the area of the SSCM and MSC. These items were chosen based on their relevance to the operational definition of the concept. The definitions of the items representing the domains and the domains themselves, as suggested by Rubio et al. (2003).

The experts received the content validation form that explicitly instructed them to carefully review both the domain and its associated items before assigning scores to each item. Additionally, the experts were encouraged to provide written and verbal feedback to improve the relevance of the items in accurately representing the intended domain, thereby ensuring the validity of the construct being measured. Qualitative feedback was thematically coded (scientific accuracy, feasibility, user-context linkage, clarity of imaginative task), and all edits were logged in a change history linking comments to item revisions. After receiving all comments, the researchers carefully considered them and incorporated the experts' suggestions, leading to modifications and refinements to both the domain and its associated items.

3.2.5 Step 5: Provide a Score on Each Item

The experts were instructed to rate each item within the instrument based on the specified assessment criteria. After thoroughly reviewing the domain and its associated items, they were requested to independently score each item using the relevant rating scale (Table 1). Once the experts had completed scoring all items, they were required to submit their responses to the researcher.

3.2.6 Step 6: Calculating on CVI

CVI can be computed either at the item level (I-CVI) or the scale level (S-CVI) (Rodrigues et al., 2017) and be able to assess whether the items in a scale effectively measure the intended concept or area being studied (Baharuddin et al., 2024). Before calculating the CVI, relevance ratings need to be encoded as either 1 (for a relevance scale of 3 or 4) or 0 (for a relevance scale of 1 or 2) (Roy & Sahu, 2024).

In this study, content validation was based on item-level content validation using item-level CVI (I-CVI). The calculation of I-CVI involved tallying the number of experts who were assigned three or four points for each rating criterion, divided by the total number of experts (N = 8), as demonstrated in formula (1).

$$I - CVI = \frac{Total\ number\ of\ experts\ that\ give\ 3\ or\ 4\ point}{N} \quad (1)$$

Calculation of I-CVI is important for deciding whether to keep, revise, or remove an item. This decision was based on Lynn's (1986) guidelines: items with an I-CVI above 0.79 were kept, items between 0.70-0.79 needed revision, and items below 0.70 were eliminated. The items that met the "appropriate" range were retained and included in the instrument.

Furthermore, this study calculated the scale-level content validity index (S-CVI), which represents a critical step in establishing the overall content validity of the instrument. The S-CVI (Polit et al., 2007; Polit & Beck, 2006) elucidated two distinct approaches for calculating this index, namely the S-CVI/UA (universal agreement) and the S-CVI/Ave (average) (Polit & Beck, 2006). As the S-CVI/Ave method is less conservative and more readily interpretable (Polit et al., 2007), the researchers adopted this approach to calculate the S-CVI for the instrument under investigation in the present study. The calculation of S-CVI/Ave involved the sum of I-CVI divided by the total number of items in each construct, as shown in formula (2).

$$\frac{S - CVI}{AVE} = \frac{\sum I - CVI}{Total\ numbers\ of\ item\ in\ each\ construct} \quad (2)$$

Table 3 shows the calculations and the acceptance values in this study.

Table 3 *Calculations and acceptance values*

Index	Values	Formula
I-CVI	Relevant item: > 0.79 Needed revision item: 0.70-0.79 Eliminated item: < 0.70 (Lynn, 1986)	[1]
S-CVI/Average	Excellent: ≥0.90 Moderate: 0.80 – 0.89 (Polit et al., 2007)	[2]

The review concluded when no items met elimination criteria and no substantive content issues remained; items in the 0.70–0.79 band were revised and, where necessary, re-circulated for confirmation. To illustrate the calculation for the CVI indices, the following are examples of calculations based on the data provided in Table 4.

i. **Experts in agreement**: sum up the relevant rating provided by all experts for each item, for example, the experts in agreement for K6= (1 + 1 +1 + 0 + 1 + 1+ 1 + 1) = 7
ii. **Universal agreement (UA)**: score '1' is assigned to the item that achieved 100% experts in agreement, for example, K1 obtained 1 because all the experts provided a relevance rating of 1, while K6 obtained 0 because not all the experts provided relevance rating of 1.
iii. **I-CVI**: the expert in agreement divided by the number of experts, for example, I-CVI of K1 is 8 divided by 8 experts equal to 1, while K6 is 7 divided by 8 experts equal to 0.88.
iv. **S-CVI/Ave (based on I-CVI)**: the average of I-CVI scores across all items, for example, the S-CVI/Ave [(8 + 8 + 8 + 8 + 8 + 7 + 8 + 8 + 8 + 8 + 8 + 8)/12] is equal to 0.99.
v. **S-CVI/Ave (based on proportion relevance)**: the average of proportion relevance scores across all experts, for example, the S-CVI/Ave [(1+ 1 + 1 + 0.92 + 1 + 1 + 1 + 1)/8] is equal to 0.99.

vi. **S-CVI/UA**: the average of UA scores across all items, for example, the S-CVI/UA [(1 + 1 + 1 + 1 + 1 + 0 + 1 + 1 + 1 + 1 + 1 + 1)/12] is equal to 0.92.

4. Result

The forms were distributed to the experts in a non-face-to-face approach, a response from eight academicians was received, and these academicians acted as experts for this study, their expertise covered the aspects and field of this study, which encompasses creativity development, manufacturing engineering, product development, product design, and TVET. All of them work as faculty members in various organizations covering Universiti Teknologi Malaysia, Universiti Tun Hussein Onn Malaysia, Universiti Putra Malaysia, and Institut Pendidikan Guru Malaysia, with 15 to 25 years of experience. After the collection of the content validation forms, a rigorous analysis was undertaken to assess the relevancy and clarity of the items, incorporating both quantitative and qualitative feedback provided by the experts. Following this comprehensive review, the content validity indices were calculated following the established formulas (1, 2); the results are presented in Tables 3 and 4.

The CVI of scientific knowledge analysis, as presented in Table 4, provides compelling evidence supporting the strong content validity of the instrument. The analysis involved eight experts (A to H) evaluating the relevance of 12 instrument items (K1 to K12) on a binary scale, with the Item-CVI (I-CVI) representing the proportion of experts who rated each item as relevant. The results indicate a remarkably high level of agreement among the experts, with 11 out of the 12 items achieving unanimous consensus (I-CVI = 1.00) on their relevance to the intended construct.

The sole exception was Item K3, where one expert dissented, resulting in an I-CVI of 0.88. This discrepancy, while minor, highlights the importance of expert panel discussions and item refinement to achieve a higher level of agreement. Furthermore, the Scale-CVI/AVE of 0.99 suggests an exceptionally high overall proportion of items rated as relevant by all experts, indicating a strong content validity for the instrument. Notably, the Scale-CVI/UA of 0.92 signifies that for 92% of the items, all experts unanimously agreed on their relevance, showcasing a remarkable level of consensus among the panel members. While a Scale-CVI/UA of 1.00 would represent perfect unanimity, the achieved value of 0.92 is still highly satisfactory, especially given the construct's complexity. It is important to note that complete unanimity among experts is often challenging to achieve, as varying perspectives and interpretations can lead to minor disagreements, even among subject matter experts. Overall, the robust CVI values obtained from this analysis provide compelling evidence that the instrument effectively captures the intended construct of scientific creativity in product design for TVET.

Meanwhile, Table 5 shows the analysis involved in evaluating the relevance of 12 items (I13 to K14) in imagination by eight experts (A to H), with the Item-CVI (I-CVI) representing the proportion of experts who rated each item as relevant. The results indicate a high level of agreement among the experts, with most items achieving an I-CVI of 1.00, indicating unanimous consensus on their relevance to the intended construct. However, there were a few instances of expert disagreement, with Item I15 and I19 receiving an I-CVI of 0.88, and Item I24 receiving an I-CVI of 0.75, suggesting that one and two experts, respectively, rated these items as not relevant. The item needed revision (Lynn, 1986). Despite these minor discrepancies, the S-CVI/Ave of 0.96 indicates a high degree of content validity, while the S-CVI/UA of 0.75 falls within the acceptable range according to some researchers (Polit & Beck, 2006).

Table 4 *Content validation of scientific knowledge*

Item	Experts									Experts in agreement	I-CVI	UA
	A	B	C	D	E	F	G	H				
K1	1	1	1	1	1	1	1	1		8	1.00	1
K2	1	1	1	1	1	1	1	1		8	1.00	1
K3	1	1	1	0	1	1	1	1		7	0.88	0
K4	1	1	1	1	1	1	1	1		8	1.00	1
K5	1	1	1	1	1	1	1	1		8	1.00	1
K6	1	1	1	1	1	1	1	1		8	1.00	1
K7	1	1	1	1	1	1	1	1		8	1.00	1
K8	1	1	1	1	1	1	1	1		8	1.00	1
K9	1	1	1	1	1	1	1	1		8	1.00	1
K10	1	1	1	1	1	1	1	1		8	1.00	1
K11	1	1	1	1	1	1	1	1		8	1.00	1
K12	1	1	1	1	1	1	1	1		8	1.00	1
Proportion relevance	1.00	1.00	1.00	0.92	1.00	1.00	1.00	1.00				
The average proportion of items judged as relevant across the expert									0.99	S-CVI /AVE	0.99	
										S-CVI /UA		0.92

Table 5 *Content validation of imagination*

Item	Experts									Experts in agreement	I-CVI	UA
	A	B	C	D	E	F	G	H				
I13	1	1	1	1	1	1	1	1		8	1.00	1
I14	1	1	1	1	1	1	1	1		8	1.00	1
I15	1	1	1	1	1	1	0	1		7	0.88	0
I16	1	1	1	1	1	1	1	1		8	1.00	1
I17	1	1	1	1	0	1	1	1		7	0.88	0
I18	1	1	1	1	1	1	1	1		8	1.00	1
I19	1	1	1	1	1	1	1	1		8	1.00	1
I20	1	1	1	1	1	1	1	1		8	1.00	1
I21	1	1	1	1	1	1	1	1		8	1.00	1
I22	1	1	1	1	1	1	1	1		8	1.00	1
I23	1	1	1	1	1	1	1	1		8	1.00	1
I24	1	0	1	0	1	1	1	1		6	0.75	0
Proportion relevance	1.00	1.00	1.00	0.92	1.00	1.00	1.00	1.00				
The average proportion of items judged as relevant across the expert									0.96	S-CVI /AVE	0.96	
										S-CVI /UA		0.75

In summary, the CVI analyses conducted in this study suggest that the measurement instruments possess acceptable to high levels of content validity, with the scientific knowledge instrument exhibiting particularly strong results. Nonetheless, further refinement of specific items with lower I-CVI scores may enhance the content validity of the imagination instruments. Additionally, subsequent research should explore other types of validity evidence to provide a more comprehensive assessment of the validity of these instruments in the context of product design.

5. Discussion

TVET focuses on equipping individuals with the skills and knowledge required for specific industries (Rodzalan et al.,2022). The design products in TVET are strongly linked with physics, mathematics, engineering, and technology (Razali et al, 2022). Based on the CVI, scientific knowledge including these disciplines shows a significantly high level of agreement among experts, with unanimous consensus reached on 11 out of the 12 items. It proved that the strong relationship between engineering, technology, mathematics, physics, and scientific knowledge is evident in their collective use in product designs. These disciplines provide the framework and structure for designing products (Li et al., 2020). Product design primarily depends on using mathematical concepts and physical principles to generate innovative product designs (Mukherjee, 2021; Farag, 2020; Pereira & Becker, 2020; Ljungberg & Edwards, 2003), allowing them to create highly effective solutions. Simultaneously, advancements in technology like artificial intelligence (AI) and virtual reality (VR) contribute to the development of design concepts that were previously unachievable (Berni & Borgianni, 2020; Min, 2021) surely shape the future of technology and affect our daily lives beyond expectations. In TVET, technology is an integral part of product design, encompassing everything from manufacturing methods such as 3D printing, need to the use of computer-aided design software (Irawan et al., 2021), which has empowered to create more efficient, cost-effective, and visually appealing products.

There is one item that did not reach experts' consensus. The item is related to the determination of position and weight loans in product design, which is an essential aspect in ensuring a solid foundation and functional efficiency of a product. However, the item may still be kept due to its CVI value above 0.79 (Lynn, 1986). This implies that the item, although disputed, nevertheless has sufficient value for further consideration. Furthermore, the expert recommended that it be used in terms of engineering applications, which are more effective than the previously used basic concepts of mathematics, which is particularly noteworthy. Mistarihi et al., (2020) demonstrated in the wheelchair design study, that the application of advanced engineering techniques in product design, particularly in contexts involving weight support and positioning, is essential for creating effective and user-centered solutions. It is a complex process that requires in-depth engineering knowledge, careful consideration of material properties, and advanced analysis and simulation techniques to achieve optimal results (Turan et al., 2016; Coşkun et al., 2019). The presence of this item in the instrument highlights the significance for students to have a strong basic understanding of engineering and technology, supported by mathematics and physics. Thus, it is essential to develop products that meet safety and performance requirements (Subramanian et al., 2023; Mantovani et al., 2021). The unanimous consensus among experts highlights the integral role of engineering, technology, mathematics, and physics as scientific knowledge in product design.

The data strongly proves that integrating the foundation of engineering applications into product design is not just beneficial, but necessary for achieving the best outcomes. Even though there wasn't a complete consensus, the decision to keep the item and classified as an engineering application shows those involved understand how important to use thorough engineering analysis in product design. This approach ensures that the product design can withstand real-world conditions, thereby reduce the risk of failure and increasing overall product reliability. The integration of scientific knowledge in TVET is essential as it provides students with a holistic understanding of product design (Muogahlu et al., 2023). According to Nurtanto et al. (2020), the synergy between these disciplines in TVET not only fosters a comprehensive understanding of the product design and production process but also enables individuals to develop practical skills that are directly applicable in real-world industry settings. Furthermore, students not only gain technical skills but also develop a deeper understanding of how these disciplines work together in product design (Matanabe et al.,2022). By immersing students in this multidisciplinary approach, TVET lays the foundation for future professionals to become versatile problem solvers and innovators in the field of product design.

Meanwhile, imagination also plays a crucial role in the field of product design within TVET (Hanafiah et al., 2020). This is because innovative ideas drive the development of practical solutions to real-world problems, fostering an environment for learning through hands-on experiences (Zain, 2023). In this study, the imagination constructs show 9 out of 12 items received unanimous approval from all experts since the item utilized is a modified version of a trusted instrument, as described by Mun et al (2015), Wang et al (2015), and Siew (2017). While this imagination fosters the generation of ideas in the product design (Wibisono et al., 2021), three items did not reach full consensus during the content validation by experts. Although these three items do not reach a level where removal is necessary, it is important to consider the expert's recommendation seriously (Zhu et al., 2022) to ensure that the construct is as accurate as possible. In resolving this issue, it is essential to obtain more detailed feedback from the experts involved in the initial validation. This approach allowed the researchers to understand the opinions of the experts better and make necessary improvements to the items in the instrument (Mokkink et al., 2020). This iterative process enabled the researchers to refine the items based on the feedback received. During a discussion or review session, the experts provided suggestions on how to refine the item to more accurately capture the specific aspect of imagination that is being evaluated.

Firstly, the item under consideration pertains to the use of multiple parts in the product design. According to the expert feedback, the item was found to be unclear, indicating that the terms used are not accurate enough to capture the true meaning intended to be conveyed. This ambiguity can cause inconsistent assessments among experts (Beck et al., 2020), thus reducing the validation of this instrument. We modified this item to "determine changes in the physical structure of the product design when used" in response to expert feedback. This modification was implemented to better align with the expert suggestion and aim of clarifying the true meaning of the item. The revised wording not only involves the use of various parts in the design but also focuses on how changes in the physical structure of the product can affect the overall design. This refinement is essential as it concentrates on an important part of imagination in product design. Siew et al. (2017) described this state of imagination in the dynamic adjustment stage of the engineering design process, where students question various solutions, and modify, and elaborate on their ideas to rearrange the physical features and functions of their creations. Davies et al. (2023) supported these findings in a study on the designing products of lamps, bags, and pillows, demonstrating that the manufacturing process dynamically shapes students' imagination ideas, with the physical embodiment of their designs playing a crucial role in refining and developing their concepts. Similarly, Lin et al. (2023) found that students were able to determine changes in the physical structure of their product designs based on their imagination during the manufacturing process using 3D printing technology. The modified items, with a clearer emphasis on physical change, are expected to provide a more accurate picture of the imaginative aspect in the context of product design.

The next item of concern is to identify as many problems as possible based on the given situation that led to the product design development. The expert stated that this item was a repetition of other items in the instrument, which led to concerns about redundancy in the instrument. The lack of consensus among experts on this item is due to its perceived repetitive nature, especially since it involves a brainstorming process. Although brainstorming is an important element in the envisioning process, it occurs consistently in all three phases of design, with the only difference lying in the specific problem and the corresponding answer (Chung et al., 2022; Siew, 2022). Therefore, the repetition of these items may result in some problems such as respondents becoming fatigued and confused in answering the questions (Schmitz & Storey,2020), thereby impacting the overall validity of the instrument (El-Den et al.,2020). It is a wise decision to eliminate this item, as it prevents redundancy and maintains the instrument's concentration on evaluating critical aspects of imagination in product design. Additionally, by reducing the cognitive load of respondents, this approach enhances the quality of the collected data.

Surprisingly, two experts disagree with the last item, which refers to build, testing, and evaluating prototypes based on sketching. Sketching, as a medium for expressing creative ideas and concepts, can evaluate imagination (Patterson et al.,2024), but relying solely on it for prototype development can introduce biases and fail to capture critical functional, ergonomic, and user considerations (Sameti et al., 2022; Soute et al., 2017). This item has received negative feedback from the experts, who insist that the assessment of sketches as a step towards building a prototype is impractical and irrelevant in measuring imagination. A holistic approach that combines ideation with empirical testing, data analysis, and user feedback is essential to create successful prototypes that meet functionality, usability, and user preference criteria (Meinel et al., 2020; Menold et al., 2017). The experts also insist that imagination is not the main factor that needs to be measured in the process of building a prototype, because this process depends more on technical skills and a deep understanding of materials and techniques. Product design requires synergizing mathematics, physics, and engineering with technologies and rigorous prototyping based on empirical testing and user feedback. Imagination is vital in the initial phases of design, particularly in generating ideas. Nevertheless, it becomes less significant during prototyping, where a more evidence-based and rigorous approach is necessary. Since sketching was already part of the imagination construct, eliminating this item is justified to sharpen the focus on aspects more pertinent to the imagination.

6. Conclusion

This study successfully demonstrates the robustness of the content validation process in assessing scientific creativity within the context of product design for TVET. By integrating scientific knowledge and imagination, this study contributes significantly to our understanding of how these elements intersect to foster scientific creativity in the field of TVET. The high levels of agreement among experts, particularly regarding the scientific knowledge instrument, underscore the validity and reliability of the measurement tools utilized. Practically, the findings of this study offer valuable insights for educators, curriculum developers, and practitioners involved in TVET. By understanding the components of scientific creativity and their validation, stakeholders can tailor instructional approaches and curricular materials to better cultivate creative thinking skills among students pursuing product design and manufacturing careers.

Furthermore, the validated instrument developed in this study has the potential to influence the TVET curriculum significantly. Apart from offering a method that can evaluate scientific creativity in product design, this instrument can be a guideline for curriculum development in identifying gaps in the practice of fostering creativity during the learning process. This situation allows improvements to be made so that the instructional design can support the learning process more aligned with the requirements of I4.0. Accordingly, policymakers should balance guidelines that enable the TVET curriculum to integrate scientific knowledge and imagination in product design. Therefore, support in terms of preparing programs to train educators to be more competent in implementing learning that prioritizes scientific knowledge and imagination as the basis for fostering students' creativity, thus making the TVET program successful in competing in the future. By influencing both curriculum development and policymakers, the instrument can play a role in providing TVET students with the essential skills to compete in a global economy that is increasingly growing more complex and driven by innovation. This alignment between education, industry needs, and policy directives can potentially enhance the overall quality and relevance of TVET programs, eventually benefiting students, industries, and the broader economy.

Based on these findings, vocational educators should modify their methods to implement the integration of scientific knowledge and imagination in product-design learning. This encompasses redefining projects as clear science-to-design challenges that translate principles into design requirements. They can explicitly teach imagination techniques and structured design tools such as morphological charts, House of Quality, SCAMPER, visual analysis, and SWOT, so students can generate ideas that are both original and workable. Then, institute short iterative prototyping cycles with testing and failure analysis linked to scientific principles. Educators also should encourage students to use computer-aided design (CAD) and simulation to explore the parameters and see how they relate to underlying science. This approach helps to integrate user research that links everyday contexts to disciplinary concepts and evaluates them using rubrics aligned with the study's indicators for both process and product. These methodologies will better cultivate students' scientific creativity and strengthen readiness for I4.0.

However, it is essential to acknowledge the limitations of this study, including the relatively small sample size of experts and the potential for bias in their assessments. Future research endeavors should aim to replicate these findings with larger and more diverse samples to enhance the generalizability of the results. Additionally, exploring other types of validity beyond content validity, such as criterion-related and construct validity, could provide a more comprehensive understanding of the effectiveness of these measurement instruments in assessing scientific creativity. Future research should aim for larger and more diverse experts and explore other forms of validity evidence beyond content validity. Furthermore, it would be beneficial to incorporate practitioners such as TVET instructors or product designers in future research as part of the expert panel. Their real-world experiences can provide valuable perspectives on the instrument's practicality and significance within actual TVET contexts, ensuring that the tools are theoretically reliable, relevant, and beneficial in everyday educational practices. Although the instrument developed in this study exhibits potential for application in educational contexts, further research is necessary to validate its efficacy. Despite these limitations, this study paves the way for future endeavors aimed at improving educational assessment in product design for TVET, ultimately enhancing teaching, and learning outcomes in this field.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *S.S;* ***data collection:*** *S.S;* ***analysis and interpretation of results:*** *S.S, M.S.R, M.O;* ***draft manuscript preparation:*** *S.S, N.A.H., N.N.J.N.N. All authors reviewed the results and approved the final version of the manuscript.*

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