JPPIPA 11(2) (2025)

Jurnal Penelitian Pendidikan IPA

Journal of Research in Science Education

http://jppipa.unram.ac.id/index.php/jppipa/index

Development and Validation of a Self-directed Learning Scale for Pre-Service Science and Technology Teacher

Wahyudi[1,2], Agus Setiawan[1*], Andi Suhandi[1], Achmad Samsudin[1]

[1] Science Education Program, Universitas Pendidikan Indonesia, Bandung, Indonesia.
[2] Physics Education Program, Universitas PGRI Pontianak, Pontianak, Indonesia.

Received: October 05, 2024
Revised: December 12, 2024
Accepted: February 25, 2025
Published: February 28, 2025

Corresponding Author:
Agus Setiawan
agus_setiawan@upi.edu

DOI: 10.29303/jppipa.v11i2.10000

Abstract: The ability of prospective science and technology teachers to engage in Self-Directed Learning (S-DL) is essential for their professional growth in an evolving educational landscape. However, existing instruments to assess S-DL readiness often lack comprehensive validation. This study aims to develop and validate an instrument to measure S-DL readiness among prospective science and technology teachers. The research followed a structured process, including instrument design, expert validation, pilot testing, and psychometric evaluation. A sample of 100 students participated in the validation process, ensuring the instrument's reliability and validity. Content validation was conducted with expert judgment, while statistical analyses, including factor analysis, were used to assess construct validity. The final instrument consists of 42 items, demonstrating strong validity and reliability. These findings confirm that the developed S-DL instrument is an effective tool for measuring students' readiness for self-directed learning. The results provide valuable insights for improving teacher education programs by integrating self-directed learning strategies and supporting further research in this field.

Keywords: Pre-service teacher; Science and technology; Self-directed learning

Introduction

In order to develop in the world of modern work, individuals must understand how to take advantage of changes in their learning, including planning, development, adaptation, and evolution in digital, interactive, and global society. Therefore, Self-Directed Learning is very important in the world today (Brandt, 2020). S-DL can be interpreted as an ability (Cheng et al., 2010; Jin & Ji, 2021), competence (Morris, 2020; Pimdee et al., 2023), or instructional approaches (Robinson & Persky, 2020; Van Lankveld et al., 2019). The diverse S-DL definitions are rooted in the definitions developed by (Knowles, 1975), that S-DL is an individual process taking initiative, with or without the help of others including the ability to diagnose their learning needs, formulate learning objectives, identify resources and material for learning, selecting and implementing the right learning strategies, and evaluating learning outcomes. However, Self-Directed Learning is a multi-perspective concept (Loeng, 2020), which must be understood from various dimensions of Self-Directed Learning so as to make an understanding of self-direct learning comprehensive.

At the level of higher education, S-DL is more interpreted as an important skill or competence for students. S-DL in higher education is more investigated in students in the field of nursing and health education through the S-DL Readiness Scale instrument (Cheng et al., 2010; M. Fisher et al., 2001; Williamson, 2007). Acar et al., (2015) developing SDLSS instruments for students of candidate science teachers, but with very limited dimensions. Not found research that developed S-DL instruments to measure the readiness of S-DL students of prospective science and technology teachers with a more comprehensive dimension.

How to Cite:
Wahyudi, Setiawan, A., Suhandi, A., & Samsudin, A. (2025). Development and Validation of a Self-directed Learning Scale for Pre-Service Science and Technology Teacher. *Jurnal Penelitian Pendidikan IPA*, *11*(2), 946–957. https://doi.org/10.29303/jppipa.v11i2.10000

Based on these gaps, it is necessary to develop new dimensions and aspects of S-DL for students of prospective science and technology teachers. Unlike previous studies, this research expands existing S-DL instruments by incorporating dimensions specifically relevant to science and technology education, ensuring a more comprehensive assessment of S-DL readiness. For students of prospective science and technology teachers, S-DL is an important ability to develop professional competencies in the era of globalization (Morris, 2019), and foster attitude as life-long learner (Salleh et al., 2019). Therefore, this study aims to develop instruments to measure the readiness of S-DL students of prospective science and technology teachers.

Systematic search on relevant literature has been carried out to develop S-DL dimensions and aspects. As a result, researchers found that instruments to measure S-DL refer to references to similar research results. These instruments refer to the dimensions developed by Fisher et al. (2001) includes self-management, desire for learning, and self-control; Williamson (2007) promote the dimensions of awareness, learning strategies, learning activities, evaluation and interpersonal skills; and Cheng et al. (2010) with the dimensions of learning motivation, planning and implementing, self-monitoring, and interpersonal communication. The S-DL dimension also refers to the definition of S-DL put forward by Guglielmino (1977), and Knowles (1975). However, these existing models do not fully capture the competencies required for self-directed learning in science and technology education.

Based on rapid analysis of the SCOPUS database, there are 4068 article publications in the last 20 years that contain the keyword "self-directed learning" in the title, abstract and keywords in all research fields. However, only 44 (1.08%) article publications also contain the keywords "science education" and "technology education". This shows that the study of "self-directed learning in the field of science and technology education is very limited. The results of the keyword mapping of the 44 articles are visualized using the VOSViewer application as shown in Figure 1.

Based on Figure 1, it is known that not many words appear that are relevant to the S-DL dimension. Keywords such as "motivation", "self-regulated learning", "controlled study", appear in the keyword network and are believed to be dimensions related to S-DL. However, the intensity of the emergence and relationship between these keywords is still relatively low. This strengthens the belief that the development of S-DL dimensions in science and technology education is still very limited.

To address this limitation, this study examines the relevance of these dimensions within the specific learning context of prospective science and technology teachers. In addition, this study integrates newer dimensions proposed by Brandt (2020), including self-regulation, motivation, personal responsibility, and autonomy, which are critical for independent learning in science and technology fields. By incorporating these elements, the proposed S-DL instrument becomes more comprehensive and better suited for assessing students' ability to navigate self-directed learning in this discipline.

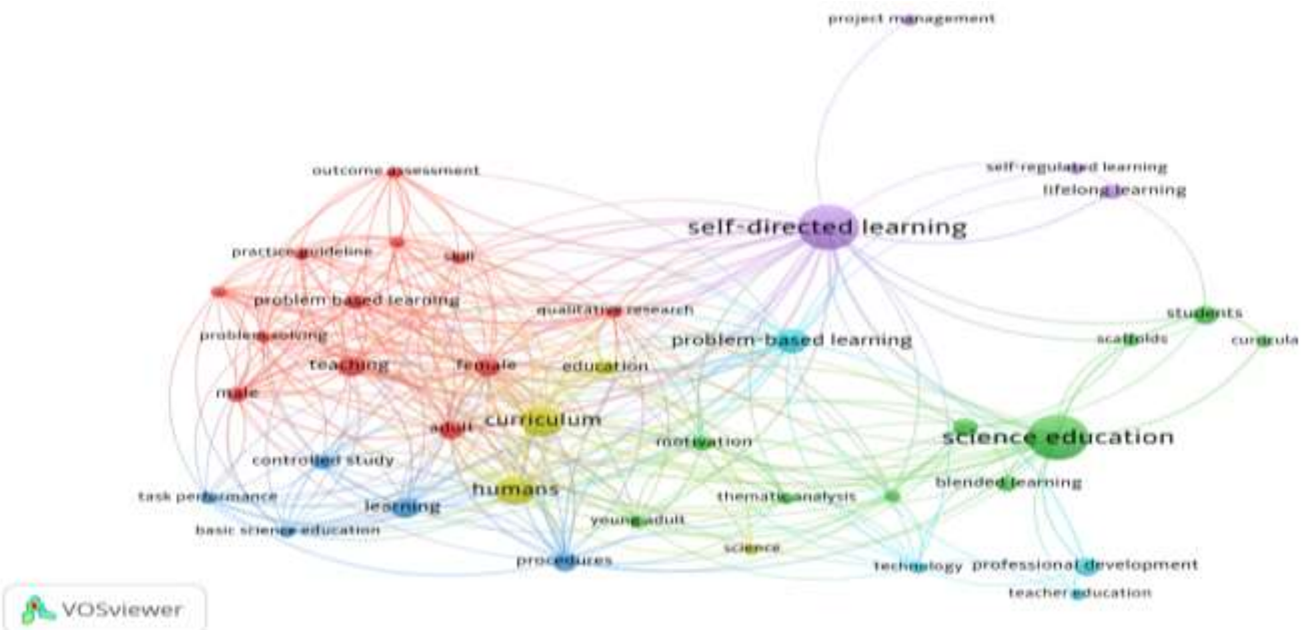

Figure 1. Keyword network of S-DL research in science and technology education globally in the last 20 years

In science and technology education, students are encouraged to learn to research, find and make new discoveries through investigations of experiments or projects (Kuo, 2019; Nugroho et al., 2021; Sari et al., 2020). At present, learning mix is widely applied in the Science and Technology Education Curriculum, so students must improve good learning experiences through S-DL (Kamp, 2019; Robinson & Persky, 2020). In the context of 21st-century education, self-directed learning is essential for prospective science and technology teachers, as it equips them with critical thinking, problem-solving (Suharlan et al., 2023), and adaptability skills needed to navigate rapid technological advancements and dynamic educational environments.

This research plays a crucial role in developing a comprehensive S-DL instrument that effectively measures various dimensions of self-directed learning. A well-validated instrument will enable an accurate assessment of prospective science and technology teachers' readiness for self-directed learning. By ensuring this readiness, students can acquire the necessary competencies to succeed in both current and future 21st-century education settings.

Research Purposes

This study aims to develop and validate an S-DL instrument to measure the readiness for self-directed learning among prospective science and technology teachers. Specifically, the study focuses on developing an S-DL instrument that incorporates various dimensions, aspects, questionnaire items and scales. Furthermore, it evaluates the validity of the instrument by assessing both content and construct validity. In addition, the study examines the reliability of the instrument to ensure its consistency in measuring self-directed learning readiness.

Method

S-DL instruments have been developed and validated using qualitative and quantitative methods. The qualitative phase is used to develop a questionnaire while the quantitative phase is used to validate instruments. This research was conducted in 4 main stages as shown in Figure 2.

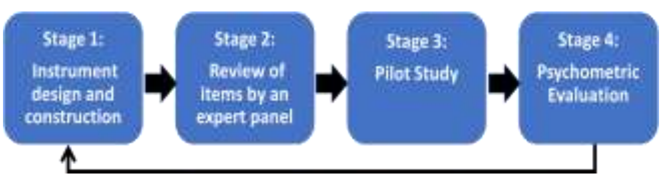

Figure 2. Research flow

Procedure

First Stage: Instrument Design and Construction

In the first stage, the S-DL instrument is designed and constructed based on a literature review related to research relevant to S-DL. A number of relevant research publications are used to develop new dimensions and S-DL aspects for science and technology education students. After the dimensions and aspects of the S-DL are determined, then the questions are compiled each S-DL questionnaire item. In the preparation of questionnaire questions, the limits are determined in the form of questions that measure student S-DL in the Physics lecture process with an inquiry and project learning approach, which is taken by all research participants.

Second Stage: Expert Judges Evaluation

In the second stage, 42 items from the S-DL instrument questionnaire were evaluated by a panel of five experts. The expert panel consisted of professionals specializing in the evaluation of science and technology learning, all of whom held doctoral degrees. The content validation process covered three main aspects: material, construction, and language, each assessed using three specific indicators. The experts provided their evaluations using a dichotomous scale, where 1 indicated validity and 0 indicated invalidity, across a total of nine content validation indicators. Additionally, revisions to the questionnaire items were made based on the comments and suggestions provided by the expert panel.

Third Stage: Pilot Study

In the third stage, pilot study is applied to adjust the S-DL instrument to the characteristics of the selected participants. The trial participant amounted to 25 people as the minimum sample number of samples required in the instrument test (Pacheco & Herrera, 2023). Test participants have the same characteristics as the characteristics of participants in the application of instruments on a wide scale. This pilot study results are also carried out to determine the readability of each questionnaire item by participants.

Fourth Stage: Instrument Psychometry Evaluation

In the last stage, the S-DL instrument is applied to a broader participant to study the nature of its psychometry. Data from the S-DL instrument survey results are analyzed using Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA).

Participant and Data Collection Techniques

The participants in this study consisted of 100 prospective science and technology teacher students. They were selected based on specific characteristics, including having completed coursework under the 'Merdeka Belajar Kampus Merdeka' curriculum and having participated in physics lectures that implemented inquiry-based or project-based learning approaches. The S-DL survey data collection was carried out through the Google Form which was distributed using WhatsApp Group and data collection was conducted for two months.

Data Analysis Technique

Descriptive statistical analysis is used to describe the characteristics of participants consisting of the number and percentage of each participant category. Content validation uses the dichotomy score assessment criteria, namely 1 (valid) and 0 (invalid). The data validation results data are then analyzed using the Aiken's V Coefficient equation (Penfield & Giacobbi, 2004; Torres-Malca et al., 2022) as Equation (1).

$$V = \frac{\bar{X} - l}{k} \tag{1}$$

with $\bar{X}$ is the average sample of expert assessment, l is the lowest scale value that is possible, and k is the range of valuation scale values on items (K = maximum score-minimum score possible). The V value ranges from 0 to 1, with the lower limit (L) and the upper limit (U) of the trust interval as Equations (2) and (3).

$$L = \frac{2nkV + z^2 - z\sqrt{4nkV(1-V) + z^2}}{2(nk + z^2)} \tag{2}$$

$$U = \frac{2nkV + z^2 + z\sqrt{4nkV(1-V) + z^2}}{2(nk + z^2)} \tag{3}$$

With n represents the number of expert appraisers), Z according to the standard normal distribution value (for example, for confidence intervals of 95% then Z = 1.96). Aiken's V's coefficient threshold value required in each item is 0.7. Items with KAV <0.7 are not included in the next stage of analysis. Psychometric property Instruments were analyzed by the EFA and CFA techniques. From this analysis the value of construct validity, reliability, CFA hierarchy and CFA correlation models will be obtained. In the EFA analysis the KMO value requirements are set >0.50, a significant Barlett's test (Sig. <0.05), Loading Factor >0.30 and Total Variance Explanation >40% to meet good instrument criteria (Alemdar & Anılan, 2020; Eliyawati et al., 2023).

Table 1. Dimensions, Aspects and Number of S-DL Instrument Items Developed

S-DL Dimensions in Theory and Terminology	Aspects (Number of Item)
Learning motivation (LM): The S-DL dimension relates to the drive from within the learner and external stimuli that encourage the desire to learn as well as the fundamental belief that intelligence and personality can change according to experience.	Intrinsic motivation (2 items) Extrinsic motivation (2 items) Growth mindset (2 items)
Learning strategies (LS): The S-DL dimension relates to the ability to independently set learning objectives, determine appropriate learning strategies and resources so that learning objectives can be achieved effectively.	Determining learning needs (2 items) Determining learning target stages (2 items) Determining learning strategies and resources (2 items)
Learning activities (LA): The S-DL dimension relates to one's ability to be actively involved in learning activities so that one can direct oneself in the learning process.	Being proactive in the learning process (2 items) Controlling the learning process (2 items) Self-efficacy in the learning process (2 items)
Learning evaluation (LE): The S-DL dimension relates to the ability to monitor and evaluate learning processes and outcomes.	Monitoring learning development (2 items) Evaluating the learning process and outcomes (2 items) Reflecting on learning outcomes (2 items)
Interpersonal communication (IC): The S-DL dimension relates to the ability to interact and communicate with others in the learning process.	Oral communication (2 items) Written communication (2 items) Social interaction in learning (2 items)
Personal responsibility (PR): The S-DL dimension relates to responsibility and awareness in learning and prioritizing integrity and ethics in the learning process.	Responsibility for learning (2 items) Initiative in learning (2 items) Integrity and ethics in learning (2 items)
Learning autonomy (LO): The S-DL dimension relates to the ability to manage learning from start to finish, make choices in decision making and engage in challenges in the learning process.	Learning management (2 items) Decision making in learning (2 items) Engaging in learning challenges (2 items)

Other criteria are CFI values> 0.90, NFI >0.90, IFI >0.90, GFI >0.95, AGFI >0.90, and RMSEA/SRMR <0.06 in CFA analysis show good compatibility in construct validity (Li et al., 2022). Alpha Cronbach value of 0.7 shows good internal consistency (Swarni et al., 2024; Taber, 2018). Construct reliability (CR) is calculated using the Composite Reliability Equation of the loading factors of each dimension, with an acceptable value if CR >0.70 (Naqsyahbandi & Prodjosantoso, 2023).

Result and Discussion

Instrument Design and Construction

The development of the instrument begins with a literature study on the topic of Self-Directed Learning. Literature is collected from the Scopus and Google Schoolar database. Various scientific articles were found, but the selection of articles was focused on the development of instruments to measure S-DL students in college.

Most research on S-DL measurements of students in tertiary institutions use instruments that have been developed by Cheng et al. (2010) with 4 dimensions of S-DL, Fisher et al. (2001) with 3 dimensions of S-DL, and Williamson (2007) with 5 dimensions of S-DL. Of the 12 dimensions of the S-DL, it is then reduced to 6 dimensions because of the similarity of the definition. This study also uses a reference to the results of literature studies conducted by Brandt (2020), and adds 1 different S-DL dimensions so that the final results of developing S-DL instruments include 7 dimensions of S-DL, as shown in Table 1. There are 21 aspects developed in the S-DL instrument which includes 42 items.

Table 2. Summary of the Aiken's V Coefficient (Confidence Interval 95%) on 42 S-DL Instrument Items

Item/Code	Material review aspect		Construction review aspect		Language review aspect		Overall aspects	
	V	95% CI	V	95% CI	V	95% CI	V	95% CI
1/LM1	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.87	0.43 - 0.98	0.96	0.52 - 0.99
2/LM2	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.87	0.43 - 0.98	0.96	0.52 - 0.99
3/LM3	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
4/LM4	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
5/LM5	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
6/LM6	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
7/LS1	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
8/LS2	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
9/LS3	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
10/LS4	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
11/LS5	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
12/LS6	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
13/LA1	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
14/LA2	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
15/LA3	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
16/LA4	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
17/LA5	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
18/LA6	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
19/LE1	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
20/LE2	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
21/LE3	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
22/LE4	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
23/LE5	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
24/LE6	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
25/ IC1	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
26/ IC2	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
27/ IC3	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
28/ IC4	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
29/ IC5	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
30/ IC6	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
31/PR1	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
32/PR2	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
33/PR3	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
34/PR4	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
35/PR5	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
36/PR6	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
37/LO1	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
38/LO2	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
39/LO3	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
40/LO4	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
41/LO5	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
42/LO6	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.50 - 1.00	0.98	0.54 - 1.00
Average	1.00	0.57 - 1.00	1.00	0.57 - 1.00	0.93	0.49 - 0.99	0.98	0.54 - 1.00

Furthermore, a questionnaire statement for 42 items was developed with 4-point Likert scale of each item, namely; 4 (very in accordance with my condition), 3 (according to my condition), 2 (not in accordance with my condition), and 1 (very incompatible with my condition). 7 Additional items with negative statements are provided for the purposes of checking consistency and seriousness of respondents in answering the questionnaire statement.

Expert Judges Evaluation

The S-DL instrument that has been constructed is further evaluated by 5 judges of learning evaluation experts. The review aspects in content validation include aspects of material, construction and language suitability. Each jury expert gives a score on each question aspect of review with a score of 1 (valid) or 0 (invalid).

As displays Table 2, two items (items 1 and 2) have the coefficient of Aiken's V of 0.96 with a 95% confidence index in the range of 0.52 - 0.99, and the remaining 40 items have a coefficient of Aiken's V of 0.98 (CI 95% in the range of 0.52 - 0.99). Material and construction review aspects have the average Aiken's V coefficient of 1.00 (CI 95% in the range of 0.57 - 1.00), which shows that all expert judges state that all S -DL questionnaire statements are valid from the material and construction aspects. While from the aspect of language preparation in the questionnaire statement has a coefficient of Aiken's V of 0.93 (CI 95% in the range of 0.49 - 0.99), which shows that the use of language in the preparation of the S -DL questionnaire statement which is also valid. It was concluded that 42 S-DL instrument items met excellent content validity criteria (overall average Aiken's v 0.98, CI95% in 0.54-1.00) and feasible to be used to collect data on student self-direct learning readiness.

The questionnaire items, particularly items 1 and 2, were revised according to the feedback from expert judges. The improvements focused on refining sentence structure to align with proper writing conventions and eliminating ambiguities. As a result, both items were enhanced to ensure clarity and precision in data collection.

Pilot Study Result

The Pilot study were carried out by applying the S-DL questionnaire to 25 students. The pilot study results show that all sentences in the questionnaire item can be understood properly and smoothly by respondents. This shows that the revision in the preparation of the sentence statement of the questionnaire makes the language construction in the questionnaire better. Then, the pilot study results score was analyzed to determine the internal consistency (initial reliability) S-DL instrument.

The results of the internal consistency testing of the S-DL instrument during the limited trials are displayed in Table 3. The S-DL instrument at a limited trial stage has a very good internal consistency. This shows that the S-DL instrument can be used to measure each S-DL dimension consistently. In addition, based on a limited trial obtained information about the length of time effective for respondents in answering all S-DL instruments.

Table 3. Internal Consistency of the S-DL Instrument in the Pilot Test

Reliability statistics	r	Interpretation
Correlation between form	0.83	Very good
Spearman-Brown coefficient	0.91	Very good
Guttman split-half	0.91	Very good

Table 4. Factor Loadings of Items from EFA

Item/Code	Factor Loadings (λ)						
	LM	LS	LA	LE	IC	PR	LO
1/LM1	0.49						
2/LM2	0.57						
3/LM3	0.51						
4/LM4	0.55						
5/LM5	0.41						
6/LM6	0.55						
7/LS1		0.46					
8/LS2		0.67					
9/LS3		0.62					
10/LS4		0.67					
11/LS5		0.66					
12/LS6		0.57					
13/LA1			0.61				
14/LA2			0.65				
15/LA3			0.62				
16/LA4			0.70				
17/LA5			0.59				
18/LA6			0.52				
19/LE1				0.59			
20/LE2				0.66			
21/LE3				0.66			
22/LE4				0.68			
23/LE5				0.63			
24/LE6				0.59			
25/ IC1					0.51		
26/ IC2					0.49		
27/ IC3					0.57		
28/ IC4					0.59		
29/ IC5					0.60		
30/ IC6					0.52		
31/PR1						0.60	
32/PR2						0.63	
33/PR3						0.64	
34/PR4						0.61	
35/PR5						0.70	
36/PR6						0.55	
37/LO1							0.66
38/LO2							0.69
39/LO3							0.70

Item/Code	Factor Loadings (λ)						
	LM	LS	LA	LE	IC	PR	LO
40/LO4							0.62
41/LO5							0.67
42/LO6							0.64
% Variance	10.4	14.6	14.8	15.9	11.8	12.6	13.5

Evaluation of Psychometry Instruments

The S-DL instrument psychometric evaluation stage is carried out through Exploratory Factor Analysis (EFA) followed by Confirmation Factor Analysis (CFA). EFA in this study was used to strengthen indicator construction (items) and clarify the indicator relationship (item) as a variable observed with the S-DL dimension as a latent variable. CFA is used to determine convergent validity, distinguishing validity, construct reliability and feasibility testing of indicator and latent variables in the S-DL instrument. Table 4 shows that all items have a loading factor value >0.40 which means that each item can explain the latent factor of its constituents (Gusmanida et al., 2024). It also shows that each item has good construction validity to measure each dimension or aspect of S-DL.

Based on the seven factors determined as S-DL dimensions (Table 4), the S-DL factor model has a total variance of 93.50%, indicating that this instrument is extremely good (Rashifah et al., 2023) in explaining self-directed learning readiness factors. Learning evaluation (15.86%) is the most dominant dimension, emphasizing the importance of evaluation, monitoring and reflecting in learning. Learning autonomy (13.46%) and personal responsibility (12.55%) also contribute significantly, highlighting the importance of learning independences and personal responsibility. Other dimensions such as learning activities (14.84%), learning strategies (14.60%), and interpersonal communication (11.80%) support S-DL readiness, while learning motivation (10.39%) acts as a supporting factor. With a high total variance, this instrument is valid and can be used to measure S-DL readiness comprehensively in the education of prospective science and technology teachers.

One of the important measurements in EFA is KMO and Bartlett's Test which is a requirement whether the factor analysis can be done or not. The results of KMO and Bartlett's Test are shown in Table 5.

Table 5. KMO and Bartlett's Test

Test	Estimate
Kaiser-Meyer-Olkin [KMO] test	0.84
Bartlett's test:	
Approx. Chi-Square	3601.96
df	861
Sig.	< 0.00

The threshold value that determines the suitability of the data for the factor analysis is the KMO value> 0.70 and the Signification of Bartlett's Test P <0.05. Based on Table 3 it is known that the data meets the suitability for factor analysis. Figure 3 shows the path diagram of the indicator relationship (items) and latent (dimensional) factors in the S-DL instrument. Path Diagram Model I is the initial model in CFA analysis and modified to get a fit model.

Table 6. Fit Indices in CFA Analysis

Index	Estimate	Interpretation
CMIN/DF	1.77	Excellent fit
GFI	0.69	Not fit
AGFI	0.64	Not fit
CFI	0.81	Good fit
IFI	0.82	Good fit
RFI	0.62	Moderate fit
NFI	0.66	Moderate fit
TLI	0.79	Moderate fit
RMSEA	0.08	Good fit

After being evaluated statistically CFA, PR2 items are removed because they have a very large covariant modification index and cause models to be less fit. PR1 and PR2 items are items with indicators related to learning responsibilities. PR1 items can represent these indicators even though PR2 items are deleted. After the model is modified into model II, the compatibility index found a fit criterion as shown in Table 6. Although the GFI and AGFI values show the value that is not fit (<0.90), the CMIN/DF ratio shows excellent fit because it is lower than 2.

As shown in Table 6, GFI, AGFI, CFI, IFI, RFI, NFI and TLI values vary between 0 and 1. There is an agreement from the literature regarding the threshold value, but the value close to 1 shows excellent fit and the value of 0.80 to 0.89 indicates good fit. Table 3 shows that the CFI and IFI values are in the good fit criteria while the FRI, NFI and TLI values are in the moderate fit category. The RMSEA value also varies between 0 to 1. The closer to 0 shows a good compatibility, and the RMSEA value between 0.08 and 0.10 indicates moderate fit. Based on table 4, it is known that RMSEA is in the category of good fit.

Table 7. Construct Reliability (CR) Analysis

Constructs	M	σ^2	α	CR
All Dimensions S-DL	3.16	0.26	0.96	0.78
Learning Motivation	3.29	0.28	0.70	0.76
Learning Strategies	3.10	0.27	0.80	0.83
Learning Activities	3.07	0.25	0.81	0.85
Learning Evaluation	3.08	0.25	0.86	0.85
Interpersonal Comm.	3.11	0.26	0.81	0.78
Personal Responsibility	3.24	0.27	0.85	0.82
Learning Autonomy	3.23	0.24	0.89	0.83

Moreover, when discussing the validation process, focusing solely on validity without considering reliability appears to be incomplete (Firdaus et al., 2021). Both aspects must be addressed to ensure the accuracy and consistency of the instrument. The results of the reliability test are presented in Table 7.

All dimensions of S-DL have Alpha-Cronbach (α) and construct reliability (CR) values of 0.96 and 0.78. The reliability value is >0.70 so that the developed S-DL instrument has high internal consistency in the latent construct (Huda et al., 2023). The highest CR value was found in the learning engagement factor of 0.85, indicating that involvement in learning is the most strongly measured aspect by its indicators. Meanwhile, the learning orientation and learning autonomy factors also have high CR, 0.83 and 0.85 respectively, indicating that long-term learning orientation and learning independence can be measured consistently. The learning strategies factor of 0.83 and personal responsibility of 0.82 also have very good reliability, indicating that learning strategies and personal responsibility in the learning process can be measured accurately. Although the interpersonal communication factor has the lowest CR (0.78), this value is still in the good and acceptable category, indicating that the indicators in this factor remain consistent in measuring the interpersonal communication aspect in independent learning.

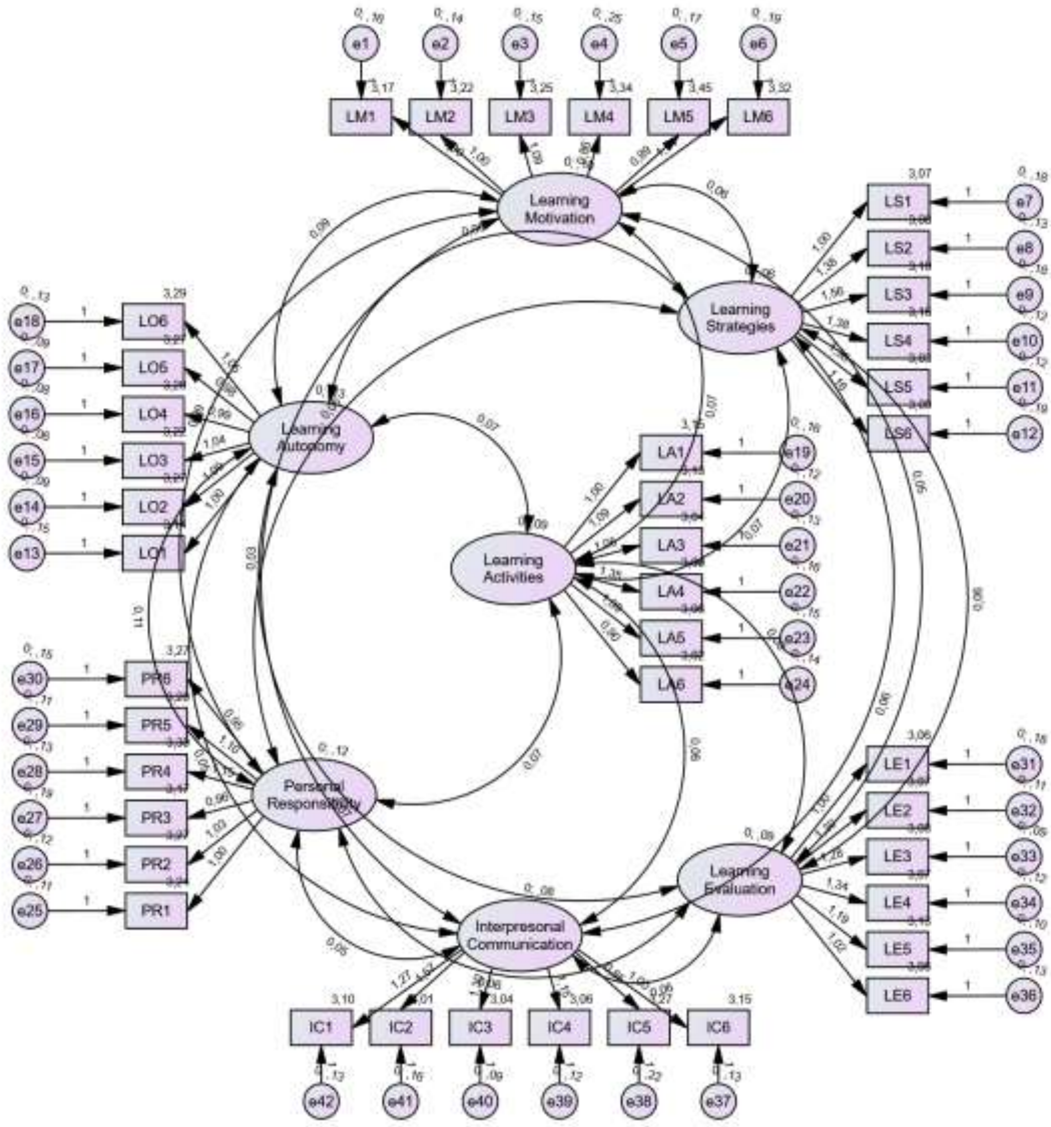

Figure 3. CFA path diagram (model I)

Discussion

This study aims to develop instruments to measure the readiness of S-DL as one of the competencies of the 21st century (Hew et al., 2016; Morris, 2019; Pimdee et al., 2023; Tan & Ling, 2014), especially for prospective science teachers and technology. Initially, seven S-DL dimensions were proposed, namely learning motivation, learning strategies, learning activities, learning evaluation, interpersonal communication, personal responsibility, and learning autonomy. Based on these dimensions, as many as 42 items are formulated.

The instrument has been examined by a team of experts and has been tested for readiness for prospective science and technology teachers. The average Aiken's V coefficient of 1.00 (CI 95% in the range of 0.57 - 1.00), which shows all expert judges state all the S -DL questionnaire statements valid from the material and construction aspects. A number of revisions were carried out after a study by a team of experts and limited trials.

Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA) have been carried out to find out the S-DL instrument properties which include the validity and reliability of the instrument. All items have a loading factor value> 0.4 so that all items show good construct validity. KMO and Bartlett's Test from EFA results showed the fulfillment of criteria for factor analysis. The CFA results showed several compatibility indicators, one main indicator is the CMIN/DF ratio that shows the excellent fit category. These results indicate the framework model (Figure 1) is a model selected and suitable in the development of S-DL instruments. The results of reliability analysis indicate that all S-DL dimensions developed have a good internal consistency value.

Based on the analysis results, the total variance explained by the seven dimensions in the S-DL model for prospective science and technology teachers is 93.50%. This value indicates that this model has very high power in explaining the factors that influence the readiness for independent learning among prospective science and technology teacher students. With a total variance above 70%, this model is included in the "very strong/excellent" category (Fisher, 2007; Sumintono & Widhiarso, 2015), so it can be relied on as a valid and representative measurement instrument. This result is higher than the findings of Chen et al. (2023) who developed the S-DL instrument with a total variance percentage of 52.10% using the factor analysis method.

Of the seven dimensions analyzed, learning evaluation dimension has the highest contribution to the total variance, which is 15.86%, which indicates that active involvement in learning is the most dominant element in S-DL readiness. This indicates that this factor is very close in directing students who are more involved in monitoring learning progress and evaluating the learning process and results. Reflecting and assessing the effectiveness of one's own performance and strategies in achieving learning goals is very important in self-regulation in learning (Radovic & Seidel, 2024; Tan & Ling, 2014).

In addition, other dimensions such as learning activities at 14.84% and learning strategies at 14.60%, also play an important role in S-DL readiness. This shows that students' ability to develop learning strategies and take initiative in the learning process is an aspect that contributes to the success of independent learning. These two factors are strong factors in forming the S-DL dimension. This result is not different from Gao et al. (2023) findings in constructing the SDL instrument, which also showed a percentage of variance of 14.44% in the learning plan and activity factors. The findings of other studies (Lufri et al., 2023) also show that learning strategies has a major influence on the success of the learning process. Meanwhile, active learning is also a determinant of learning success (Ismail et al., 2024), so that the success factor of S-DL is also determined by the activeness of students in learning. Measurement of learning activities needs to be emphasized (Prihartina et al., 2023), to determine the success of the learning strategy implemented.

Personal responsibility, interpersonal communication, and learning motivation have variances of 12.6%, 11.8% and 10.39% respectively act as supporting factors for S-DL readiness, although they are not the most dominant factors compared to direct involvement in learning. This is different from what was stated by Joa et al. (2023) that personal responsibility is a basic and primary role in S-DL. The motivation factor is a factor with the smallest percentage of variance as a shaper of the S-DL instrument. The results of this study are supported by the findings of other studies (Kumar et al., 2021), which also show that the desire to learn or motivation to learn is a factor with the smallest percentage of variance of the S-DL instrument.

Overall, these results show that the developed instrument is able to measure S-DL readiness comprehensively, with the main factors reflecting the characteristics of prospective science and technology teacher students in facing the challenges of independent learning. With a high total variance, this model can be used as a valid evaluation tool and can be further developed, especially by considering the increasingly developing digital learning aspects in 21st century education.

This developed S-DL instrument can be used to measure S-DL Candidates for Science and Technology Teachers. S-DL is one of the important competencies for Candidates for Science and Technology teachers (Mercado, 2024). Various learning strategies are used to improve students' S-DL such as project-based learning, inquiry-based learning, problem-based learning and a number of other learning strategies (Brandt, 2020).

However, S-DL measurements comprehensively become important as an evaluation of the success of the learning strategy used to improve S-DL. In addition, complete measurement of S-DL dimensions can also be useful in mapping the achievements of each S-DL dimension and contributing to designing more effective learning strategies (Kırıkkaya & Yıldırım, 2021), and increasing S-DL students of Candidates for Science and Technology Teachers.

However, there are limitations of this study, namely that the instrument developed does not include questions or scales to measure S-DL in the context of technology-based learning. In addition, psychometric measurements have not considered various demographic aspects of respondents as measured by Sultana et al. (2024). Future research needs to apply this instrument by considering the demographic variation aspects of respondents because there are still other factors that influence the S-DL dimensions. Future research should focus on refining the instrument by integrating items that assess students' attitudes and readiness for independent learning in a digital environment, to ensure its application in the 21st century education era.

Conclusion

This study developed and validated an S-DL instrument to assess the self-directed learning readiness of prospective science and technology teachers. The final instrument consists of 42 items representing seven dimensions of S-DL, which confirmed to have strong content and construct validity. Confirmatory Factor Analysis results further demonstrated that the proposed framework is both valid and reliable. Beyond its psychometric properties, this study contributes theoretically by reinforcing the multidimensional nature of S-DL, emphasizing its role in fostering autonomy, self-regulation, and lifelong learning in science and technology education.

Acknowledgments
The authors want to thank the expert teams from the Indonesian University of Education to validate the instrument.

Author Contributions
Conceptualizations, W., and A.S.W.; Methodology, W., and A.S.W.; Software, W.; Formal Analysis, W., and A.S.W.; Investigation, W.; Resources, A.S.W.; Data Curation, W.; Writing-Original Draft Preparation, W.; Writing-Review and Editing, W., and A.S.W.; Visualization, W.; Supervision, A.S.W., A.S.H., and A.S.M.; Validation, A.S.W., A.S.H., and A.S.M. All authors have read and agreed to the published version of manuscript.

Funding
The authors would like to thank the Ministry of Education, Culture, Research and Technology of the Republic of Indonesia through DRTPM and the Universitas Pendidikan Indonesia for providing this postgraduate research funding with Contract Number: 082/E5/PG.02.00.PL/2024.

Conflicts of Interest
There is no conflict of interest in this research article.

References

Acar, C., Kara, İ., & Ekici, F. T. (2015). Development of Self Directed Learning Skills Scale for Pre-Service Science Teachers. *International Journal of Assessment Tools in Education*, *2*(2), 3–13. https://doi.org/10.21449/ijate.239562

Alemdar, M., & Anılan, H. (2020). The Development and Validation of the Emotional Literacy Skills Scale. *International Journal of Contemporary Educational Research*, *7*(2), 258–270. https://doi.org/10.33200/ijcer.757853

Brandt, W. C. (2020). *Measuring Student Success Skills: A Review of the Literature on Self-Directed Learning* (Issue Maret). Dover, NH: National Center for the Improvement of Educational Assessment.

Chen, S., & Fan, J. (2023). Validation of the psychometric properties of the Self-Directed Learning Readiness Scale. *Nursing Open*, *10*(3), 1639–1646. https://doi.org/10.1002/nop2.1418

Cheng, S., Kuo, C., Lin, K., & Lee-hsieh, J. (2010). Development and preliminary testing of a self-rating instrument to measure self-directed learning ability of nursing students. *International Journal of Nursing Studies*, *47*(2010), 1152–1158. https://doi.org/10.1016/j.ijnurstu.2010.02.002

Eliyawati, E., Widodo, A., Kaniawati, I., & Fujii, H. (2023). The Development and Validation of an Instrument for Assessing Science Teacher Competency to Teach ESD. *Sustainability*, *15*(3276), 1–14. https://doi.org/10.3390/su15043276

Firdaus, L., Masiah, M., Ibrohim, I., Lestari, S. R., Dewi, I. N., Mahsul, A., & Muliadi, A. (2021). Translation of Reflective Thinking Questionnaire: A Structural Equation Model. *Jurnal Penelitian Pendidikan IPA*, *7*(SpecialIssue), 305–311. https://doi.org/10.29303/jppipa.v7ispecialissue.1036

Fisher, M., King, J., & Tague, G. (2001). Development of a self-directed learning readiness scale for nursing education. *Nurse Education Today*, *21*, 516–525. https://doi.org/10.1054/nedt.2001.0589

Fisher, W. P. (2007). Rating Scale Instrument Quality Criteria. *Rasch Measurement Transactions*, *21*(1), 1095. Retrieved from http://www.rasch.org/rmt/rmt211m.htm.

Gao, Z., Zhang, L., Ma, J., Sun, H., Hu, M., Wang, M., Liu, H., & Guo, L. (2023). Reliability and validity of the Chinese version of hte self-directed learning instrument in Chinese nursing students. *BMC Nursing*, *22*(51), 1–9. https://doi.org/10.1186/s12912-023-01201-3

Guglielmino, L. M. (1977). *Development of the self-directed learning readiness scale*. University of Georgia.

Gusmanida, G., Sujati, H., & Herwin, H. (2024). Testing the Construct Validity and Reliability of the Student Learning Motivation Scale Using Confirmatory Factor Analysis (CFA). *Jurnal Penelitian Pendidikan IPA*, *10*(7), 4227–4234. https://doi.org/10.29303/jppipa.v10i7.7518

Hew, K. F., Law, N., Wan, J., Lee, Y., & Kwok, A. (2016). Self-directed learning in science education: Explicating the enabling factors. *Proceedings of International Conference of the Learning Sciences, ICLS*, *1*, 679–686. https://doi.org/10.22318/icls2016.88

Huda, N., Rohaeti, E., & Ikhsan, J. (2023). Investigating the Attitudes of Chemistry Students Towards Blended Learning: A Survey Cross Sectional. *Jurnal Penelitian Pendidikan IPA*, *9*(4), 1621–1631. https://doi.org/10.29303/jppipa.v9i4.2784

Ismail, I. A., Jhora, F. U., & Insani, M. (2024). Enhancing Science Learning Activities through the Implementation of Discovery Learning and Teaching at the Right Level Method. *Jurnal Penelitian Pendidikan IPA*, *10*(4), 1886–1895. https://doi.org/10.29303/jppipa.v10i4.7359

Jin, M., & Ji, C. (2021). The correlation of metacognitive ability, self-directed learning ability and critical thinking in nursing students: A cross-sectional study. *Nursing Open*, *8*(2), 936–945. https://doi.org/10.1002/nop2.702

Joa, C. Y., Abuljadail, M., & Ha, L. S. (2023). YouTube self-directed learning in the US and Taiwan: an application of the personal responsibility orientation model. *Online Information Review*, *2023*. https://doi.org/10.1108/OIR-01-2021-0051

Kamp, A. (2019). Science and Technology Education for 21st Century Europe: Discussion Paper. *CESAER*, *2019*. https://doi.org/10.5281/zenodo.3582544

Kırıkkaya, E. B., & Yıldırım, İ. (2021). Investigating the Effect of Using Web 2.0 Tools on 7th-Grade Students' Academic Achievements in Science and Self-Directed Learning with Technology. *Journal of Turkish Science Education*, *18*(3), 439–460. https://doi.org/10.36681/tused.2021.83

Knowles, M. S. (1975). *Self Directed Learning*. Cambridge: Englewood Cliffs.

Kumar, A. P., Omprakash, A., Kumar, P., Mani, C., Swaminathan, N., Maheshkumar, K., Maruthy, K. N., Sathiyasekaran, B. W. C., Vijayaraghavan, P. V, & Padmavathi, R. (2021). Validation of Internal structure of Self - Directed Learning Readiness Scale among Indian Medical Students using factor analysis and the Structural equation Modelling Approach. *BMC Medical Education*, 1–13. https://doi.org/10.1186/s12909-021-03035-6

Kuo, H. (2019). Promoting college student's learning motivation and creativity through a STEM interdisciplinary PBL human-computer interaction system design and development course. *Thinking Skills and Creativity*, *31*, 1–10. https://doi.org/10.1016/j.tsc.2018.09.001

Li, J., Zhang, L., Zhou, J., Wang, G., Zhang, R., Liu, J., Liu, S., Chen, Y., Yang, S., Yuan, Q., & Li, Y. (2022). Development and validation of self - management scale for tuberculosis patients. *BMC Infectious Diseases*, *22*(502), 1–13. https://doi.org/10.1186/s12879-022-07483-3

Loeng, S. (2020). Self-Directed Learning : A Core Concept in Adult Education. *Hindawi Educational Research International*, *2020*, 12. https://doi.org/10.1155/2020/3816132

Lufri, Verina, F., Razak, A., & Sholichin, M. (2023). Analysis the Implementation of the Active Learning Learning Process in MTs Negeri Throughout Tanah Datar Regency. *Jurnal Penelitian Pendidikan IPA*, *9*(12), 11401–11406. https://doi.org/10.29303/jppipa.v9i12.5115

Mercado, J. (2024). Self-Directed Learning in STEM Teaching and Learning: A Systematic Review of Empirical Evidence. *Scientechno: Journal of Science and Technology*, *3*(1), 53–84. https://doi.org/10.55849/scientechno.v3i1.739

Morris, T. H. (2019). Self-directed learning: A fundamental competence in a rapidly changing world. *International Review of Education*, *65*(4), 633–653. https://doi.org/10.1007/s11159-019-09793-2

Morris, T. H. (2020). Creativity through self-directed learning: three distinct dimensions of teacher support. *International Journal of Lifelong Education*, *39*(2), 168–178. https://doi.org/10.1080/02601370.2020.1727577

Naqsyahbandi, F., & Prodjosantoso, A. K. (2023). Instrumental Analysis of Student Perceptions of Chemistry Learning with the STEM Approach at the end of the Covid-19 Pandemic using Second Order Confirmatory Factor Analysis. *Jurnal Penelitian Pendidikan IPA*, *9*(3), 1480–1485. https://doi.org/10.29303/jppipa.v9i3.2186

Nugroho, O. F., Permanasari, A., Firman, H., Riandi, R., Teacher, P., Program, E., Unggul, U. E., Program, S. E., & Indonesia, U. P. (2021). The Urgency of STEM Education in Indonesia. *Jurnal Penelitian Dan*

Pembelajaran IPA, *7*(2), 260–279. https://doi.org/10.30870/jppi.v7i2.5979

Pacheco, C. S., & Herrera, C. I. (2023). Development and validation of the Complex Thinking Assessment Instrument (CTAI). *Thinking Skills and Creativity*, *48*(December). https://doi.org/10.1016/j.tsc.2023.101305

Penfield, R. D., & Giacobbi, P. R. (2004). Applying a Score Confidence Interval to Aiken ' s Item Content-Relevance Index. *Measurement in Physical Education and Exercise Science*, *8*(4), 37–41. https://doi.org/10.1207/ s15327841mpee0804_3

Pimdee, P., Ridhikerd, A., Moto, S., & Siripongdee, S. (2023). How social media and peer learning influence student-teacher self-directed learning in an online world under the ' New Normal .' *Heliyon*, *9*(3), e13769. https://doi.org/10.1016/j.heliyon.2023.e13769

Prihartina, Y., Salirawati, D., & Wiyarsi, A. (2023). Measuring Student Learning Activities Through Articulate Storyline 3-Based Mobile Learning. *Jurnal Penelitian Pendidikan IPA*, *9*(4), 2252–2258. https://doi.org/10.29303/jppipa.v9i4.3113

Radovic, S., & Seidel, N. (2024). Self-regulated learning support in technology enhanced learning environments: A reliability analysis of the SRL-S Rubric. *Journal of Assessment Tools in Education*, 675–698. https://doi.org/10.21449/ijate.1502786

Rashifah, H., Rahmawati, Y., & Riyadi. (2023). Development of Instrument of Emotional Climate and Attitude Measurement on Science Learning Environment. *Jurnal Penelitian Pendidikan IPA*, *9*(11), 9313–9323. https://doi.org/10.29303/jppipa.v9i11.5029

Robinson, J. D., & Persky, A. M. (2020). Developing self-directed learners. *American Journal of Pharmaceutical Education*, *84*(3), 292–296. https://doi.org/10.5688/ajpe847512

Salleh, U. K. M., Zulnaidi, H., Rahim, S. S. A., Zakaria, A. R. Bin, & Hidayat, R. (2019). Roles of self-directed learning and social networking sites in lifelong learning. *International Journal of Instruction*, *12*(4), 167–182. https://doi.org/10.29333/iji.2019.12411a

Sari, U., Duygu, E., Şen, Ö. F., & Kirindi, T. (2020). The Effects of STEM Education on Scientific Process Skills and STEM Awareness in Simulation Based Inquiry Learning Environment. *Journal of Turkish*, *17*(3), 387–405. https://doi.org/10.36681/tused.2020.34

Suharlan, L. S., Arsyad, M., & Palloan, P. (2023). The Influence of Problem Based Learning and Self Directed Learning Models on Students ' Problem Solving Abilities. *Jurnal Penelitian Pendidikan IPA*, *9*(12), 11386–11393. https://doi.org/10.29303/jppipa.v9i12.4730

Sultana, S., Panda, B. K., & Sinha, M. (2024). Evaluating Self-directed Learning of Students across different Educational Level. *Educational Quest: An International Journal of Education and Applied Social Sciences*, *15*(01), 15–26. https://doi.org/10.30954/2230-7311.1.2024.3

Sumintono, B., & Widhiarso, W. (2015). *Aplikasi Pemodelan Rasch pada Assessment Pendidikan [Application of Rasch Modeling in Educational Assessment]* (1st ed.). Penerbit Trim Komunikata.

Swarni, A., Herwin, & Sujati. (2024). Testing the Construct Validity and Reliability of the Student Learning Interest Scale Using Confirmatory Factor Analysis (CFA). *Jurnal Penelitian Pendidikan IPA*, *10*(9), 6322–6330. https://doi.org/10.29303/jppipa.v10i9.8794

Taber, K. S. (2018). The Use of Cronbach's Alpha When Developing and Reporting Research Instruments in Science Education. *Research in Science Education*, *2018*(48), 1273–1296. https://doi.org/10.1007/s11165-016-9602-2

Tan, L., & Ling, J. K. H. (2014). *Self-directed learning: Learning in the 21st century*. Educational Technology Division, The Singapore Ministry of Education.

Torres-Malca, J. R., Vera-Ponce, V. J., Zuzunaga-Montoya, F. E., Talavera, J. E., & De La Cruz-Vargas, J. A. (2022). Content validity by expert judgment of an instrument to measure knowledge, attitudes and practices about salt consumption in the peruvian population. *Revista de La Facultad de Medicina Humana*, *22*(2), 273–279. https://doi.org/10.25176/rfmh.v22i2.4768

Van Lankveld, W., Maas, M., Van Wijchen, J., Visser, V., & Staal, J. B. (2019). Self-regulated learning in physical therapy education: A non-randomized experimental study comparing self-directed and instruction-based learning. *BMC Medical Education*, *19*(1), 1–9. https://doi.org/10.1186/s12909-019-1484-3

Williamson, S. N. (2007). Development of a self-rating scale of self-directed learning. *Nurse Researcher*, *14*(2), 66–83. https://doi.org/10.7748/nr2007.01.14.2.66.c6022