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Research Article

How can scientific talent be recognized in the early years? Validating a scientific talent test for pre-school age

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Abstract

Currently, there is no scientific talent test for preschool age. In the "Kleine BegInNa – Kleine begabt in Naturwissenschaften [small ones gifted in science]" project, such a test instrument was developed. It aims to determine scientific talent in pre-school. This is of particular relevance since subsequent support and promotion along with individual competences identified by this test can have a long-term positive effect on the later school performance of the children. Here, our test instrument structure is examined and checked in a comparative study with comparative tests of already validated intelligence instruments in a sample of 69 children aged between four and a half and six and a half years (n_{male}= 31; n_{female} = 38) in North-Rhine Westphalia, Germany. Almost all paired subtests (i.e., test pairs from the scientific talent test and equivalent subtests of existing intelligence diagnostics) positively correlate with each other. This indicates the validity of our scientific talent test. An exploratory factor analysis did not reveal any separation of individual competences areas from the scientific talent test subtests with respect to the internal structure, but all subtests load on the factor *general scientific talent*, with a variance clarification of 41.17%. Further studies are needed to confirm the test structure with a bigger and more inclusive sample.

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Introduction

Within the last decade, the demand for science education and support in pre-primary education (e.g., Lück, 2013; NRC, 2013; OECD, 2018) has become increasingly more important. As a result, there is a need to fund pedagogical specialists not only to train them on how to connect and integrate new knowledge into the prior knowledge and pre-concepts of the children but also to expand existing thought structures children already have by using a scientific approach (Bürgermeister et al., 2019; Leuchter et al., 2014). A prerequisite to successfully sustain support is to create an appealing learning environment designed with science-specific principles (Leuchter & Saalbach, 2014). In addition to collecting diverse experiences for pre-concept differentiation (Schneider et al., 2012), creating cognitive conflicts (Hardy et al., 2006), an active child-specialist interaction (Gisbert, 2004) and a research-discovering learning processes (Leuchter &

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Saalbach, 2014), determining the amount of previous knowledge is also considered an important parameter when promoting connectivity (Carey, 2000). However, a literature review by Schäfers and Wegner (2020) showed that there are hardly any scientific test instruments to comprehensively diagnose scientific talent in pre-school. Moreover, the effectiveness and quality of promotion are directly dependent on the scientific and didactic competencies of the pedagogical specialist (e.g., Bruns, 2014; Kauertz & Gierl, 2014; Schäfers & Wegner, 2020).

Children show a high interest in scientific phenomena and questions (Textor, 2012) and can train scientific literacy (Steffensky, 2017) in STEM[6] subjects at an early stage with appropriate support (Kaderavek et al., 2020). Due to the special brain structure with many synapses that children have at this age (Braun, 2012), they are immediately able make new connections, integrate new aspects and understand relationships between concepts. This logical thought process is important for science education (Sodian & Thoermer, 2002). In addition, current events such as climate change, the pandemic or rapid technological progress show that it is important for children to acquire scientific skills at an early age to deal with such problems and challenges (Kähler et al., 2020; Schäfers & Wegner, 2021). With this in mind, day-care facilities should play a central role in the promotion of science education (Schäfers & Wegner, 2022a). Long-term studies demonstrate that acquired skills in preschool are important for later school performance (e.g., Claessens & Engel, 2013; Guo et al., 2015; Morgan et al., 2016). These studies led to the implementation of science education in educational plans within the federal states (Roßbach, 2008; Steffensky et al., 2012) and establishes pre-school as the first stage of the education system in Germany.

Scientific Competences, Scientific Literacy and Scientific Education

Since little is known about scientific competencies in children (Haus der kleinen Forscher, 2018), a definition by Weinert (2001) is used as a basis. In this context, competencies are understood as the cognitive abilities and skills available in individuals or that can be learned by them to solve specific problems, as well as the associated motivational, volitional, and social readiness and abilities to be able to use the problem solutions successfully and responsibly in variable situations (Weinert, 2001). Thus, for the present article, competence is defined as the ability of a person to successfully solve different types of problems. To relate this to the natural sciences, the *IPN - Leibniz Institute for Science and Mathematics Education* uses the description of scientific competence from the *PISA Consortium Germany* (2007), to define scientific competency with a scientific literacy approach (IPN, n.d.). According to this, there are three sub-competencies of scientific literacy: the recognition and formulation of questions that can be investigated and answered scientifically, the description and explanation of scientific phenomena and the interpretation of scientific evidence (IPN, n.d.). A distinction is made between scientific knowledge and knowledge about science, and affective characteristics, such as interest, motivation, or individual involvement, are identified as central to the acquisition of scientific literacy. The goal of successful science education is thus to strengthen interest, show appreciation for research processes and develop a sense of responsibility for the outside world. This definition also guides the understanding of basic science education in pre-school education for this article, since the foundation for critical-reflexive attitudes and scientific thinking structures are established at an early age.

Why Scientific Talent and Not Giftedness?

Hardly any other topic is as controversial in giftedness research as the diagnosis of giftedness in early childhood. Several authors agree that giftedness should be recognized during preschool, as children can only become balanced and overcome difficulties if they receive support that corresponds to their cognitive performance level (Hartmann et al., 2016). Haese (2020) even postulates that giftedness can be lost without appropriate support. Through polarizing articles in the media and educational guidebooks, parents are often given the impression that a missed diagnosis and a lack of individual support can result in behavioral problems, which could have been prevented if detected early (Rohrmann & Rohrmann, 2017).

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[6] *"STEM* is a broad term that encompasses the academic disciplines of science, technology, engineering and mathematics. Its comparable counterpart is the German acronym MINT for mathematics, informatics, natural science and technology" (Science Blog Uni Bremen, 2023).

Other researchers postulate that talent diagnostics only provide meaningful results at the age of five years and upwards (Baudson et al., 2014), as infantile development can be unpredictable and varies among individuals at an early age (Bergs-Winkels & Schmitz, 2018). It is therefore difficult to differentiate between giftedness and a developmental advantage (Rohrmann & Rohrmann, 2017). They conclude that every child in day-care should be individually perceived and differentially supported according to their developmental needs and competences, but that this does not require the labelling of giftedness and that a diagnosis at this age should not be understood as a long-term prognosis. Therefore, this project only focuses on scientific talent or giftedness (as conceptually overlapping terms; e.g., Stoeger et al., 2018), which is defined as an above-average expression of scientific competence without an IQ-averaging intelligence diagnosis.

Research Concerns

Although there are existing instruments for assessing scientific literacy in elementary school, such as the model to assess scientific literacy development in the *Science-P project* (Hardy et al., 2010), an extensive literature review highlights that there are currently no tests to holistically assess scientific literacy at the pre-school level (Schäfers & Wegner, 2021). The project " Kleine BegInNa " (small ones gifted in science) at the Osthushenrich-Center for Gifted Research at the Faculty of Biology (OZHB) at Bielefeld University (Wegner et al., 2020) focuses on a theoretically sound and practical approach to determine and promote scientific competency in pre-school children (Schäfers & Wegner, 2021), with the following goals in mind (Schäfers & Wegner, 2022a):

- Develop a natural scientific talent test for pre-school age
- Further train for pedagogical professional
- Extend scientific promotion offers for the pre-school level

A natural scientific talent test for pre-school age was developed in 2019 and tested in 2020 with subtests of existing intelligence diagnostic instruments. The present study focuses on validating the test instrument with regard to the following research questions (RQs):

RQ1: Are there correlations between the developed test instrument and comparative tests?

RQ2: How consistent is the internal structure of the developed test instrument (exploratory factor analysis)?

Method

Study design

A comparative study was conducted to validate the scientific talent test, which aims to establish correlations between the results of the first and second tests. Participants were only included if all legal guardians gave their consent. The response rate of the age-eligible children was approximately 75%. Children were first tested with the scientific talent test (t_0) and then, at two-week intervals, tested with fragments from existing intelligence tests (t_1). Each child took the test independently. On average, children needed about 45 minutes to complete the scientific talent test and 35 minutes for the comparison tests. Before the tests, the children were observed in groups for the test administrators to become familiar with the participating children and for the children to get used to the test administrators.

Participants

Test results from 69 children (n_{male} = 31; n_{female} = 38) were used to validate the developed natural scientific talent test instrument. The children were between 4;6 and 6;4 years old and came from three day-care centers in the region of Ostwestfalen-Lippe in North Rhine-Westphalia (Germany).

Test Instrument

Natural Scientific Talent Test

The theoretical basis of the *Natural Scientific Talent Test* for pre-school level is the CHC theory of cognitive abilities according to Cattell (1963), Horn (1991), and Carroll (1993), which is an internationally recognized and frequently used general theory of intelligence (Mickley & Renner, 2019). CHC theory implies a hierarchical differentiation of general intelligence to measure and distinguish between different facets of intelligence (Mickley & Renner, 2010). The theory is a synthesis of the Gf-Gc theory from Cattell and Horn (Horn, 1991; Horn & Blankson, 2005) and the three-stratum theory of Carroll (1993), based on Spearman's (1904) finding that there is a general factor of intelligence, which he called the g-factor. Thus, a three-level hierarchical model of intelligence emerged, which is further broken down per level. Stratum III is described as the overall performance of intelligence (*factor g*). Subordinate to this is the Stratum II level, which divides general intelligence into ten *general abilities* (Carroll, 1993). At the Stratum I level, the general abilities are differentiated into *specific abilities*. This synthetic theory is currently referred to as the model that most differentiates and summarizes intelligence and intelligence structures (Baudson, 2012).

However, not all general and specific abilities summarized in the CHC theory are equally important when developing a natural scientific talent test. Based on the scientific literacy approach (OECD, 2006), which guides science education at pre-school level, intelligence domains relevant for scientific content knowledge and teaching, such as the development of scientific ways of thinking and working, were identified, such as *fluid intelligence (Gf), visual processing (Gv), long-term storage (Glr), processing speed (Gs),* and *quantitative knowledge (Gq)* (Schäfers & Wegner, 2022a). The natural scientific talent test for pre-school age is based on the aforementioned abilities that have been identified as relevant to science and are partly based on sub-tests of already validated test instruments (Schäfers & Wegner, 2022a). In eight tasks, children deal with solving different scientific problems and questions (see table 1). A manual guides trained administrators, and results are recorded, along with an observation sheet (Schäfers et al., 2020), based on the Leuven Engagement Scale (Laevers, 2009).

Table 1. Tests to determine scientific talent

Task	Description
Memorize a story	A story is read and afterwards, they must answer questions about the story.
Spatial memory	The children must discover and name farm animals from pictures.
Number range	A row of 20 wooden cubes is built up in front of the children. Children should give the test administrator as many blocks as the administrator asks them for.
Ordinality	A row of 20 wooden cubes is built up in front of the children. Children should give the test administrator a specific wooden block out of 20 wooden blocks, for example the third or the twelfth.
Recognize the largest quantity	The children should identify which group of animals has the largest amount of a particular species.
Recognize cube sides	On a self-constructed cube, pairs of similar animals are depicted on opposite sides. Children must deduce which animal is (facedown) on the table from a picture.
Continue flower series	The children must recognize the sequence rule in a row of flowers and fill in the missing gap with the matching flower.
What happens if…?	Five experiments on phenomena from inanimate nature are set up and the children must hypothesize what happens in the experiment and why. Depending on the quality of the conjecture, the children receive different points.

Comparative Test

The comparative test is composed of seven subtests of existing intelligence diagnostic instruments, which serve as a template for the natural scientific talent test. The subtests are from the *BIVA* (Schaarschmidt et al., 2004), *HAWIVA-III* (Ricken et al., 2007), *IDS-P* (Grob at al., 2013), and *KABC-II* (Kaufmann & Kaufmann, 2015). There is no equivalent for the subtest “What happens if…?” (see table 2). The subtests of the natural scientific talent test and the fragments of already standardized test instruments differ from each other primarily in their scientific content and methodological focus. Thus, the natural scientific talent test only has the content and the competencies relevant to science.

Table 2. Overview of developed natural scientific talent test subtests compared with existing subtests from different intelligence and diagnostic instruments

Natural scientific talent test (T1)	Comparison test (T2)
Fluid Intelligence (Gf)	
☐ What happens if ...? (T1.7)	☐ no template
☐ Continue flower row (T1.6)	☐ BIVA: Series continuation (T2.6)
Visual processing (Gv)	
☐ Recognize cube sides (T1.5)	☐ HAWIVA-III: Mosaic test (T2.5)
Long-term storage (Glr)	
☐ memorize a story (T1.1)	☐ KABC-II: Atlantis (T2.1)
Processing speed (Gs)	
☐ Spatial thinking (T1.2)	☐ IDS-P: Memory spatial-visual (T2.2)
Quantitative knowledge (Gq)	
☐ Number range (T1.3) Ordinality (T1.3)	☐ IDS-P: Think logically-mathematically (counting, ordinality, concept of quantity [T2.3] ...
☐ Detect largest quantity (T1.4)	☐ ... and Recognizing quantities [T2.4])

Statistical Analysis

Item difficulty and discriminatory power

To determine the quality of the test instrument and the collection of floor and ceiling effects, both the item difficulty and the discriminatory power of each item were calculated. The item difficulty (*Pi*) should be between 30 and 70, the ideal value being reached at 50. An item difficulty < 30 indicates a flooring effect, as the task might be too difficult and not allow differentiation of weak performances, and > 70 indicates a ceiling effect, as it was correctly solved by more than 70% of children. Discriminatory power is directly related to item difficulty and compares each item with the mean value of other items. The discriminatory power should be greater than 0.3.

Correlations

After analyzing quality criteria by evaluating objectivity, reliability, and validity (Schäfers & Wegner, 2022b), correlations between the scientific talent subtests and the comparison test were calculated using SPSS. Since maximum scores between the tests differ, scores were given as percentages.

Explorative factor analysis

To check the internal structure of the developed scientific talent test and to test the scales of the measurement instrument, an exploratory factor analysis was carried out in SPSS (version 28.0.1.0). This aims to show the extent to which the newly developed subtests allow for the same theoretical assumptions as the previously validated subtests. Based on these results, hypotheses can therefore be made about the relational structure of the items in the developed test instrument. Here, the number of dimensions and relationships between the dimensions and variables were determined from the data.

Results

Item Difficulty and Selectivity

Item difficulties range from -19.81 to 100.00 (see table 3). Thus, there are tasks that could be solved by almost all children, but also tasks that could not be solved by any child and some which are mis-keyed and should be revised. The tasks are evenly distributed in difficulty, to cover a wide variety of difficulty levels. Most test items exceed a discriminatory power of 0.25 and can thus be retained for further testing.

Table 3. Item difficulties and discriminatory power of the items of the scientific talent test

		T1.1	T1.2	T1.3	T1.4	T1.5	T1.6	T1.7
Item 1	P_i	2.90	69.08	100	75.36	94.78	45.89	56.52
	$Var(x_1)$	0.03	0.95	0.00	0.19	0.04	0.25	0.88
	$r_{it(1)}$	0.04	0.37	0.00	-0.07	0.12	0.16	0.36
Item 2	P_i	8.70	71.98	34.78	97.10	79.13	16.91	33.33
	$Var(x_2)$	0.08	0.93	0.60	0.03	0.17	0.24	0.64
	$r_{it(2)}$	0.20	0.35	0.29	0.21	0.43	0.48	0.26
Item 3	P_i	0.00	76.33	59.42	72.46	68.38	45.90	7.97
	$Var(x_3)$	0.00	0.89	0.83	0.20	0.69	0.25	0.25
	$r_{it(3)}$	0.00	0.57	0.35	0.30	0.52	0.49	0.17
Item 4	P_i	18.84	71.01	36.23	98.55	74.42	30.43	12.32
	$Var(x_4)$	0.16	0.76	0.56	0.01	1.03	0.25	0.39
	$r_{it(4)}$	0.18	0.40	0.19	0.15	0.57	0.38	0.30
Item 5	P_i	47.83		42.03	59.42	87.82	13.04	48.55
	$Var(x_5)$	0.25		0.80	0.25	0.12	0.23	1.03
	$r_{it(5)}$	0.24		0.59	0.34	0.32	0.51	0.28
Item 6	P_i	84.06		48.13	82.61	85.77	-6.28	30.43
	$Var(x_6)$	0.14		0.84	0.15	0.40	0.16	0.80
	$r_{it(6)}$	0.35		0.50	0.15	0.48	0.28	0.13
Item 7	P_i	55.07		39.74	73.91	81.03	-0.48	15.94
	$Var(x_7)$	0.25		0.77	0.20	0.50	0.19	0.54
	$r_{it(7)}$	0.24		0.50	0.09	0.56	0.34	0.09
Item 8	P_i	14.49		20.67	81.16	84.14	-14.01	7.79
	$Var(x_8)$	0.13		0.40	0.16	0.81	0.13	0.25
	$r_{it(8)}$	0.16		0.29	0.40	0.58	0.36	0.25
Item 9	P_i	27.54			76.81		-17.87	55.80
	$Var(x_9)$	0.20			0.18		0.10	0.60
	$r_{it(9)}$	0.18			0.35		0.23	0.03
Item 10	P_i	68.12			37.68		-19.81	34.06
	$Var(x_{10})$	0.22			0.24		0.09	0.37
	$r_{it(10)}$	0.27			0.01		0.25	0.22
Item 11	P_i							39,13
	$Var(x_{11})$							0.97
	$r_{it(11)}$							-0.14
Item 12	P_i							25.36
	$Var(x_{12})$							0.55
	$r_{it(12)}$							-0.04
Item 13	P_i							21.74
	$Var(x_{13})$							0.69
	$r_{it(13)}$							0.17
Item 14	P_i							48.55
	$Var(x_{14})$							0.97
	$r_{it(14)}$							0.03

Correlations

The data is made up by the subject number (ID) along with the scores (t0 and t1) of the individual subtest pairs. Except for the pair *Recognize Largest Quantity* and *Recognize Quantities* ($r = .04$, $p = .74$, $n = 67$), all other subtests were significantly correlated with moderately strong effects (Cohen, 1992): *Remembering an story* and *Atlantis* ($r = .37$, $p < .01$, $n = 67$), *Spatial Memory* and *Memory Spatial-Visual* ($r = .44$, $p < .001$, $n = 67$), *Number Range + Ordinality* and *Thinking Logical-Mathematical* ($r = .44$, $p < .001$, $n = 67$), *Recognizing Cube Sides* and *Mosaic Test* ($r = .43$, $p < .001$, $n = 67$), and *Continuing Flower Series* and *Continuing Sequence* ($r = .40$, $p < .01$, $n = 67$) (see table 4).

Table 4. Intercorrelation matrix for testing the correlation between developed subtests and equivalent fragments of already validated intelligence tests

		T2.1	T2.2	T2.3	T2.4	T2.5	T2.6
T1.1	*r*	.37*	.21	.13	.06	.15	.16
	p (2-sided)	< .01*	.08	.30	.64	.24	.21
	n	67	67	67	67	67	67
T1.2	*r*	.215	.44*	.27*	.19	.26*	.25*
	p (2-sided)	.08	< .001*	< .05*	.13	< .05*	< .05*
	n	67	67	67	67	67	67
T1.3	*r*	.27*	.41*	.44*	.38*	.43*	.54*
	p (2-sided)	< .05*	< .001*	< .001*	< .01*	< .001*	< .001*
	n	67	67	67	67	67	67
T1.4	*r*	.25*	.36**	.20	.04	.16	.13
	p (2-sided)	< .05*	< .01**	.11	.74	.19	.29
	n	67	67	67	67	67	67
T1.5	*r*	.32*	.30*	.46*	.15	.43*	.38*
	p (2-sided)	<.01*	< .05*	< .001*	.24	< .001*	.001*
	n	67	67	67	67	67	67
T1.6	*r*	.374*	.09	.34*	.29*	.37*	.40*
	p (2-sided)	< .01*	.48	< .01*	< .05*	< .01*	< .01*
	n	67	67	67	67	67	67

*Notes: Pearson's correlation effect size = r. *p < .05; n = sample size.*

Exploratory factor analysis

Both Bartlett's test (*chi-square* (21) = 105.406, p < .001), which confirms that the constructs are correlated, and the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO = .732), which can be classified as fairly good according to Kaiser and Rice (1974), indicate that the variables included are suitable for exploratory factor analysis. Therefore, a principal component analysis with direct-oblimin rotation, as there are inter-individual correlations between subtests, was used. Although this indicates two factors with an eigenvalue greater than 1.0, a one-factor solution was chosen based on the Screeplot (see figure 1), which explains a total of 41.17% of the variance.

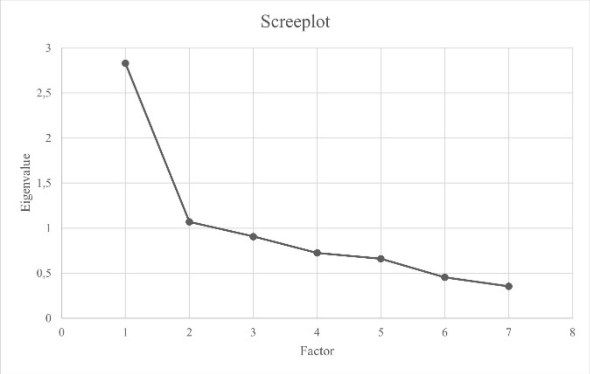

Figure 1. SPSS output - Screeplot to the exploratory factor analysis

Individual dimensions from the analysis equally contribute to the overall variance (see table 5).

Table 5. Communalities for the elucidation of the share in the total variance

	Initially	**Extraction**
Memrorize a story	1.000	.575
Spatial memory	1.000	.654
Number range + ordinality	1.000	.607
Detect largest quantity	1.000	.660
Recognize cube sides	1.000	.407
Continue flower series	1.000	.408
What happens if...?	1.000	.639

Notes: Extraction method: principal component analysis

Due to the one-factor solution with the overall scientific performance as the general factor, a re-analysis was performed to determine a modified component matrix. Since only one factor is selected, the direct-oblimin rotation is omitted. The component matrix indicates that all variables have at least one loading of + .540 and therefore can be uniquely assigned to factor 1 (see table 6).

Table 6. Adjusted component matrix

	Component 1
Memrorize a story	.606
Spatial memory	.631
Number range + ordinality	.725
Detect largest quantity	.585
Recognize cube sides	.682
Continue flower series	.702
What happens if…?	.540

Discussion

This study explored correlations between the subtests of our developed scientific talent test and existing subtests are, as well as the internal structure of our scientific talent test. All but one of the test pairs show positive significant correlations, indicating the validity of our test to measure the same competences as comparative tests. It is also noticeable that further pairings between subtests within our test produce significant correlations. These correlations contradict a specificity and differentiation of the individual competence areas. In addition, we also investigated the structure of the scientific talent test and show that due to the one-factor solution, individual competence areas of the scientific talent test cannot be differentiated from each other. The lack of differentiation may be explained by the fact that cognitive abilities only develop during their primary school years (Büttner, 2017). However, since we did not see a differentiation between the subtests and could only identify one factor, this may be explained as a general score relating to the overall scientific performance. Following studies should explore whether scientific aptitude can be determined as a general factor by the test instrument or as the intelligence factor g according to Spearman (1907). Item difficulty and discriminatory power show that some items are not suitable for differentiation as a few have floor and ceiling effects. Nevertheless, some items will still remain in the test in order to identify both strengths and weaknesses. It is particularly important for children of this age to find the motivation and self-confidence to tackle difficult tasks through easy tasks. Further data collection for a review of the results of this study is currently underway. Thus, these results will soon be compared with a confirmatory factor analysis.

Limitations of study

As this study has a small sample size (N = 69), it is a drawback to use a one-factor solution, since an N > 300 is often applied to derive meaningful results (Herz, 2021). Nevertheless, the result of the scree plot was used in this study because the one-factor solution supports the theoretical preliminary considerations: Factor 1 can constitute the children's scientific talent, which subdivides during their primary school years (Büttner, 2017). In addition, age was not included in the analysis, preventing us from identifying age-related differences in performance. A differentiation of the results according to age should be done with a larger sample. Follow-up studies should use a confirmatory factor analysis to test the single-factor structure on a new sample.

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