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The Important Role of Spatial Abilities in Learning with Chemical Representations

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Theoretical Framework

1 Relationship between representational competence and content knowledge

- To learn chemical content knowledge (CK) from representations, students require well-developed representational competence (RC). (Rau, 2017, 2018)
  - ⇨ Empirical research provides evidence supporting the distinction between the two concepts. (Edelsbrunner et al., 2023; Nickel et al., 2025; Nitz et al., 2014)
- *Interpretation*, *translation*, and *construction* (fig. 1) are considered the core of RC. (Gilbert, 2008; Kozma & Russell, 1997, 2005)
  - ⇨ The three skills are highly interrelated, and their separability is questionable. (Nickel et al., 2025; Scheid et al., 2018; Taskin et al., 2015; Ward et al., 2025)

Interpretation [2]	The ability to identify, analyze, and interpret features and patterns of chemical representations and to use them to describe chemical phenomena. [1]
Translation [2]	The ability to translate a chemical representation into one with a similar degree of abstraction and explicit information without changing the represented entity itself and to change perspectives. [1]
Construction [2]	The ability to construct or select a (new) chemical representation by significantly modifying the degree of abstraction and to generate representations that are distinct from the original. [1]

Figure 1: *Lower-level skills of RC ([1] Kozma and Russell, 1997, 2005) and their categorization ([2] Nitz, 2012).*

2 Spatial abilities and their relevance in chemistry

- Spatial abilities are positively correlated with chemistry performance, making them strong predictors of success. (Buckley et al., 2018; Stieff & Uttal, 2015; Uttal et al., 2013; Uttal & Cohen, 2012; Yang et al., 2020)
  - ⇨ Especially four spatial factors seem to be of crucial importance:
    - **1)** *flexibility of closure* (pattern recognition) [2,3,6,9]
    - **2)** *visualization* (mental manipulation) [5,8]
    - **3)** *speeded rotation* (2-D rotation) [5,9]
    - **4)** *spatial relation* (3-D rotation) [1,3,4,5,7]

([1] Bodner & Guay, 1997; [2] Bodner & McMillen, 1986; [3] Carter et al., 1987; [4] Harle & Towns, 2011; [5] Harris et al., 2013; [6] Hodgkiss et al., [7] 2018; Sorby, 2009; [8] Wai et al., 2009; [9] Wu & Shah, 2004)

Research on spatial abilities in chemistry often emphasizes a **single spatial factor**, while **neglecting other relevant factors**, their **intercorrelations**, and the **role of CK**.

Research Questions, Designs and Methods

RQ1: What correlative relationship can be identified between spatial factors and both RC and declarative CK in chemistry?

RQ2: Which spatial factors predict performance on representation-based chemistry tasks?

- **Quantitative cross-sectional study with a non-experimental design**
- **Correlation analyses** were conducted to examine the relationships between the constructs (RQ_1), and **path analysis** was used to identify predictor variables and account for interrelations (RQ_2).
- N = 494 (n_{female} = 274, n_{male} = 130, $n_{N/A}$ = 90) students from university preparatory chemistry courses in September/October 2024 (M_{age} = 19.5 a, SD_{age} = 2.7 a; M_{grade} = 11.5 pts (B+), SD_{grade} = 2.5 pts)

Results and Discussion

RQ1: Correlation between spatial factors and both RC and declarative CK

- Most **spatial factors show significant correlations with RC**, with ***speeded rotation***, ***visualization***, and ***spatial relations*** exhibiting the strongest coefficients. (fig. 2)
  - ⇨ The three spatial factors have been identified as important predictors of performance in chemistry. (Buckley et al., 2018; Harle & Towns, 2010; Harris et al., 2013; Sorby, 2009; Wai et al., 2009; Wu & Shah, 2004)
- **Declarative CK showed no significant correlations** with the spatial factors, except for speeded rotation. (fig. 2)
  - ⇨ The acquisition of declarative CK does not require spatial abilities; these abilities likely become important when procedural knowledge is enacted.

spatial abilities	Cronbach's α	RK	declarative CK
visual memory	.79	.25#	.02
speeded rotation	.97	.40***	.23*
flexibility of closure	.98	.33***	.13
perceptual speed	.95	.29**	.13
spatial scanning	.93	.20#	.11
visualization	.79	.45***	.09
spatial relation	.84	.54***	.17

Figure 2: *Cronbach's α to assess internal consistency, and Spearman's rank correlation coefficient (ρ) to examine the relationships between the spatial factors (CTT) and both RK (IRT) and declarative CK (IRT).*

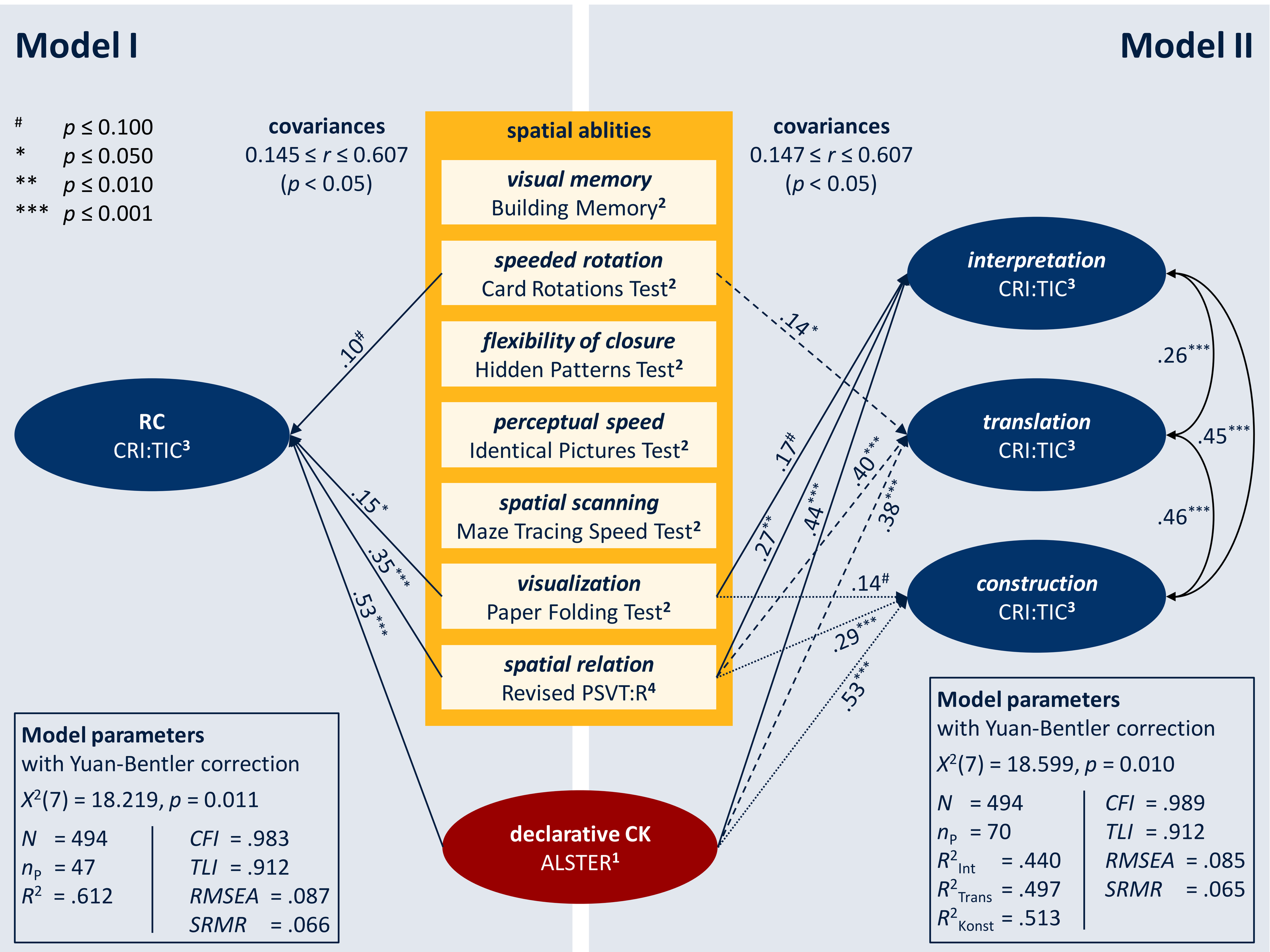

Figure 3: *Path model to assess the influence of spatial factors and declarative CK on RC (Model I), and a more detailed model focusing on the three lower-level skills interpretation, translation, and construction (Model II). Intercorrelations among the spatial factors were considered but not depicted for reasons of clarity ([1] Averbeck, 2021; [2] Ekstrom et al., 1976; [3] Nickel et al., 2025; [4] Yoon, 2011).*

RQ2: Predictors for solving representation-based chemistry tasks

- **Declarative CK** showed the strongest influence, with ***spatial relation***, ***visualization***, and ***speeded rotation*** following in decreasing order. (fig. 3; Model I)
  - ⇨ Considering the intercorrelations among the spatial factors and the influence of declarative CK, the assumptions and findings regarding their relevance can be confirmed in this context. (Buckley et al., 2018; Harle & Towns, 2010; Harris et al., 2013; Sorby, 2009; Wai et al., 2009; Wu & Shah, 2004)
- A nuanced analysis involving the three lower-level skills indicates that **declarative CK and the spatial factors** – *spatial relation*, *visualization*, and *speeded rotation* – **vary in the extent of their influence on the skills.** (fig. 3; Model II)

Besides **declarative CK**, the spatial factors ***speeded rotation*** (2-D rotation), ***spatial relation*** (3-D rotation), and ***visualization*** (mental manipulation) are **crucial for solving representation-based chemistry tasks**.

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LITERATURE