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Investigating the role of representational competence and spatial ability in learning with chemical representations

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Theoretical Framework

- Chemists use representations (e.g., graphs, chemical equations) to **understand and depict chemical phenomena** (Rau, 2017; Harle & Towns, 2011), to **develop content knowledge** and for **problem-solving processes** (Rau, 2017; Kozma et al., 2000).
- "**Representation dilemma**": students have to learn content they do not understand from representations they may not yet understand, either (Rau, 2018). ⇒ **representational competence** (table 1) to overcome this dilemma (Kozma & Russell, 2005; Rau, 2018)
- Representations in chemistry are fairly abstract and highly spatial (Rau, 2017). ⇒ students need **spatial abilities** (Stieff et al. 2018)

Table 1 Synthesis of the lower-level skills from Kozma and Russell (1997, 2005) with the characterization of representations for a better operationalization (Gurung et al. 2022).

Lvl.	Category	Skill: The ability to …
lower-level skills	*Interpretation*	Identify, analyze, and interpret features and patterns of chemical representations and to use them to describe chemical phenomena.
	Translation	to translate a chemical representation into one with a similar degree of abstraction and explicit information without changing the represented object itself (e. g. to translate a stick-and-ball model into a dash-wedge diagram, without changing the molecule) and to change perspectives.
	Construction	to construct or select a (new) chemical representation for a particular purpose by significantly modifying the degree of abstraction and explicit information (e. g. to generate a skeletal structure from a molecular formula) and to generate representations that are distinct from the original (e. g. to generate the isomers of a given molecule).

Research Gaps and Research Questions

The model provided by Kozma and Russell (1997, 2005) has not been empirically tested and no appropriate instrument is available.

RQ_1 To what extent can the theoretical skills *interpretation*, *translation* and *construction* be empirically distinguished?

Relationship between representational competence, content knowledge and spatial ability has only been partially investigated.

RQ_2 Which is the relationship between *interpretation*, *translation* and *construction, content knowledge,* and different spatial factors in chemistry?

Study 1 - Chemical Representation Inventory: Translation, Interpretation, Construction (CRI:TIC)

Development of the CRI:TIC

- Adaption and construction of representation-based (symbolic, visual-graphical, and hybrid forms) multiple-choice and semi-opened items ⇒ assignment to the three skills: κ_{Fleiss} = .87 (3 raters)
- Text-based items to measure content and concept knowledge ⇒ reference to the "representational dilemma"

Evaluation of the CRI:TIC (freshmen in different STEM domains, N=185 ($n_{♀}$=130, $n_{♂}$=53), M_{age}=19.31 a, SD_{age}=1.99 a)
Rasch analysis with partial credit model and multidimensional Rasch analysis to check the item fit (*outfit*) and model fit (*AICc, saBIC, SRMSR, Q3-Statistics*)

- ***Representational competence***
  - Good item fit after deletion of five items (content issues, too difficult, bad outfit) ▶Table 2
  - *SRMSR, MADaQ3, and Q3-statistics* are comparable for all models ▶Table 3
  - *saBIC* suggest a multi-dimensional model and *AICc* the one-dimensional model ▶Table 4

  ⇒ Statistical results favor the one-dimensional model, nevertheless it makes sense to distinguish the three skills from theory.
- ***Representational competence (RC) & content knowledge (CK)***
  - Model comparison suggests to distinguish RC and CK (*AICc, saBIC*) ▶Table 5
  - Model fits (*SRMSR, Q3-statistics*) are comparable ▶Table 6

  ⇒ We distinguish RC and CK based on statistical findings and theory.

Study 2 - Interplay Between Representational Competence, Content Knowledge, & Spatial Ability

- CRI:TIC to measure RC (and CK) and eight psychometric instruments to measure different factors of spatial ability
- Correlation analysis to investigate their interplay
- Preliminary finding: ▶Table 7
  - *3-D rotation* and *identifying figures in patterns* shows strongest correlations with RC
  - Translation shows less correlations than interpretation/construction
  - CK shows no correlation with spatial ability

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Homepage & Literature

Study 1 - Chemical Representation Inventory: Translation, Interpretation, Construction (CRI:TIC)

Table 2 *Outfit and infit statistics of the Items for the 1-, 2- and 3-dimensional model of RC.*

Model	Outfit			Infit		
	range	*M*	*SD*	range	*M*	*SD*
1-dimensional	$0.63 \leq outfit \leq 1.39$	0.92	0.19	$0.80 \leq infit \leq 1.16$	0.96	0.10
2-dimensional	$0.79 \leq outfit \leq 1.36$	0.99	0.15	$0.89 \leq infit \leq 1.21$	1.00	0.08
3-dimensional	$0.80 \leq outfit \leq 1.39$	1.00	0.16	$0.89 \leq infit \leq 1.19$	1.00	0.08

Table 3 *Model fit (SRMR, MADaQ3) and Q3-statistics for the 1-, 2- and 3-dimensional model of RC.*

Model	Model fit		Q3-statistic		
	SRMSR	*MADaQ3*	range	*M*	*SD*
1-dimensional	.067	.070	$-.26 \leq Q3 \leq .32$	-.02	.08
2-dimensional	.067	.071	$-.30 \leq Q3 \leq .31$	-.02	.09
3-dimensional	.067	.071	$-.29 \leq Q3 \leq .31$	-.02	.09

Table 4 *Model comparison of the 1-, 2- and 3-dimensional models of RC. The p-values represent the significance of ANOVA for comparing the 2- and 3-dimensional with the 1-dimensional model.*

Model	*LL*	n_p	*AIC*	*BIC*	*AICc*	*saBIC*	*p*
1-dimensional	-3748	68	7632	7851	7713	7635	
2-dimensional	-3744	70	7627	7853	7716	7631	.014
3-dimensional	-3741	73	7629	7864	7726	7633	.023

Table 5 *Model fit (SRMR, MADaQ3) and Q3-statistics for the 1-, 2- and 3-dimensional model of RC and CK.*

Model	Model fit		Q3-statistic		
	SRMSR	*MADaQ3*	range	*M*	*SD*
1-dimensional (RC + CK)	.076	.072	$- .58 \leq Q3 \leq .33$	- .013	.088
2-dimensional (RC / CK)	.074	.070	$- .55 \leq Q3 \leq .33$	- .015	.086

Table 6 *Model comparison of the 1-and 2-dimensional models of RC and CK.*

Model	*LL*	n_p	*AIC*	*BIC*	*AICc*	*saBIC*	*p*
1-dimensional (RC + CK)	-5308	87	10791	11071	10949	10795	
2-dimensional (RC / CK)	-5288	89	10754	11041	10923	10759	< .001

Study 2 - Interplay Between Representational Competence, Content Knowledge & Spatial Ability

Table 7 *Preliminary findings on correlations between the person abilities (lower-level representational skills and content knowledge) and the measured factors of spatial ability with bonferroni correction.*

	PSVT:R	BM	CRT	GCT	IPT	MTST	PFT	HPT
Interpretation	$.52^{***}$	-	$.30^{*}$	-	-	-	$.32^{*}$	$.34^{*}$
Translation	$.45^{***}$	-	-	-	-	-	-	$.33^{*}$
Construction	$.43^{***}$	-	$.37^{***}$	-	-	-	$.32^{*}$	$.38^{*}$
Content Knowledge	-	-	-	-	-	-	-	-

*** $p \leq .001$
** $p \leq .01$
* $p \leq .05$

PSVT:R 3-D rotation of figures
BM memorize pictures shortly
CRT 2-D rotation of figures
GCT identify incomplete pictures
IPT compare figures quickly
MTST find a path through a labyrinth
PFT mental manipulation of figures
HPT identify figures in complex patterns