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ORIGINAL RESEARCH

Fostering knowledge integration through individual competencies: the impacts of perspective taking, reflexivity, analogical reasoning and tolerance of ambiguity and uncertainty

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Abstract

The present study examines the influence of individual competencies on knowledge integration in inter- and transdisciplinary work. Perspective taking, reflexivity, analogical reasoning, and tolerance of ambiguity and uncertainty were investigated as core competencies for fostering knowledge integration. Additional hypotheses assumed that the positive effects are valid in the scientific and economic contexts and that individual competencies predict knowledge integration at different levels of expertise. To test the hypotheses, 421 participants, comprised of students ($N=165$) and individuals working in science ($N=152$) and economics ($N=104$), answered questionnaires on knowledge integration and competencies of knowledge integration in an online survey. Further questions collected demographic data and inquired about experience and expertise in inter- and transdisciplinary work. The main result was that all postulated competencies positively related to knowledge integration. Analogical reasoning and perspective taking showed the strongest relationships with knowledge integration. Further results show that all competencies are positively related to knowledge integration in the student and expert sample, yet the interrelationships differ between the scientific and economic sample. This investigation into the competencies of knowledge integration contributes to the education of inter- and transdisciplinarians in academia and business practice.

Keywords Knowledge integration · Individual competencies · Inter- and transdisciplinary work · Transdisciplinary education · Structural equation modeling · Perspective taking

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Introduction

The complex social, economic, technological, and ecological problems of the twenty-first century can only be solved through interdisciplinary and transdisciplinary cooperation (OECD, 2020). Interdisciplinarity is a process of integrating perspectives from different scientific disciplines to extend the existing knowledge of a problem or to generate new knowledge (Klein, 2014; Mansilla, 2017; Newell, 2007). The transdisciplinary approach additionally incorporates perspectives from stakeholders outside academia (Lang et al., 2012; Pohl & Hirsch Hadorn, 2007). The goal is to produce socially robust knowledge that can be applied in science and practice (Nowotny et al., 2013).

With the growing demand for inter- and transdisciplinary (ITD) projects, the training of ITD actors has been investigated with increasing frequency (Bammer, 2006; Nash, 2008; Xue et al., 2020). In addition to the implementation of ITD practice at universities (Newell, 1990), the education of individual characteristics and competencies as predictors of job-related performance has received increased attention (Augsburg, 2014; Bammer, 2019; Brandstädter et al., 2018; Pearce et al., 2018; Stokols, 2014). Knowledge integration is one of the core competencies of ITD work (Godemann, 2008; Klein, 2012; Newell, 2010; Repko & Szostak, 2017). Therein, individuals and teams combine knowledge from multiple disciplines and fields of practice to solve a problem, achieve a deeper understanding, or provide a more holistic view of a research topic. Several reviews and models of competencies in ITD work exist today (Brandstädter et al., 2018; Claus & Wiese, 2019; Fam et al., 2017; Guimarães et al., 2019; Misra et al., 2015; Nash, 2008; Pearce et al., 2018). However, the specific challenges of ITD work, such as knowledge integration, remain widely unaddressed. Instead, predominantly established competencies from the work sciences are examined in relation to interdisciplinarity and, in fewer cases, transdisciplinarity.

One example is Brandstädter and colleagues (2018), whose postulated model consisted of 39 individual competencies, including project management, performance motivation, and teamwork. They found that the model positively related to individual experience in interdisciplinary collaboration as well as projects' interdisciplinary character. In contrast, Claus and Wiese (2019) defined knowledge integration as one of four competencies of interdisciplinary work. They observed a positive relationship between interdisciplinary competencies and interest in both interdisciplinary work and teamwork self-efficacy, as well as a preference for team work. However, it remains uncertain how and through which competencies knowledge integration can be fostered.

In contrast to the broad competence models used in previous studies, we focus on knowledge integration as one key challenge of ITD work. Based on previous literature, we define knowledge integration as the cognitive ability to combine different disciplinary insights into a common knowledge base to achieve a more comprehensive understanding of a complex ITD problem (Claus & Wiese, 2019; Newell, 2010; Repko & Szostak, 2017). We assume that knowledge integration can be viewed as a super-ordinate competency that builds on many of the specific competencies examined in the prior research. Given that assumption, our main research question is as follows: Which individual competencies facilitate knowledge integration and therefore contribute to successful ITD work?

Knowledge integration

Knowledge integration is studied in many fields, ranging from organizational knowledge management (Malik et al., 2020) to pre-service teacher education (Lehmann et al., 2018) and engineering (Bernard et al., 2007). Although definitions of the construct vary across disciplines, it generally emphasizes the promotion of knowledge integration to enhance professional development and performance (Lehmann, 2021). In general, the construct is defined as a "process of merging two or more originally unrelated knowledge structures into a single structure" (Schneider, 2012, p. 1684). From the perspective of the instructional sciences, Linn and colleagues (2003) defined knowledge integration as a process through which learners gradually analyze, connect, and reorganize conflicting ideas regarding scientific phenomena to achieve a deeper understanding.

Knowledge integration can be promoted in several ways, such as by linking scientific phenomena to everyday experiences and by visualizing the process through graphical or textual elements. It can also be promoted by empowering students to learn from each other and navigate difficult questions autonomously (Linn, 2000). In particular, knowledge integration is considered an integral aspect of, and the primary methodology and process for, ITD research (Klein, 2011; Pohl and Hirsch Hadorn, 2007). Unrelated knowledge structures arise from divergent disciplinary perspectives on a particular problem or issue. Analogous to a single structure, the goal is to achieve a more holistic understanding of the problem by linking those perspectives. The ITD process consists of several steps, one of which involves selecting the appropriate disciplines to follow iterative and recursive sequences (Newell, 2007; Repko & Szostak, 2017; Repko, 2008). According to Repko and Szostak (2017), knowledge integration comprises four steps: identifying conflicts between insights and their sources, creating common ground, constructing a more comprehensive understanding, and testing the more comprehensive understanding.

Competencies related to knowledge integration

Competencies are learnable abilities that enable individuals to understand the complexity of their environment and to complete tasks by acting in a goal-oriented, self-confident, reflective, and responsible manner (Kauffeld et al., 2002; Sonntag & Schaper, 2016). Although prior research findings have uncovered some of the competencies that enable knowledge integration, no study has directly examined the individual competencies that support knowledge integration. To determine which individual competencies are central to knowledge integration, we examined the mechanisms and competencies primarily associated with it in the literature. The determined competencies and their relationships with knowledge integration are presented below.

Tolerance of ambiguity and uncertainty

A disciplinary perspective considers a discipline's epistemic position, underlying assumptions, as well as any corresponding phenomena, concepts, theories, and methods (Repko, 2008). To achieve knowledge integration, it is necessary to analyze the complex problem at hand from each relevant disciplinary perspective. This can uncover conflicts between insights, such as the use of similar terms for different phenomena (Repko & Szostak, 2017). As a result, the ITD researcher faces ambiguity and uncertainty when detecting and resolving conflicts (Bromme, 2000). In particular, epistemological pluralism is a source of ambiguity because it challenges the disciplinary construction of reality and invalidates the concept of absolute truth (Repko & Szostak, 2017).

Tolerance of ambiguity and uncertainty describes the ability to navigate ambiguity, lack of information, and uncertainty regarding the process, outcomes, and a person's own role in the project (Bromme, 2000; Welch, 2011; Wolfe & Haynes, 2003). In addition to viewing the problem from different disciplinary perspectives, ambiguity in the ITD context arises from the problem's complexity (Stokols, 2006). Even through the interaction of several disciplines, the complexity can never be fully grasped, leading to missing information during the development process (Repko & Szostak, 2017). The final goal of ITD processes is to produce knowledge that can be communicated to science and practice (Lang et al., 2012; Pohl & Hirsch Hadorn, 2007). This requires considering multiple, potentially conflicting interests (Walter et al., 2007). It is difficult to establish simultaneous acceptance by all involved individuals, societies, and groups. Thus, the process involves making decisions under uncertainty and ambiguity. Fam and colleagues (2017) demonstrated an empirical relationship between tolerance of uncertainty and transdisciplinary work. They categorized tolerance of ambiguity under the competence field curiosity, which as a higher-level skill can encourage scientists to view uncertainty as an opportunity rather than an obstacle.

Perspective taking

Examining the ITD problem from numerous perspectives enables the detection of differences and similarities between conflicting insights. In turn, the process modifies disciplinary elements to establish a common cognitive framework: the common ground (Newell, 2010). Engaging in perspective taking is integral to the simultaneous acquisition of multiple disciplinary insights into one mental representation (Repko & Szostak, 2017). Perspective taking is an intentional process aimed at understanding a person's thoughts, feelings, and motives depending on environmental parameters (Gehlbach, 2004). Participating in perspective taking requires cognitive, motivational, and affective resources.

In relation to knowledge integration, perspective taking is defined as a person's cognitive ability to place themselves into the perspective of another scientific discipline without neglecting their own disciplinary perspective (Repko & Szostak, 2017). Ideally, this process generates multiple solutions for the problem, leads to the adoption of a holistic view, and engenders awareness of gaps in personal knowledge. In the theoretical literature, perspective taking is considered one of the central competencies for ITD work (Klein, 2005; Repko et al., 2014). The empirical literature has also found evidence of the importance of this competence. Brandstädter and Sonntag (2016) demonstrated that perspective taking correlates positively to interdisciplinary collaboration, a project's perceived interdisciplinarity, engagement in interdisciplinary work, and job satisfaction and performance. Similarly, Misra and colleagues (2015) established a link between perspective taking, as part of the transdisciplinary orientation scale, and knowledge integration in scientific publications, the societal impact of research, and ITD experience.

Analogical reasoning

The use of metaphors in the ITD process facilitates understanding of one research object in terms of another (Repko & Szostak, 2017). The strongest link between metaphors and knowledge integration was provided by Mansilla (2017), who described metaphors as an effective integrative tool. According to her, metaphors frame the reality of a research object by restructuring constructs from different fields into one coherent model. In addition, Bammer (2018) suggested the use of metaphors as a method in the problem framing phase, arguing that metaphors help individuals close gaps in their understanding or accelerate the overall understanding process. Moreover, metaphors can help verify the quality of a new understanding formed during the ITD process (Newell, 2007); they emphasize the most important properties of the new understanding without neglecting the underlying multiperspectivity.

The individual competence to form and understand metaphors is called analogical reasoning (Gentner & Maravilla, 2018; Moser, 2001). Specifically, analogical reasoning refers to the ability to identify and evaluate common relational structures between different contexts (Lakoff & Johnson, 2011). It involves transferring information from a known source domain to a less known or abstract target domain (Mason, 2004). Understanding of the unknown target domain can be enhanced by outlining not only the appropriate inferences based on structural similarities, but also the differences between source and target (Gentner & Maravilla, 2018). Analogies are cognitive learning tools for retrieving knowledge from memory, structuring it meaningfully, and revising the conception of knowledge representations. In the learning process, several analogies can be presented simultaneously to promote structural alignment. Alternatively, analogies for complex problems or scientific phenomena can be formed in a creative process (Mason, 2004). The ability to form analogies was reflected in Brandstädter and colleagues' (2018) cognitive competence called capacity for abstraction (Zehetmeier et al., 2019). Cognitive competencies demonstrated positive correlations with interdisciplinary collaboration, the perceived interdisciplinarity of a project, engagement in interdisciplinary work, and job satisfaction and performance. Furthermore, cognitive competencies correlated positively to interdisciplinary experience. According to the authors, this finding indicated the relevance of cognitive factors in ITD work.

Reflexivity

Szostak (2009) described reflexivity as an ability consisting of four facets. The first facet involves reflection on outcomes, where the individual considers the extent to which the disciplinary perspectives were successfully integrated (Mansilla et al., 2009). The second facet comprises reflection on the steps taken for knowledge integration. The final two facets encompass result-oriented self-reflection, wherein the individual critically questions their own biases, the range of their assumptions, and the gaps in their knowledge of other disciplines (Bromme, 2000; Szostak, 2009). These final facets stem from the understanding of reflexivity as a metacognitive competence in the transformative learning process (Keestra, 2017; Mezirow, 2012). In this view, reflexivity is crucial to meaning construction through the accurate integration of a person's own assumptions, as well as the assumptions of others, into holistic interpretations. Reflexivity (also reflection) is also part of many competence models in the ITD context. Guimarães and colleagues (2019) recently published a review of previous works on this topic, in which they overviewed the motivation, attitudes, and competencies of individuals and teams. In that context, reflexivity belongs to individual competencies and is defined as disciplined self-reflection and rigor in argumentation.

Brandstädter and colleagues (2018) divided reflexivity into self-reflection and process reflection categories. In so doing, they assigned both facets to topic competencies that serve as cognitive abilities enabling individuals to work interdisciplinarily. As a cognitive competence, in this analysis reflexivity showed the same positive relationships with interdisciplinary work as capacity for abstraction. Claus and Wiese (2019) established a more direct link between reflexivity and knowledge integration. They observed a significant positive, medium-strength correlation between knowledge integration and reflexivity as well as significant positive correlations between reflexivity and interest in interdisciplinary work, and interdisciplinary experience in years. Based on these theoretical considerations on reflexivity, perspective taking, analogical reasoning, and tolerance of ambiguity and uncertainty, and their suggested relationships to Knowledge Integration, the purpose of this study was to test the following hypothesis:

H1: The competencies of reflexivity, perspective taking, analogical reasoning, and tolerance of ambiguity and uncertainty positively relate to knowledge integration.

Contexts and factors affecting the relationships between individual competencies and knowledge integration

The relationships between individual competencies and ITD work are subject to several influences and contexts discussed in ITD competence research (Brandstädter et al., 2018; Claus & Wiese, 2019; Guimarães et al., 2019). ITD and knowledge integration are relevant in both scientific and economic working contexts (Pohl et al., 2010; Robert et al., 2008). Brandstädter and colleagues (2018) and Claus and Wiese (2019) compared the impact of their competence models when applied in scientific and economic domains. Their investigations revealed that the competencies were relevant across both disciplines. To replicate their previous findings (Brandstädter & Sonntag, 2016) from an academic sample in the economic domain, Brandstädter and colleagues (2018) asked 20 interdisciplinary leaders about the importance of the postulated competencies in successful interdisciplinary work. They rated special competencies such as calmness, commitment, and leadership skills as marginally more important than did experts from the academic sector. Claus and Wiese (2019) validated their competence model, consisting of initiative for exchange, target group-specific communication, reflection, and knowledge integration in two samples comprising academics ($N=315$) and non-academics ($N=448$). The results illustrated that knowledge integration and other interdisciplinary competencies influence the success of interdisciplinary work in both domains. Nevertheless, it remains undetermined how knowledge integration relates to other important competencies, such as perspective taking, in different samples. Furthermore, Brandstädter and colleagues (2018) did not indicate how team members rated the competencies, with the importance level being assessed solely by team leaders. To extend the results of previous research, we assume the following:

H2: The competencies of reflexivity, perspective taking, analogical reasoning, and tolerance of ambiguity and uncertainty are positively related to knowledge integration in both economic and scientific contexts.

Prior researchers have predominantly interviewed ITD experts to identify relevant competencies and characteristics (Brandstädter et al., 2018; Guimarães et al., 2019; Misra et al., 2015). This raises the question of the extent to which ITD competencies are performed only by experts. Pearce and colleagues (2018) outlined design principles for competency areas to promote transdisciplinary education in sustainability science among undergraduate and graduate students. The authors drew on their extensive experience in the TdLab for a total of seven annual transdisciplinary courses for bachelor's, master's, and PhD students.

They postulated six fields of competence that follow a transdisciplinary process. The components of their model include self-reflection on biases and perceptions and dealing with frustration and uncertainty. The authors stated that testing and validation of the effect of their heuristic framework was pending. Their experience in training transdisciplinary competencies among scientists with different levels of expertise led to the third hypothesis:

H3: The interrelationships between knowledge integration and the competencies of reflexivity, perspective taking, analogical reasoning, and tolerance of ambiguity and uncertainty are present in different levels of expertise.

Materials and methods

Design and procedure

To test the hypotheses, an online survey was conducted using the Qualtrics Survey software. First, participants were given detailed definitions with examples of interdisciplinary and transdisciplinary work. They were then asked to assess their expertise in ITD. Interdisciplinary work was defined as a collaboration between different disciplines or fields of expertise to solve a problem or complete a task. Transdisciplinary work extends beyond interdisciplinary work and occurs when multiple scientific disciplines interact with non-scientific actors. Afterwards, two measures—the competencies of knowledge integration and knowledge integration itself—were presented in a random order, with demographic data collected at the end.

Participants

Participants with previous experience in inter- and/or transdisciplinary work were recruited to complete the online survey. Of the 616 people who followed the study link, 447 (73%) completed the survey. Seventeen of the 447 respondents were excluded from the analysis because they had never worked in an ITD context. Seven more were excluded because of a uniform answer pattern where, for example, they only ticked the "never = 1" option. Two others were excluded due to a lack of plausibility in their answers combined with an overly short response time of under five minutes. Ultimately, 421 persons were included in the analyses, among whom 245 were female (64%), 132 male (35%), and 5 diverse (1%). The average age was $M = 32.49$ ($SD = 11.30$), and age overall ranged from 19 to 79 years. The sample consisted of a total of 152 ITD scientists, 165 students, and 104 employees from the economic sector.

To reach inter- and transdisciplinarians from the scientific sector, all doctoral students and some professors from the 12 NRW Research Colleges were asked to participate. The NRW Research Colleges are an initiative of the Ministry of Culture and Science of the State of North Rhine-Westphalia in Germany (Kultur und Wissenschaft in Nordrhein-Westphalen, 2020). Within those colleges, junior researchers from multiple disciplines collaborate on topics of high socio-political relevance.

Participants were additionally recruited from leading transdisciplinary research institutes in Germany and the td-academy.de transdisciplinary network. To acquire respondents from the economic sector, companies with a high interdisciplinary orientation were selected. All participants from the scientific and economic sectors were asked to participate

Table 1 Sample characteristics

	N	Age range	*M* Age (*SD*)	Gender[a]	Education degree (%)
Scientific sample	152	24–79	35.32 (10.61)	m 51 f 88 d 2 w.s 11	master 81(57) doctor 28(20) postdoc.[b] 12(9)
Economic sample	104	22–68	39.88 (12.10)	m 51 f 49 d 0 w.s 4	bachelor 17(17) master 58(58) doctor 6(6)
Student sample	165	19–47	24.51 (4.45)	m 30 f 108 d 3 w.s 24	abitur 78(55) bachelor 43(30) master 10(10)

[a]*m* male, *f* female, *d* diverse, *w.s* without specification

[b]postdoctoral qualification

via personalized serial e-mails. Students were recruited from the Ruhr-University Bochum and study participation Facebook groups. Table 1 describes the subsamples in greater detail.

Measure

Competencies related to knowledge integration

Since there exist no scales measuring intraindividual competencies in the context of knowledge integration, new scales were developed for the present study. The item formulations were based on the constructs' theoretical definitions in the ITD context. The study included a total of 52 items, with all participants being asked to rate each item on a Likert scale from "1 = completely disagree" to "6 = completely agree." Reflexivity comprised a total of 14 items, divided into the facets of process-, result- and self-reflection (e.g.: "Even after the completion of a project, I still thought about the results and their effects for a long time"). Perspective taking was composed of eight items, with one example being, "It is easy for me to put myself in the perspective of other disciplines." Analogical reasoning was examined using 11 items (e.g.: "If I have to demonstrate similarities and differences between disciplines, I prefer to use metaphors"), and tolerance of ambiguity and uncertainty using 10 items (e.g.: "I don't mind that contradictions constantly arise between the disciplines involved").

To reduce the overall number of items, all items with factor loadings of $\lambda < 0.300$ and a discriminative power of $r_{it} < 0.300$ were stepwise excluded. After excluding each item, changes in discriminative power, factor loadings, and Cronbach's α for each item were examined considering the item content. Reflexivity was reduced to six items, perspective taking to five, analogical reasoning to eight, and tolerance of ambiguity and uncertainty to seven items.

A confirmatory factor analysis was conducted with the postulated four factors ($\chi^2(293) = 881.266$, $p < 0.001$, CFI = 0.776, TLI = 0.751, RMSEA = 0.069, SRMR = 0.077) using the remaining 26 items for validity assessment. The modification indices were compared to changes in the internal consistency, following which three further items with high loadings on more than one construct were excluded. Given the proposed modification indices, correlations between the items' residuals were examined based on their order and the similarity of their meanings (Bandalos, 2021). The residuals between items that included the term "metaphor" or synonyms like "analogy" or "comparison" were correlated to improve the model fit (AR1 and AR3; AR1 and AR4; AR3 and AR4; AR1 and AR6; AR5 and AR7). Furthermore, the residuals of items P4 and P5 were correlated due to their similar contents, as were the residuals of items P4 and R1 due to the item order presented in the survey. The resulting model contained a total of 23 items and provided an acceptable model fit ($\chi^2(217) = 372.408$, $p < 0.001$, CFI = 0.913, TLI = 0.900, RMSEA = 0.045, SRMR = 0.055). Table 2 provides an overview of all standardized factor loadings and the constructs' internal consistencies.

Table 2 Factor loadings and internal consistencies

Construct/item number	Factor loading (λ)	*M*	*SD*	Skew	Kurtosis	AVE	α (*ω*)
Perspective taking (P)				− 0.11	− 0.19	.238	.625(.590)
1	.512	4.47	1.02				
2	.470	3.88	1.22				
3	.406	3.92	1.13				
4	.544	3.92	1.24				
5	.575	4.56	1.15				
Reflexivity (R)				− 0.35	0	.373	.743(.746)
6	.681	4.49	1.12				
7	.587	4.34	1.31				
8	.601	4.03	1.21				
9	.657	4.05	1.34				
10	.518	4.11	1.14				
Analogical reasoning (AR)				0.00	− 0.15	.280	.792(.695)
11	.647	3.77	1.47				
12	.522	4.59	1.09				
13	.640	3.26	1.28				
14	.696	3.70	1.20				
15	.508	4.15	1.01				
16	.557	4.22	1.12				
17	.475	4.26	1.14				
18	.546	4.00	1.01				
Tolerance of ambiguity and uncertainty (AU)				− 0.05	0.1	.246	.618(.617)
19	.517	3.66	1.32				
20	.408	4.06	1.31				
21	.578	3.40	1.32				
22	.455	3.02	1.34				
23	.500	3.48	1.25				

Factor Loadings in the Confirmatory Factor Analysis with 23 Items ($\chi^2(224) = 492{,}061$, $p < .001$; CFI = .850; TLI = .830; RMSEA = .054; SRMR = .065), *ω* = composite reliability, AVE = average variance extracted

The reliability of the constructs of reflexivity and analogical reasoning exhibited good internal consistencies at $\alpha > .700$. The constructs of perspective taking and tolerance of ambiguity and uncertainty each had an internal consistency of $\alpha > .600$. These are considered low but still acceptable. Moosbrugger and Kelava (2012) recommended using constructs with low reliability if there are no existing constructs in the investigation area with which to measure this feature. For that reason, perspective taking and tolerance of ambiguity and uncertainty were included in further analyses.

Knowledge integration

The German version of the "knowledge integration" scale from Claus and Wiese's (2019) "interdisciplinary competencies" questionnaire was used to measure knowledge integration. Claus and Wiese (2019) defined knowledge integration as the cognitive process of connecting different academic perspectives. The scale consists of three items. Items one and two focus on the integrative linkage between knowledge of different disciplines (e.g., "In interdisciplinary work, I am good at connecting and integrating knowledge from different disciplines"). The third item concerns the comprehension of different disciplinary content ("In interdisciplinary teams, I can easily comprehend what other members work on with regard to content"). All items were rated on a six-point Likert scale, and, since the authors did not specify any internal consistencies, we calculated Cronbach's α in our dataset. With $\alpha = .830$, the scale was highly reliable.

Expertise

To compare experts and novices in ITD work, student, scientific, and economic samples were collected (see Participants). Moreover, expertise was assessed with the following one-item measure: "How do you judge your own expertise in interdisciplinary and/or transdisciplinary work?". The participants were asked to rate the question on a 10-point Likert scale, ranging from "novice" to "expert". To examine the extent to which the single-item measure of expertise differentiated between novices and experts, the student sample was compared to the scientific and business samples. An ANOVA calculated to investigate differences in expertise between the groups revealed significant results $F(2,418) = 30.56$, $p < 0.001$, $\eta^2 = .13$. Planned contrasts demonstrated that students rated themselves to a significantly larger extent as novices than as experts compared to the other groups $t(418) = 7.82$, $p < 0.001$, $d = .78$. In contrast, there was no difference between the scientific and business samples $t(418) = 1.13$, $p = 0.260$, $d = .14$. The results confirmed that students exhibited a lower self-assessment of expertise in ITD work than did employees in science and economy. This finding in turn illustrates that the one-item measurement was an appropriate tool for assessing expertise in the study sample.

Data analysis

All statistical analyses were conducted using the RStudio statistics program (RStudio, 2020). In the first step, the validity of the four competence constructs was tested. For this purpose, a descriptive item analysis was performed using the R packages *psy* and *psych*, and a confirmatory factor analysis (CFA) was built using the *lavaan* package. Model quality was evaluated using the approximate fit statistics comparative fit index (CFI), the Tucker-Lewis index (TLI), the root mean square error of approximation (RMSEA), and the standardized root mean square residual (SRMR). For acceptable model quality, SRMR and RMSEA should be < 0.80. In addition, a CFI TLI of > 0.95 is considered good and that of > 0.90 is acceptable (Hu & Bentler, 1999; Kline, 2011).

To test the first hypothesis, a multiple regression analysis including all predictors simultaneously was performed. The resulting model was used to test hypotheses H2 and H3. In H2, the group was included as a moderator in the regression model. The differences between the individual path coefficients were compared using the simple slopes method. To test H3, expertise was included as an additional predictor. All regression analyses were conducted using the robust bootstrapping method with 2,000 bootstrap samples. The significance of those results was examined with bias-corrected and accelerated confidence intervals of bootstrapping.

Results

Preliminary analyses

Prior to the hypothesis testing, bivariate correlations between each predictor variable and knowledge integration were calculated to illustrate the relationships (Table 3). Table 3 demonstrates that all knowledge integration competencies were significantly related to knowledge integration with medium to strong effects (Cohen, 1988).

Hypothesis 1

A multiple regression model was developed to test whether the competencies of reflexivity, perspective taking, analogical reasoning, and tolerance of ambiguity and uncertainty positively relate to knowledge integration. It included the competencies as independent variables and knowledge integration as the dependent variable (Table 4, Model 1).

Table 4 shows that the competence constructs explained 36% of the variance in knowledge integration ($R^2 = 0.36$, $F(4,416) = 61.12$, $p < 0.001$). The bias-corrected confidence intervals for all beta weights did not contain zero, so H_0: $\beta = 0$ can be rejected for the relationships between the competence constructs and knowledge integration. Analogical reasoning ($b = 0.29$) and perspective taking ($b = 0.26$) demonstrated the highest predictability in the regression model, followed by tolerance of ambiguity and uncertainty ($b = 0.21$) and reflexivity ($b = 0.12$).

Hypothesis 2

The study also examined whether the postulated competencies have positive relationships with knowledge integration in the economic and scientific contexts. To investigate those relationships, a moderated regression analysis was performed with the group as mediator variable ($R^2 = 0.34$, $F(9,246) = 15.96$, $p < 0.001$). Path coefficients tested with simple slopes differed between groups (Table 5). The relationship between analogical reasoning and knowledge integration became significant in both groups. In the scientific sample, the impact of reflexivity was also significant, but not the effects of tolerance of ambiguity and uncertainty and perspective taking. Contrarily, in the economic sample, the effects of tolerance of ambiguity and uncertainty and perspective taking on knowledge integration were significant, whereas the impact of reflexivity was not observed.

Table 3 Correlation matrix

	KI[a]	Persp	Reflex	Analog	Tol.[b]
Perspective Taking	.490***				
Science[c]	.427***				
Economy[d]	.474***				
Students[e]	.567***				
Reflexivity	.371***	.500***			
Science[c]	.325***	.477***			
Economy[d]	.298**	.515***			
Students[e]	.494***	.534***			
Analogical Reasoning	.491***	.423***	.210***		
Science[c]	.464***	.437***	.236***		
Economy[d]	.512***	.320***	.241**		
Students[e]	.509***	.461***	.421***		
Tolerance[b]	.430***	.448***	.169***	.311***	
Science[c]	.351***	.448***	.131[n.s]	.372***	
Economy[d]	.537***	.432***	.212*	.383***	
Students[e]	.402***	.466***	.244***	.377***	
Expertise	.415***	.238***	.057[n.s]	.272***	.397***
Science[c]	.509***	.297***	.142[n.s]	.301***	.327***
Economy[d]	.503***	.245**	.054[n.s]	.487***	.401***
Students[e]	.211**	.173*	.092[n.s]	.113[n.s]	.321***

Bivariate Spearman correlations. Cohen's d effect sizes: r_s of .10 = small effect, r_s of .30 = medium effect, r_s of .50 = large effect

n.s not significant

$^*p<.05$, $^{**}p<.01$, $^{***}p<.001$

[a]Knowledge integration

[b]Tolerance of ambiguity and uncertainty

[c]bivariate Spearman correlations in the scientific sample ($N=152$)

[d]bivariate Spearman correlations in the economy sample ($N=104$)

[e]bivariate Spearman correlations in the student sample ($N=165$)

Neither the interaction effect on the overall model ($b=-0.19$, $SE=0.59$, $t=-0.33$, $p=0.74$, 95% CI [−0.00, 0.29]) nor the moderation effects on the regression paths ($b_{Tolerance\ of\ Ambiguity\ and\ Uncertainty}=-0.09$, $SE=0.12$, $t=0.81$, $p=0.42$, 95% CI [0.25, 0.35]; $b_{Perspective\ Taking}=-0.06$, $SE=0.15$, $t=0.44$, $p=0.66$ CI [-0.35, 0.08]; $b_{Analogical\ Reasoning}$=—0.01, $SE=0.13$, $t=0.10$, $p=0.92$, CI [-0.23, 0.25]; $b_{Reflexivity}=-0.14$, $SE=0.11$, $t=-1.20$, $p=0.23$, CI [−0.10, 0.32]) became significant.

Hypothesis 3

The third hypothesis was to investigate whether interrelationships between the competencies of reflexivity, perspective taking, analogical reasoning, and tolerance of ambiguity and uncertainty with knowledge integration are present at different levels of expertise.

Table 4 Multiple regression results for knowledge integration

Variable	Model 1					Model 2				
	B	95% *CI* for *B*		*SE B*	*t*	*B*	95% *CI* for *B*		*SE B*	*t*
		LL	*UL*				*LL*	*UL*		
Constant	0.98	0.54	1.45	0.24	4.29***	0.86	0.41	1.30	0.23	3.89***
Tolerance	0.21	0.12	0.31	0.05	4.46***	0.13	0.04	0.22	0.05	2.67**
Perspective Taking	0.26	0.13	0.37	0.06	4.29***	0.24	0.12	0.35	0.06	4.21***
Analogical Reasoning	0.29	0.19	0.41	0.06	5.78***	0.26	0.15	0.38	0.05	5.21***
Reflexivity	0.12	0.03	0.20	0.05	2.57*	0.13	0.05	0.21	0.04	3.03**
Expertise						0.16	0.10	0.21	0.03	5.92***
ΔR^2	$R^2 = .36$, $F(4,416) = 61.12$, $p < .001$					$\Delta R^2 = .05$, $F(1,415) = 35.083$, $p < .001$				

CI bias-corrected and accelerated confidence intervals with 2000 bootstrap samples; *LL* lower limit; *UL* upper limit; *Tolerance* Tolerance of Ambiguity and Uncertainty

**p* < .05, ***p* < .01, ****p* < .001

Table 5 Group comparison of multiple regression results for knowledge integration

Variable	Science ($N = 152$)					Economy ($N = 104$)				
	B	95% *CI* for *B*		*SE B*	*t*	*B*	95% *CI* for *B*		*SE B*	*t*
		LL	*UL*				*LL*	*UL*		
Constant	1.34	0.57	2.22	0.36	3.73***	1.15	0.27	1.99	0.43	2.67**
Tolerance	0.15	−0.00	0.29	0.08	1.96	0.24	0.11	0.41	0.09	2.76**
Perspective Taking	0.18	−0.03	0.37	0.09	1.89	0.24	0.01	0.46	0.10	2.41*
Analogical Reasoning	0.33	0.15	0.53	0.08	4.04***	0.34	0.17	0.52	0.09	3.63***
Reflexivity	0.15	0.03	0.28	0.07	2.29*	0.01	−0.16	0.18	0.09	0.15

CI bias-corrected and accelerated confidence intervals with 2000 bootstrap samples; *LL* lower limit; *UL* upper limit; *Tolerance* tolerance of ambiguity and uncertainty

**p* < .05, ***p* < .01, ****p* < .001

Expertise was included as an additional predictor in Model 1 (Table 4, Model 2) and exhibited a significant effect on knowledge integration ($b = 0.16$, $SE = 0.03$, $t = 5.92$, $p < 0.001$, CI [0.10, 0.21]). Expertise explained only 5% of the additional variance in knowledge integration in addition to competencies. The inclusion of expertise decreased the predictability of knowledge integration by tolerance of ambiguity and uncertainty from $b = 0.21$ (Model 1) to $b = 0.13$ (Model 2). The predictability of knowledge integration through the other competencies remained similar.

Discussion

Until the current study, few empirical investigations had reported results on intraindividual competencies' impact on ITD work. Moreover, the existing studies have primarily focused on broader aspects of interdisciplinary work, such as contextual work experience, as well as the quality of publications (Brandstädter et al., 2018; Claus & Wiese, 2019). The results of this study are the first to link intraindividual competencies to knowledge integration while accounting for both interdisciplinary and transdisciplinary backgrounds of experience.

The test for the first hypothesis uncovered that all postulated competencies had a significant positive relationship with knowledge integration. In particular, analogical reasoning and perspective taking were the strongest predictors of knowledge integration, followed by tolerance of ambiguity and uncertainty and reflexivity. The relationship between analogical reasoning and knowledge integration arises from the cognitive nature of both competencies. Engaging in knowledge integration requires a holistic representation of the insights, underlying assumptions, and epistemic positions of other disciplines (Repko, 2008). The ability to identify structural similarities and differences between various concepts can support the process of achieving a more accurate understanding of another discipline in comparison to one's own assumptions (Mansilla, 2017; Mason, 2004). Discovering similarities and differences between concepts is also the common component of capacity for abstraction and analogical reasoning (Brandstädter et al., 2018; Zehetmeier et al., 2019). Based on previous findings and the results of this study, it can be assumed that this cognitive component plays a central role in knowledge integration, and knowledge integration in turn positively influences ITD work. Discovered differences between disciplines result in conflicting mental representations of a complex ITD problem (Newell, 2007). Transforming these into a shared knowledge base (common ground) requires perspective taking to extend the meaning of an insight beyond the boundaries of disciplinary understanding (Newell, 2007; Repko & Szostak, 2017). Our results aligned with the presumption from previous work that perspective taking is central to knowledge integration. Brandstädter and Sonntag (2016) assigned perspective taking to expert competencies in interdisciplinary work. However, correlative results demonstrated that the competence is positively related to knowledge integration for both novices and experts.

The ITD process is accompanied by ambiguity and uncertainty. Longstanding disciplinary expertise can be doubted in the ITD process and engender concerns about the self-concept as a scientist/expert (Welch, 2011). During long-term collaboration in ITD projects, tolerance of ambiguity and uncertainty increases openness to different disciplinary demands and requirements, mitigating perceived role conflicts and strengthening the identity as an ITD researcher/expert. In contrast to previous results, reflexivity controlled for the other competencies demonstrated the weakest relationship with knowledge integration. Previous findings defined reflexivity predominantly as self-reflection (Brandstädter & Sonntag, 2016; Claus & Wiese, 2019; Guimarães et al., 2019). In the present study, process and outcome reflection were additionally measured as part of reflexivity, explaining the differences in the results. According to Keestra (2017) and Mezirow (2012), reflexivity is a meta-cognitive competence in higher education.

We defined knowledge integration as a super-ordinate competence in the ITD framework. Therefore, both competencies could be meta-competencies that are positively related while contributing individually to success in ITD processes. Although competencies explained 36% of the variance in knowledge integration, they exhibited low to moderate beta weights, suggesting that knowledge integration is subject to a wider range of influences. The aim of the study was to consider individual factors. In addition, methodological approaches in the ITD process and design principles have an impact on knowledge integration. The methodological approach comprises methods that facilitate joint knowledge integration among participating stakeholders and result in higher-quality co-produced knowledge (Defila & Di Giulio, 2015). Design principles are applied in the organization of ITD processes, especially in the selection of the right disciplines and stakeholders for a particular problem, and time resources influence the integration degree of joint outcomes (Balsiger, 2005; Lang et al., 2012).

Working context

Our assumption (Hypothesis 2) that the competencies relate positively to knowledge integration equally among the scientific and economic actors could not be confirmed. Scientific work differs from interdisciplinary work in economic organizations (Brandstädter et al., 2018). Moreover, knowledge integration, as defined in the present study, is an essential element of research in the philosophy of science and sustainability sciences. Accordingly, the target of those respective research studies typically consists of scientists. In economics, by contrast, knowledge integration is primarily understood as an organization's ability to integrate the knowledge of its employees into its own organizational structures in the long term (Grant, 1996). Differences in the requirements of scientific and organizational ITD work may in turn lead to differences in the required competencies for knowledge integration.

Tolerance of ambiguity and uncertainty, as well as perspective taking, did not show significant relationships in the scientific sample. One potential explanation lies in the characteristics of scientific research. Knowledge generation is the main objective of doctoral studies. Challenges in knowledge generation similar to challenges in knowledge integration include integrating different conceptual frameworks and navigating conflicting roles (Berger, 2015). As a consequence, the competencies of perspective taking and tolerance of ambiguity and uncertainty can be regarded as core competencies in science education and development. Therefore, these competencies are presumably not explicitly related to knowledge integration but to scientific work per se.

Reflexivity is needed to examine the more comprehensive understanding developed in the ITD process (Newell, 2007; Repko & Szostak, 2017). In the economic sector, interdisciplinary teams are a solution for meeting increased competitive pressure by promoting creativity and innovation (Brandstädter et al., 2018). Team results are typically evaluated through the achievement of organizational goals and are rewarded through monetary incentives (Jehn & Bezrukova, 2004). Reflexivity of individual performance and its role in the interdisciplinary team are less central, which explains the unrelatedness between reflexivity and knowledge integration in the economic sample.

Expertise

The test of the third hypothesis revealed that expertise positively influences knowledge integration. Despite the inclusion of expertise in the model, the competencies continued to show positive relationships with knowledge integration. Thus, it follows that the four competencies are relevant at different levels of expertise. This implies that fostering the competencies of novices, such as undergraduates, leads to effective knowledge integration. Furthermore, the competencies of perspective taking, analogical reasoning, and tolerance of ambiguity and uncertainty are integral aspects of the area-specific knowledge that characterizes an expert in ITD work. Correlative results revealed that, unlike the remaining competencies, experts do not exhibit higher levels of reflexivity than novices, supporting our assumption of reflexivity as a meta-cognitive competence (Keestra, 2017). In the ITD context, metacognition refers to the observation and evaluation of a person's own cognitive processes and mental representations during the ITD process. Metacognitions are far more difficult for novices and experts to learn and train than other competencies. This might explain why experts in this study did not demonstrate higher levels of reflexivity than novices.

Limitations

As part of the present study, a new questionnaire to investigate knowledge integration competencies was developed and validated for the first time. The low reliability of the constructs of perspective taking and tolerance of ambiguity and uncertainty constitute a restriction for the present results (Moosbrugger & Kelava, 2012). In addition, the average variance extracted (AVE) measuring convergent validity was below the appropriate value of .50 (Fornell & Larker, 1981). Low reliability and validity may result in significant relationships not being discovered even though they are present, leading to higher measurement errors (Shook et al., 2004). Although the bootstrapping method controls for measurement error, the constructs' low reliability could have caused the corresponding competencies to demonstrate low beta weights and to avoid showing significant effects in the scientific sample. To reflect the broad range of competency facets from previous literature, our questionnaire measured multiple facets of each construct. An example is the tolerance of ambiguity and uncertainty scale, which measures the management of doubts regarding one's own expertise, the management of emerging conflicts, and the management of unexpected situations. The multifaceted approach we used in our questionnaire provides an explanation for the low AVEs (Fornell & Larker, 1981). Another limitation was that the residuals of some items were correlated to achieve an acceptable model fit. The correlation of the residuals was based on theoretical assumptions regarding item similarity and order effects (Bandalos, 2021). The questionnaire's validity was determined by construct validity. Criterion validity was tested using correlations with knowledge integration. Since competencies are performance-related characteristics, further relationships with performance measures are necessary to confirm comprehensive criterion validity.

All results were based on self-reports, which are correlative relationships. As a result, the postulated competencies could not be assumed to causally impact knowledge integration.

Instructional implications

There is still a need for ITD training and education (Sibbald et al., 2015). The results of the first hypothesis demonstrated that analogical reasoning and perspective taking deserve more attention in future ITD stakeholders' training. One way to promote individual competencies in educational programs is to methodically design ITD teamwork, which typically emerges in an ad hoc and informal manner (Pfirman & Martin, 2010). Perspective taking can be fostered through cross-training, in which participants change positions in task processing to learn the skills and knowledge that their teammates require in task solving (Salas et al., 2007). Analogical reasoning can be encouraged through the guided creation of boundary objects (Mansilla, 2017), which are objects that combine knowledge structures from different disciplines and establish links between them.

From the results of the second hypothesis, it follows that the competencies studied have different relevance for the respective contexts of application. The training of analogical reasoning is relevant for the scientific and the economic context. Within the economic context, the results suggest an increased emphasis on training for perspective taking and tolerance of ambiguity and uncertainty. Because tolerance of ambiguity and uncertainty increases with experience, it is more difficult to teach. To foster the competency, coaching is a suitable method for encouraging results-oriented problem reflection on decision making under uncertainty and arising conflicts (Greif, 2007). Coaching usually takes place between a coach and a coachee over several sessions, allowing for an intensive examination of one's own duties and objectives, as well as the establishment of self-development criteria. This method can have a leverage effect for self-development and long-term transfer, especially in the case of competencies that are difficult to learn.

In academic education, it is important to train reflexivity to counteract disciplinary biases (Bromme, 2000). In particular, since expertise does not necessarily increase reflexivity, it is advisable to introduce relevant learning objectives early in the curriculum. An example of incorporating such objectives and practical reflexivity training is illustrated by Pearce and colleagues (2018). In the TDLab, reflexivity is an inherent learning objective in designing interdisciplinary courses even at the undergraduate level. This helps students develop cognitive awareness of their perceptions and internalize values to deal with biases such as prejudices against other disciplines.

The outcomes of the third hypothesis suggest that the requirement for ITD competency training remains consistent, regardless of individuals' level of expertise. ITD work frequently takes the form of project-based collaborations (Pohl & Hirsch Hadorn, 2007). To address varying levels of expertise between stakeholders, training components can be integrated into the project framework. In this regard, the Network for Transdisciplinary Research offers a range of knowledge co-production methods (Network for Transdisciplinary Research, 2023). The "td-net toolbox" comprises techniques for various project phases, empowering participants to establish a common ground regardless of their prior experience.

Future research

Our study focused on a core challenge of ITD work. In addition to knowledge integration, other major issues include interdisciplinary communication or interaction in group processes (Frodemann, 2014). Further individual competencies (for example, Creativity and Curiosity; Guimarães et al., 2019) should be empirically investigated for certain challenges. In particular, it is exceedingly feasible that competencies promoting knowledge integration also favor other central mechanisms of ITD work, or vice versa. The empirical development of a manageable competency model to promote key mechanisms of ITD work could advance future research into ITD processes and be applied to train inter- and transdisciplinarians.

Another challenge to supporting knowledge integration in ITD practice is context-specific training. In a series of online trainings with PhD students, Xue & colleagues (2020) investigated the trainability of knowledge integration in an interdisciplinary context. The authors examined the frequency and quality of knowledge integration and knowledge transfer based on participant interactions, observing that mentoring is a facilitating factor for knowledge integration relations. Further research examining competencies related to knowledge integration is needed to determine which key mechanisms can be incorporated into training programs. Currently, mechanisms such as the identification and resolution of conflicts between insights can be evaluated in educational programs. Previous research has demonstrated that relevance instruction enhances the knowledge integration of different content (Linn, 2000; Zeeb et al., 2019). Psychological prejudice and coaching research currently work with brief instructions to place a person in someone else's position or in a new context (Galinsky & Ku, 2004). These instructions could be adapted to encourage students to engage proactively with competing disciplinary insights.

Further research should also examine the interactions between the different competencies. In the current study, the relationships between the competencies and knowledge integration demonstrated low to medium effects. In the developed questionnaire, primarily cognitive facets of the competencies were assessed due to knowledge integration's cognitive requirements. However, intraindividual competencies contain additional affective and motivational components. In particular, engagement in perspective taking depends on motivational effects and situational factors (Gehlbach, 2004). Motivation and positive/negative experiences in ITD work should be assessed in future research to understand the extent to which the investigated competencies contribute to knowledge integration. Future studies should also improve upon the developed questionnaire used to measure the competencies. Single items from the constructs of perspective taking and tolerance of ambiguity and uncertainty could be exchanged to improve reliability. The individual facets of the constructs should be extended by multiple items, aiming at stronger construct validity. In addition, experimental studies should examine whether an increase in individual competencies causally increases knowledge integration. It would be advisable in such a situation to use different measurement tools to enable several quality measures of the knowledge integration that actually occurs. We selected the knowledge integration scale (Claus & Wiese, 2019) because it was validated on company members with an interdisciplinary focus. The writing task in a pre-service teacher education context represents another way to measure knowledge integration (Lehmann et al., 2019). In contrast to self-report measures, writing tasks allow for an actual assessment of the subjects' performance. It is therefore recommended that they be used in experimental studies.

Supplementary material

Supplementary materials are available at. https://osf.io/9yqtg/?view_only=d293a7deb03446e69ab43eb85ed9c1ed

The supplementary materials include:

- Constructs and items of the questionnaire "Competencies of Knowledge Integration" in english and german language
- All 52 items ("Competencies of Knowledge Integration") included in the analysis with item order presented in the study
- Test of Confirmatory Factor Analysis: Variance—covariance matrix
- Interaction diagrams of the moderation analysis

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Data availability The data that support the findings of this study are available from the corresponding author, Olga Vogel, upon reasonable request.

Code availability The R code used to calculate the results of this study is available upon request from the corresponding author, Olga Vogel.

Declarations

Conflicts of interest The authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee of the Ruhr-University Bochum (Faculty of Psychology, Case No. 568) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent for publication Explicit consent was obtained from all authors and from all responsible authorities at SecHuman College at Ruhr University Bochum as well as responsible authorities at Faculty of Psychology at Ruhr University Bochum.

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