A MULTILEVEL PERSPECTIVE ON FACTORS INFLUENCING STUDENTS' STATISTICAL LITERACY

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Over the last two decades statistics has been recognized as an important part of the school curriculum worldwide. As a result, questions related to impact factors on statistical literacy merit focused attention in empirical research. For instance, interdependencies with individual factors such as general cognitive abilities, reading comprehension or specific elements of mathematical content knowledge is still scarce. We report empirical results from two studies on relationships between statistical literacy and potential influencing factors. The findings provide insight into the role of such covariates and support the validity of the competency measure we used to assess a key aspect of statistical literacy. The evidence further suggests that statistical literacy also depends on class variables beyond individual dispositions.

Statistical literacy involves abilities of making sense of statistical data for decision-making under uncertainty and active participation in society. Hence, a lack of statistical literacy impedes responsible citizenship. Knowing which learner characteristics impact on statistical literacy could help to identify their needs and to design powerful learning material. Consequently, this paper reports results from two studies focusing on different sets of covariates and aims at drawing conclusions on which variables influence how statistically literate a learner is. The first study investigated relations between statistical literacy and reading comprehension, general cognitive abilities, grades in mathematics as well as students' socio-economic status. The second study assessed interdependencies with conceptual knowledge in the domains probability and functional reasoning. Beyond individual impact factors, the analyses included also the class level.

Even though our findings refer to two different studies, there is strong evidence that statistical literacy requires specific conceptual knowledge additionally to general cognitive abilities. The socioeconomic status as an indicator for classes' proximity to education appears to explain differences on the class level.

In the first section, we give an overview about the theoretical background and introduce our research questions. The second section will outline the samples and measures of the two studies. Results will be presented and discussed separately for the two studies in Section 3, our conclusions follow in the fourth section.

THEORETICAL BACKGROUND

Statistical literacy integrates various sub-aspects, some of them appear to be crucial for building up this competency. One of its key aspects is *dealing with statistical variation*, which means that differences and deviations in the data are to be modelled with respect to the context. Whereas several changes in data may have systematic origins and therefore are essential for explanation, prediction or control, others can be attributed to randomness and should be disregarded when focusing on a trend or a signal in the data (Wild & Pfannkuch, 1999). Watson and Callingham (2003) integrated *dealing with variation* as a central thought in a competency model for statistical literacy.

Modeling variation often requires manipulating data through *reduction*. Kroepfl, Peschek and Schneider (2000) pointed out that meaningful overviews on data often need to omit details that are non-relevant for the initial question. A study of Reading (2002) showed that competencies in the domains *data representation and reduction* can be considered as representative for learners' over-all statistical literacy.

Curcio (1987) introduced three hierarchical levels of data comprehension in order to classify requirements when working with statistical information. Kuntze, Lindmeier and Reiss (2008; see also Kuntze, 2013) used the idea of *data-related reading* and added the key aspects *dealing with variation* and *reducing data* in order to describe learners' competencies in the area of statistical literacy. They established the competency model *using models and representations in*

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statistical contexts and a corresponding evidence-based test instrument. In the present studies, we refer to this competency model under the label SLCC (Statistical Literacy Competency Construct).

As this competency model is based on *data-related reading*, linguistic reading may appear as a potential impact factor on statistical literacy. Reading can be considered as constructing sense in an active fusion between the learners' individual knowledge and textual content (Bundesministerium für Bildung und Forschung, 2007). This description can be extended theoretically from linguistic reading to data-related reading. Hence, the underlying procedures could overlap and cause high correlations. As such process similarities are possible, we approach reading comprehension in the sense of pure linguistic reading comprehension to avoid further content overlaps, unlike in the PISA reading competency measure (OECD, 2003), which also encompassed reading from statistical representations. Measuring reading comprehension in a text-oriented perspective additionally enables us to assess if the wording of the SLCC test is appropriate for the learners or whether a low reading comprehension score impedes their performance.

Both, linguistic and data-related reading, are mental processes, thus, their relation to general cognitive abilities merits investigation. As there are various approaches within intelligence research that establish different structures of cognitive abilities we do not refer to one of these models in particular. Being aware that some cognitive abilities are culture-independent and others draw on cultural factors such as linguistic knowledge (Holling, Preckel & Vock, 2004) we consider both, culturally independent (figural reasoning) and language oriented (verbal reasoning) aspects of cognitive abilities. Whereas the PISA study showed a close interrelatedness between general cognitive abilities and mathematical competency, such studies are rare for competencies in the domain of statistics.

Besides learners' dispositions, mathematical knowledge in specific domains could also favor achievement related to SLCC. Within mathematics, the domains of probability and functional reasoning appear to frame SLCC. On the one hand, conceptual knowledge related to functional reasoning addresses for instance graphical diagrams of functions, a representation format that is inherent in SLCC. On the other hand, knowledge about probability may support modelling random differences in data and therefore foster dealing with variation – a key aspect of SLCC.

As there is still a lack of empirical evidence about impact factors on statistical literacy in the above-mentioned domains, this paper focuses on the following research questions:

- To which extent are reading comprehension and SLCC interdependent?
- Which role do verbal and nonverbal general cognitive abilities play for SLCC?
- How do further covariates such as students' grades in mathematics and the socioeconomic status influence SLCC?
- Is there a relationship between SLCC and conceptual knowledge in the domains of probability and functional reasoning?

METHOD

As we report on two different field studies, we will give information about the context, the sample and the measures of the studies separately. Nevertheless, as data involving students from different school classes tends to be clustered with a complex dependency structure, both studies were designed to allow for multilevel hierarchical linear models (also called mixed effect models, multilevel models). Ordinary multiple regression neglects the dependency structure in the data and therefore could lead to wrong parameter estimates or to wrong conclusions concerning the level of interpretation (Hox, 2010). Multilevel analysis allows including predictors on the individual and on the class level, hence provides a broader scope on possible impact factors.

Study 1 (from Project ReVa-Stat)

In this paper, we will present results of the first phase of the project ReVa-Stat ("Developing concepts of data-related reduction and statistical variation as a support for building up statistical literacy"). The sample comprises 503 8th-graders (263 boys and 240 girls) from 25 classes in eight German middle schools. They were aged from 12 to 15 years (M = 13.5; SD = 0.6) and had not experienced any specific statistics instruction prior to their participation in this study. During two consecutive periods of 45-minute lessons in the academic year 2012/13, the students completed paper-and-pencil tests referring to statistical literacy on the one hand and general cognitive abilities as well as reading comprehension on the other.

To assess students' statistical literacy, we used a SLCC test instrument with five hierarchical levels (cf. Kuntze, 2013). The competency model as well as sample items can be found in Sproesser, Kuntze and Engel (submitted). Prior research has shown that the competency scores fit to a one-dimensional Rasch model (Fröhlich, Kuntze, & Lindmeier, 2007).

To measure particular aspects of cognitive abilities, we used test instruments with specific foci. The "Cognitive Abitilies Test" ("KFT4-12+", Heller & Perleth, 2000) quantifies the dimensions verbal, nonverbal and numerical cognitive abilities. In this study, we assessed the nonverbal subscale N2B (internal consistency coefficient 0.9) and the verbal subscale V3B (internal consistency coefficient 0.81). Sample items can be found in the test manual (Heller & Perleth, 2000) or in Sproesser et al. (submitted).

Reading comprehension was evaluated by the test "LGVT6-12" (Schneider, Schlagmüller & Ennemoser, 2007) which had been designed in the framework of the German extension study of PISA 2000 (OECD, 2003).

Additionally to these variables, we collected data concerning students' grades in mathematics and German as well as an indicator for the socioeconomic status (Paulus, 2009) directly from the students and their teachers.

Study 2 (from Project RIKO-STAT)

This study is based on data from 535 9th-graders (283 boys and 252 girls) from the project RIKO-Stat (see also Kuntze et al., 2010). Participants were from 22 classes in eight German middle schools with an age range between 14 and 18 years (M = 15.4; SD = 0.7). These students also completed the SLCC test. Additionally and among others, their conceptual knowledge in the neighboring domains of probability and functional reasoning was assessed.

RESULTS AND DISCUSSION

Study 1

To begin our analysis, we investigated the differences between the classes concerning the competency "using models and representations in statistical contexts" by determining the intra-class correlation (ICC). The ICC of 3.4% indicates rather low but significant differences between the classes. Even if Snijders and Bosker (1999, pp. 46 & 151) recommend an ICC of at least 5% in the field of education, they also admit that all ICCs greater than 0 merit a multilevel perspective within the social sciences. In the following, all regression weights are standardized in order to facilitate direct comparison. As the dependent variable is also standardized, the intercept of all models is not significantly unequal to 0. Hence in the interest of clarity they are omitted in the tables. The analysis steps were carried out in the order of the research questions.

Firstly, we investigated the influence of reading comprehension on the competency score. A multilevel regression analysis indicated that reading comprehension is a significant predictor ($p < 0.001$) for the competency score with a standardized regression weight of ß = 0.15 (SE = 0.04).

Introducing additionally the independent variables of verbal and nonverbal general cognitive abilities into the multilevel regression analysis rendered reading comprehension non-significant. This means that reading comprehension does not explain variance beyond general cognitive abilities, even if it correlates moderately with the competency score. Model 1 (see Table 1) includes verbal and nonverbal general cognitive abilities as individual predictors that explain about 16.3% of the SLCC variance.

Table 1. Model 1 Including Verbal and Nonverbal Cognitive Abilities

Fixed effect	Coefficient	SE	p-value	Pseudo-R
Verbal cognitive abilities	≈0.27	≈0.04	<0.001	≈16.3%
Nonverbal cognitive abilities	≈0.21	≈0.04	<0.001	

(Pseudo-R^2 indicates the ratio of explained variance by the independent variables within a model to the overall variance in the intercept only model)

In the next step, we investigated the further impact of grades in mathematics and German as well as an indicator for the socioeconomic status on the individual level. Whereas grades in German and the socioeconomic status could not explain variance of the competency score beyond cognitive abilities, the grades in mathematics explained further variance. Integrating this variable in Model 2 (Table 2) significantly improves the model fit and leads to a variance explanation of 20.7%. As a result of the ceteris paribus effect, the coefficients of verbal and nonverbal abilities have decreased in comparison to Model 1.

Table 2. Model 2 Including Grades in Mathematics, Verbal and Nonverbal Cognitive Abilities

Fixed effect	Coefficient	SE	p-value	Pseudo-R²
Grades in mathematics	≈-0.23	≈0.05	<0.001	
Verbal cognitive abilities	≈0.22	≈0.04	<0.001	
Nonverbal cognitive abilities	≈0.17	≈0.04	<0.001	≈20.7%

(The German scale for grades labels very good performance with 1 and insufficient performances with 6. Therefore the relationship to the competency score (i.e. regression weight) is negative.)

The above-mentioned variables could not explain the differences on the class level. Indicators for high-performing classes like high averages concerning cognitive abilities, reading comprehension or school grades did not explain better competency scores. On the individual level the socioeconomic status did not impact on the SLCC competency score, however, in contrast, its average turned out to be an adequate predictor on the class level. Its inclusion into the model explained the variance between the classes to such a degree (85.9% from the initial class differences) that the classes did no longer differ significantly. Model 3 (Table 3) also contains the individual socioeconomic status to ensure that the class effect is adjusted for the individual effect.

Table 3. Model 3 Including the Socio-Economic Status, Grades in Mathematics, Verbal and Nonverbal Cognitive Abilities

Fixed effect	Coefficient	Standard error	p-value	Pseudo-R²
Socioeconomic status (class level)	≈ 0.15	≈0.04	<0.001	
Socioeconomic status (individual level)	≈ 0.05	≈0.05	0.243	
Grades in mathematics	≈-0.24	≈0.05	<0.001	
Verbal abilities	≈ 0.21	≈0.04	<0.001	
Nonverbal abilities	≈ 0.16	≈0.04	<0.001	≈22.9%

Summing up and discussing the evidence, the results from the first study (project ReVa-Stat) revealed some variables influencing statistical literacy. Apparently, linguistic reading comprehension and data-related reading are empirically different constructs. In particular, SLCC is relatively independent from reading comprehension. Insofar, a lack of reading comprehension does not prevent learners from succeeding in SLCC. Moreover, language-oriented learning environments can be designed as intended in the project ReVa-Stat. As far as general cognitive abilities are concerned, we found a moderate relationship with SLCC similar to PISA results referring to mathematical competency. The fact that cognitive abilities do not completely explain the competency score helps to empirically validate the test instrument and shows that it is a domain-specific construct measuring more than general learners' dispositions.

Whereas PISA found a relationship between mathematical competency and the individual socio-economic status, this variable could explain variance between the classes in ReVa-Stat. A possible interpretation of this finding could be that classes with higher averages of the socioeconomic status could enable the teachers to perform a cognitive more activating instruction and therefore lead to better individual performances in SLCC.

Mathematical knowledge also appears to interrelate with SLCC. However, grades in mathematics can hardly be considered as reliable measures because they do not directly reflect mathematical competency. In particular, we have to expect substantial differences between the grading of different teachers. Concerning mathematical domains, grades in mathematics give a rather general indication of mathematical competencies. Taking a closer look to the influence of mathematical knowledge in neighboring domains of SLCC could provide more precise insight into the influence of mathematical knowledge. Therefore, data from the prior study RIKO-Stat will be analyzed in a multilevel perspective.

Study 2

The following analysis steps give insight into how SLCC is influenced by specific conceptual knowledge in the areas of probability and functional reasoning. Since these domains of knowledge are more directly related to statistical literacy than grades in mathematics, this analysis may help to interpret the results presented above concerning the influence of these grades on the competency score.

The ICC of 9.7% showed somewhat larger differences between the classes concerning SLCC for the second study (project RIKO-Stat) than for the first study (ReVa-Stat).

Prior analysis steps (Kuntze et al., 2010) already revealed a moderate relationship between specific conceptual knowledge and SLCC. Introducing such specific conceptual knowledge about probability and functional reasoning in a multilevel regression model shows similar results: both regression weights are significant ($p < 0.001$) with a moderate predominance of conceptual knowledge related to probability. Model 4 (see Table 4) containing these predictors explains about 15.0% of the SLCC competency's variance.

Table 4. Model 4 Including Conceptual Knowledge related to Probability and Functional Reasoning

Fixed effect	Coefficient	Standard error	p-value	Pseudo-R^2
Conceptual knowledge about probability	≈ 0.29	≈0.04	<0.001	≈15.0%
Conceptual knowledge about functional reasoning	≈ 0.19	≈0.04	<0.001	

Discussing these results, we have to state that a direct comparison between the regression weight for grades in mathematics from Table 3 and the values related to the conceptual knowledge areas probability and functional reasoning in Table 4 is hardly possible because of the additional covariates in Model 3, which partly correlate with grades in mathematics and therefore reduce its regression weight. Inspecting Pseudo-R^2 of Model 4 and a further model with only grades in mathematics as single predictor gives more insight into the degree of impact that these predictors provide. Grades in mathematics explain about 11.0% of the competency's variance (for reasons of space, we do not display a table with this model here), whereas conceptual knowledge in the two neighboring areas explain about 15.0%. Insofar, these more content-specific independent variables appear to predict the competency score better than grades in mathematics. This might be on the one hand due to the fact that grades in mathematics may reflect more general mathematical competencies whereas knowledge related to probability and functional reasoning is more closely connected to SLCC. On the other hand, grades in mathematics appear to depend considerably on the teacher in terms of which aspects of the mathematical classroom enter to what extent into the grading. We can retain from these findings that specific mathematical knowledge plays a role for SLCC but – as seen for individual dispositions – it does not completely explain this competency. The predominance of knowledge in the domain of probability may be due to the fact that probability relates to *dealing with variation*, a key aspect of SLCC.

CONCLUSION

Both studies revealed differences concerning SLCC between the classes. They could partly be explained by the class average of socioeconomic status. Whereas we can only speculate about this outcome, it appears to be certain that there are variables on the class level that influence students' SLCC. Further research should investigate such predictors and review to which extent the socioeconomic status is adequate to explain these differences.

Summarizing the results of both studies, we point out that SLCC requires general cognitive abilities as well as mathematical knowledge. Within mathematical knowledge, more specific domains connected to SLCC such as probability and functional reasoning appear to predict the competency score better than more general indicators such as grades in mathematics. In this respect, in the study ReVa-Stat we investigate how students' SLCC can be fostered by the even more specific aspects *variation* and *reduction* within statistical literacy. Results of this study could complement the above-mentioned findings.

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