How Teachers in Different Educational Systems Value Central Concepts of Computer Science

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ABSTRACT
The 16 German states exhibit substantial differences regarding the organization as well as the substantial focus of computer science education at their schools. This empirical study investigates how teachers from two German states with different educational systems assess the value of central concepts of computer science. We asked 120 teachers in each country to complete our questionnaire, received 38 responses and applied a specific split-plot design to evaluate the results. The findings show that the assessments by the two groups differ regarding the content concepts model, system, computer, and information. Additionally, we detected differences in the rating of some individual process concepts (analyzing, classifying, finding relationships, generalizing, comparing, and ordering) in relation to the content concept model. These results are consistent with the differences in the focus of the curricula as well as with the content of the teacher education programs in the two states.

Categories and Subject Descriptors
K.3.2 [Computer and Information Science Education ]: Computer science education.

General Terms
Human Factors

Keywords
computer science education, teacher education, subject domain knowledge, central concepts.

1. INTRODUCTION
The educational systems of the 16 German states exhibit substantial structural differences. This applies to the implementation of computer science education in schools as well as to the teacher education programs. This empirical study investigates how teachers from two German states differ in their evaluations of central concepts of computer science that are given particular emphasis in the curricula respectively in the teacher training programs of these states.

The provision of effective computer science education (CSE) in schools requires computer science (CS) teachers who are able to draw on three types of professional knowledge [41], [48], [7, 26], [1]:
(1) disciplinary knowledge of the subject taught (content knowledge),
(2) general pedagogical knowledge (pedagogical knowledge), and
(3) knowledge of how to teach specific subject matter (pedagogical content knowledge).

A crucial tasks for teacher training programs is to define what the subject of computer science is and what it is not: “One of the challenges we face when discussing computer science education is that the field of computer science seems to progress so quickly that is difficult even for computer scientists to clearly define its contents and prescribe its boundaries” [12].

This study builds on different approaches to teacher training programs (See sections “Theoretical Background” and “Related Work”). Specifically, we investigated whether and how computer science teachers differ from the two different German states Baden-Württemberg (BW) and Bavaria (BY) in their evaluations of the relationships between central content concepts and central process concepts of the discipline. We also examine whether Bavarian computer science teachers evaluate the concepts given in their training programs (data, model, process, structure, information) [43] as being of particular importance. By addressing these research questions, we hope to provide insights that can inform the pre- and in-service training of computer science teachers.

2. THEORETICAL BACKGROUND
In the last decade the research-based approach to teacher education has been gaining ground [24], [35], [12], [11]. It is characterized by three main desiderata:
(1) teachers need in-depth knowledge of recent research advances in the subject they teach,
(2) teacher training should itself be an object of research,
(3) teachers need to internalize a research-based approach to their work.

In implementing curricular reforms, moreover, it is important to consider a bottom-up approach [10], [14] that explicitly draws on teachers’ knowledge and perspectives: “To understand the role of teachers with respect to educational reform, it has been suggested that their beliefs and views (…), or their practical knowledge (…) be analyzed” (see [10], p. 138). Fincher and Tenenberg [13] as well as Ni [34] have discussed the application of the bottom-up approach to training programs for computer science teachers.
Deciding on the subject matter to be taught is a key challenge for those involved in the design of computer science education [44]. The spectrum currently ranges from training the use of computer office software to programming courses or to the theoretical solution of algorithmic problems. Teachers’ uncertainty is evident in the fact that course content tends to reflect current trends and developments and to draw on short-lived product knowledge [16]. Given the rapid pace of development in the field of information technology, however, this knowledge soon becomes obsolete. Instead, computer science education should equip students with knowledge and skills that will remain relevant in the longer term, that they can use in their everyday lives, and that are to some extent representative of the subject [33].

The contents to be covered in computer science education have previously been discussed primarily in the context of fundamental ideas [39], first introduced by [5]. According to [39], a fundamental idea is a scheme of thinking, action, description, or explanation that satisfies four criteria: It must be relevant in multiple domains of a discipline (horizontal criterion). It must be teachable on every intellectual level (vertical criterion). It must remain relevant in the longer term (time criterion). And it must be related to everyday language and/or thinking (sense criterion). Arguments based on these criteria have been applied also to justify the learning content covered in the new school subject of computer science in Bavaria. Additionally, however, it has been postulated that the modeling of real or planned systems using special representation techniques from software engineering (e.g., object and class diagrams or data flow charts) is of particular importance in the context of general education [19]. Computer science instruction is expected to explain the basic functioning of computer systems, and the abstract representation of these systems in the form of such models is expected to further this aim. Moreover, computer science instruction is expected to develop students’ ability to structure complex systems, which is clearly also the goal of such modeling activities [4].

3. RELATED WORK

Several scientists have proposed catalogues of the basic concepts or fundamental ideas of computer science [36], [39]; [2]; [8], [27], [17], [47].

However, these catalogues have a number of shortcomings in terms of validity:

(1) they are based on the subjective judgments of a single author or small group of authors,
(2) they lack empirical verification,
(3) they relate only to subdomains of computer science,
(4) their validity has been established only for the national context in which they were developed.

We have addressed points (1) to (3) in previous research. Specifically, the results of our three studies [49], [50], [51] were based on the judgments of a larger sample of experts, were empirically derived, and related to various subdomains of computer science.

In the current discussion on curriculum development in computer science education, the combination of two scientifically informed oriented approaches is considered crucial: first, the structure of the discipline approach introduced by [5]; second, the process as content approach, based on the work of Parker and Rubin [37], which has more recently enjoyed a renaissance thanks to Costa and Liebmann [6].

In 2003, Meyer and Land introduced the idea of threshold concepts, core concepts in a discipline that are transformative, irreversible and integrative [28]. Recently Sorva presented a comprehensive overview of research about this issue [42], while Sanders et al. investigated the relations between threshold concepts and threshold skills in computing [38].

In the study byZendler, Spannagel, and Klaudt [51], which drew on these two approaches and on a constructivist theory of learning [3], [29], For the study 24 German computer science professors rated the relevance of 15 content concepts (e.g., algorithm, problem, and model) with respect to 16 process concepts (e.g., analyzing, categorizing, and classifying) on a 6-point scale from (“no importance”) to 5 (“great importance”). The main finding of the study was that there are specific groups of content concepts that should be taught in combination with specific groups of process concepts. In total, 15 blocks of content and process concepts were identified as being particularly relevant (e.g., the blocks of the content concepts algorithm, data, information, problem, model, and structure in combination with the process concepts categorizing, classifying, finding cause-and-effect relationships, and generalizing).

In 2009 we have investigated the view of active teachers on the recently installed compulsory subject of informatics in the state of Bavaria [32], [22]. Regarding the valuation of CS concepts we found that the teachers could be assigned to one of three different clusters as far as their valuation of the CS concepts is concerned [32]:

(1) “office users”, concentrating on the application of software systems,
(2) “fans of the curriculum” and “anti-programmers”, preferring object-oriented modeling (OOM) instead of programming and algorithmic concepts,
(3) “traditional computer scientists” that focus on traditional algorithmic views instead of OOM.

4. COMPUTER SCIENCE EDUCATION

4.1 General Education in BY and BW

The educational systems of BY and BW are quite similar, at least as far as the structure of the general education is concerned (see Fig. 1). In both states the 4-yeared primary education takes place in the Grundschule. Following this, the students split according to their performance level in 3 types of secondary schools:

(1) Gymnasium (8 years),
(2) Realschule (6 years),
(3) Hauptschule (5-6 years).

Figure 1. School System in BW and BY

As our data were gathered among teachers at Gymnasium, we will restrict the following explanations to this school type, which is
attended by about a 33-40% of all school students in grade 5 currently.

4.2 CSE in BY and BW

By the occasion of the extensive reform project of the Bavarian Gymnasium in 2004 (from G9 to G8) a new (at least partly) compulsory subject of CS was incorporated. Fig. 2 displays the organization of the new subject and the years it has started in the different grades. In grade 6 and 7, CS is incorporated formally in the subject combination Nature and Technology (NuT) that comprises the Biology (in grade 5 and 6), Physics (in grade 7) and CS (in grade 6 and 7). Nevertheless, all three subjects are taught separated in a prescribed number of lessons per week by teachers that need a university degree in the respective subject.

<table>
<thead>
<tr>
<th>direction of study</th>
<th>(Natural) science &amp; technology</th>
<th>others</th>
<th>starting in</th>
</tr>
</thead>
<tbody>
<tr>
<td>grade 6</td>
<td>1 lesson/week</td>
<td>1 lesson/week</td>
<td>2004</td>
</tr>
<tr>
<td>grade 7</td>
<td>1 lesson/week</td>
<td>1 lesson/week</td>
<td>2005</td>
</tr>
<tr>
<td>grade 8</td>
<td>2 lesson/week</td>
<td>2006</td>
<td></td>
</tr>
<tr>
<td>grade 9</td>
<td>3 lesson/week</td>
<td>2007</td>
<td></td>
</tr>
<tr>
<td>grade 10</td>
<td>2 lesson/week</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td>grade 11</td>
<td>3 lesson/week</td>
<td>2009</td>
<td></td>
</tr>
<tr>
<td>grade 12</td>
<td>3 lesson/week</td>
<td>2010</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. The subject of CS in Bavarian Gymnasiums

In the Science & Technology direction of study, the students have to attend CS as a compulsory subject in grade 9 and 10. In average about 50% of the students choose this direction. In grade 11 and 12, an elective CS course might be chosen instead of a second natural science or a second foreign language. In the final examination, CS can be chosen for written as well as for oral examination.

The learning topics of the subject of CS are prescribed in several curricula, which we have described in several publications, e.g. [18], [19], [20].

In contrary to the situation in Bavaria, there is no compulsory subject of CS in BW. Despite there are working groups beside the regular schedule up to grade 10. From this point of time, the students can choose an elective course that is designed according to the proposed educational standards of the German Gesellschaft für Informatik [15].

5. TEACHER EDUCATION

Regarding the curricula of regular teacher education programs, there aren’t big differences between the two states, at least as far as the teachers at Gymnasiums are concerned. The education takes place at the Universities in contrary to the teachers for the other school types in BW, who are educated at specific pedagogical colleges (Pädagogische Hochschulen). The content of the teacher education in CS was standardized in 2008 by the German Kultusministerkonferenz (KMK), the national board of the 16 secretaries of states that are in charge for the schools, which worked out Standards for Teacher Education [40]. Thus we can assume that the subject knowledge content of the regular teacher education courses is not much different in the two states.

Nevertheless, in Bavaria, many of the teachers that are active teaching currently were educated in specific courses that were installed in order to support the introduction of the new compulsory subject. At this time, the dilemma associated with all new subjects has to be addressed: On the one hand, if teachers are trained before a new subject is introduced, there is a risk that they will not find employment after graduation. On the other hand, a new subject can be successfully introduced only if sufficient numbers of appropriately trained teachers are available. When computer science was first implemented as a compulsory subject in academic-track schools (called Gymnasiums) in the southern German state of Bavaria, this dilemma was resolved by providing specific in-service training programs for teachers who had already been appointed to teach two other subjects before [43].

These programs emphasized the importance of modeling techniques in computer science. In particular, the modeling of processes [21] and object-oriented modeling formed the core of the SIGNAL and FLIEG in-service-courses attended by the majority of the currently active computer science teachers in Bavaria, who have received further training to date. Specifically, the courses contained the following modules M1 to M8:

- M1: Data modeling and database systems
- M2: Modeling processes
- M3: Object-oriented modeling and programming
- M4: Algorithms and data structures
- M5: Software technology
- M6: Technological computer science, data security
- M7: Theoretical computer science
- M8: The teaching of computer science

As the content of these specific courses is well-tailored to the curriculum of the Bavarian subject of CS, there might exist substantial differences to the regular teacher education in BW.

6. METHODOLOGY

6.1 Study design

The hypothesis was tested in a 2×15×16 split-plot design (3-factor design with repeated measures of factors B and C, see Fig. 3; [46]; [25]. Factor A comprised the p = 2 groups surveyed, with factor level a1 representing group G1 of n1 Baden-Württemberg (BW) teachers of computer science and factor level a2 representing group G2 of n2 Bavarian (BY) teachers of computer science teachers. Factor B represented the q = 15 content concepts (CC) b1, ..., b15: problem, information, model, algorithm, data, structure, system, computation, process, software, program, test, communication, language, and computer. Factor C consisted of the r = 16 process concepts (PC) c1, ..., c16: analyzing, classifying, problem solving and problem posing, categorizing, investigating, finding relationships, generalizing, creating and inventing, comparing, finding cause-and-effect relationships, questioning, transferring, communicating, presenting, collaborating, and ordering.

Figure 3. Layout of the 2×15×16 split-plot design
While the factors $A$, $B$ and $C$ were regarded as independent variables, the dependent variable was the respondents’ evaluation of the importance of a specific process concept for a specific content concept. Ratings were given on a 6-point scale from 0 (“no importance”) to 5 (“great importance”).

6.2 Power analysis
A power calculation of type II, $N$ being a function of power ($1-\beta$), $A$, and $a$, was used to determine the necessary sample size for the 2$\times$15$\times$16 split-plot design (see 31]). With a power ($1-\beta$) of 0.99, only large effects ($f = 0.80$) on the dependent variable being considered significant, and a significance level of $\alpha = 0.05$, a total sample of approximately $N^* = 30$ ($n^* = 15$ Baden-Württemberg teachers of computer science teachers, $m^* = 15$ Bavarian teachers of computer science teachers), would be required, based on the power computations of Mueller and Barton [30] or Mueller et al. [31] for $\alpha$-corrected F tests.

6.3 Operational hypothesis
Given the study design and the above specification of the independent and dependent variables, the operational hypothesis of the study can be formulated as follows: “CS teachers from BW differ from CS teachers from BY in their evaluations of the relations between central content concepts of computer science (CC, see section 2.1) and central process concepts of computer science (PC, see section 2.1), as operationalized by their rating on a six-point scale of the importance of a specific process concept for a specific content concept.”

6.4 Sampling
A total of 120 CS teachers in BW and 120 CS teachers in BY were contacted and invited to complete a questionnaire pertaining to computer science concepts. The questionnaire began with a short introduction, in which the 15 central content concepts and the 16 central process concepts were listed in tabular form in alphabetical order. Following this, the $q = 15$ content concepts and the $r = 16$ process concepts were presented in alphabetical order in a matrix, with the content concepts in the rows and the process concepts in the columns. Participants were asked to rate the following statement for each of the 15x16 = 240 cells of the matrix: Each cell represents a combination of a concept and a process and requires an integer from 0 (no importance) to 5 (great importance) indicating the relevance of the combination. Participants filled in each cell on a 6-point scale from 0 (“no importance”) to 5 (“great importance”).

To maximize the return rate, we mailed both samples the questionnaire in sealed, pre-addressed return envelope franked with stamps showing flower design (see [9] for recommendations on increasing return rates). The return rate for the BW teachers was 14.2% ($n_1 = 17$ valid questionnaires), which can be considered reasonable for a postal survey (see [45]). The return rate for the BY teachers was 17.5% ($n_2 = 21$ valid questionnaires).

6.5 Data Analysis
The procedure used to analyze the experimental data was as follows: First, we performed a descriptive analysis (7.1-7.2), focusing on the content concepts. Second, we conducted a three-factor analysis of variance with repeated measures (7.3) in accordance with the SPF$\times$15$\times$16 split-plot design (see Winer [46], chapter 7). Third, we conducted a posteriori comparisons of means to test for significant effects of the $A \times B$ interaction (7.4) and the $A \times B \times C$ interaction (7.5). The process concepts were included in analyses (2) to (4).

Data analyses were conducted using SPSS 17.0; the power analysis was computed with PASS 8.0.9.

7. RESULTS
Fig. 6 in the appendix displays the original data of the mean ratings obtained from the BW teachers ($a_1$) and the BY teachers ($a_2$) for each of the 15 $\times$ 16 combinations of content concepts $\times$ process concepts (repeated measures factors $B \times C$).

7.1 Means
The four content concepts with the highest averages (see Appendix) are the same for the two groups of teachers: problem, information, model and algorithm. The concept with the lowest average is also the same, namely computer. Major differences in the assessment of content concepts between the two groups of teachers can be found for the content concepts information (2.79 vs. 3.11), model (2.62 vs. 3.30), system (1.90 vs. 2.44) and computer (1.62 vs. 2.04).

7.2 Process-related coverage
To determine differences in the assessment of content and process concepts by the two groups of teachers, the process-related coverage can be used: A concept has high process-related coverage if it is rated as highly important ($> 2.50$) for many of the process concepts; it has lower process-related coverage if it is rated as less important ($\leq 2.50$) for many of the process concepts. It is striking that the content concepts information, model and system are rated highly in relation to more process concepts by the BY teachers compared to the BW teachers. On the other hand, teachers from Bavaria rate more process concepts highly in combination with the content concepts information (14 vs. 11), model (15 vs. 12) and system (6 vs. 1) compared to the BW teachers, while the latter rate more process concepts highly in combination with computation (8 vs. 3) and program (8 vs. 5).

7.3 Analysis of Variance
To examine whether the BW teachers differed from the BY teachers in their evaluations of the relationships between the content concepts and the process concepts, we formulated three statistical hypotheses, which were tested at the significance level of $\alpha = 0.05$. The three null hypotheses were chosen as follows:

i) The means of the content concepts $\mu_1$ under factor level $a_1$ (BW teachers) and $\mu_2$ under factor level $a_2$ (BY teachers) are equal, such that:

$$H_0: \mu_1 = \mu_2.$$

ii) The means of the content concepts $\mu_1$, $\mu_2$, ..., $\mu_2$ under the $2 \times 15$ levels of the factor combinations $A \times B$ are equal, such that:

$$H_0: \mu_1 = \mu_2 = \ldots = \mu_2.$$

iii) The means of the content concepts $\mu_1$, $\mu_2$, ..., $\mu_2$ under the $2 \times 15 \times 16$ levels of the factor combinations $A \times B \times C$ are equal, such that:

$$H_0: \mu_1 = \mu_2 = \ldots = \mu_2.$$

For an analysis of variance of a split-plot design, the data must satisfy the condition of sphericity. This assumption was tested using Mauchly’s $W$ test for sphericity, with the test statistic $W$ being compared to a chi-square distribution to assess the adequacy of the sphericity assumption.
The assumption of sphericity was not met for either the content concepts ($W = 0.003$, $\chi^2_{104} = 178.35$, $p < 0.001$) or the process concepts ($W < 0.001$, $\chi^2_{119} = 248.60$, $p < 0.001$) at the $\alpha$ level of 0.05. In the further analyses, we therefore applied the $\varepsilon$ correction of degrees of freedom proposed by [23], as presented in table 1.

### Table 1. Results of the ANOVA with Huynh–Feldt $\varepsilon$ correction of degrees of freedom

<table>
<thead>
<tr>
<th>Sources of variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>$F$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Between subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$A$</td>
<td>28.94</td>
<td>1</td>
<td>28.94</td>
<td>0.24</td>
<td>&lt; 0.63</td>
</tr>
<tr>
<td>$A \times B$</td>
<td>164.32</td>
<td>10</td>
<td>16.43</td>
<td>2.26</td>
<td>&lt; 0.02*</td>
</tr>
<tr>
<td>$A \times B \times C$</td>
<td>260.54</td>
<td>78</td>
<td>3.34</td>
<td>1.09</td>
<td>&lt; 0.29</td>
</tr>
<tr>
<td><strong>Within subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$A \times B$</td>
<td>4365.81</td>
<td>36</td>
<td>121.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$A \times B \times C$</td>
<td>8634.84</td>
<td>2809</td>
<td>3.07</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The main effect $A$ (BW vs. BY teachers) was not significant at the $\alpha$ level of 0.05 ($F_{10, 36} = 0.24$, $p > 0.63$). The corresponding $H_0$ was therefore not rejected: The teachers from BW respectively BY did not differ in their global evaluations of the content concepts.

The interaction effect $A \times B$ (group $\times$ content concept) was significant at the $\alpha$ level of 0.05 ($F_{10, 360} = 2.26$, $p < 0.02$). The corresponding $H_0$ was therefore rejected: The teachers from BW respectively BY differed significantly in their evaluations of individual content concepts.

The interaction effect $A \times B \times C$ (group $\times$ content concept $\times$ process concept) was not significant at the $\alpha$ level of 0.05 ($F_{78, 2809} = 1.09$, $p > 0.29$). The corresponding $H_0$ was therefore not rejected: The teachers from BW respectively BY did not differ in their evaluations of the relationships between individual content concepts and individual process concepts.

### 7.4 Individual Comparisons for the $A \times B$ Interactions

The global test of the $A \times B$ interaction revealed a significant overall effect of group $\times$ content concept. Therefore we evaluated, which concepts were rated differently by comparing the mean ratings of the two groups of teachers ($a_1$, $a_2$) at the $\alpha$ level of 0.05 ($t_{996} = 2.23$, $p < 0.027$). The differences for system, computer, and information are remarkable, but not significant.

### 7.5 Individual Comparisons for the $A \times B \times C$ Interaction

The global test of the $A \times B \times C$ interaction did not reveal a significant overall effect of group $\times$ content concept $\times$ process concept. Taking into account the significant difference regarding the content concept model (see section 7.4), it makes sense to compare only this concept with respect to the process concepts a posteriori. Fig. 5 displays the comparisons of the means on the concept model regarding the different process concepts.

These were calculated by applying 16 $t$-tests to analyze simple $AC$ effects for SPF-$p\times q\times r$ experimental designs ([46], pp. 535-536); An $\varepsilon$ correction of degrees of freedom was taken into account again (see above). The $t$-tests were calculated at an adjusted $\alpha$ level of 0.05/16 = 0.0031. It turned out that the ratings from BW teachers ($a_1$) respectively from BY teachers ($a_2$) differed significantly regarding the content concept model related to the following process concepts: classifying, finding relationships, generalizing, comparing, questioning, and ordering.

### 8. DISCUSSION

The results of the performed evaluations support the research hypothesis that computer science teachers from Baden-Württemberg differ from computer science teachers from Bavaria in the assessment of key content concepts of computer science related to central process concepts of computer science. Already from the descriptive evaluation, it has become clear that there are differences in the assessment of content concepts by the two groups of computer science teachers. There were differences for the concepts of content model, system, computer, and information. The analysis of variance and the individual comparisons showed that the two groups rated the individual process concepts classifying, finding relationships, generalizing, comparing, questioning, and ordering differently with respect to the content concept model.

As the regular teacher education programs in the German states are standardized by the KMK (see section 5), it is not likely that those differences would be caused by the courses of lessons in CS that the teachers had attended at their universities. Therefore, the
reason has to be sought outside the regular programs. In Bavaria this might have been a specific in-service program like SIGNAL or FLIEG (see section 5), attended by many Bavarian teachers instead of regular programs, a specific didactical training programs for the new Bavarian subject of CS or the daily teaching environment at schools. It would be plausible to assume one of those three reasons because all those courses or environments focus on modeling and thus might cause a quite special view on the concept model as well as on the salient process concepts, e.g. classifying or finding relationship.

On the other hand, there are certainly some threats to the validity of our results. Firstly, the question of the interview could be more precise, e.g. asking to assess the value of the concepts for CS courses in school or as background of the teachers. A stimulating text passage before the question might help also. Secondly, the teachers had not much time to think about the 240 combinations of content and process concepts.

9. CONCLUSION AND FUTURE WORK
Suggested by this comparison of two different states, we aim to conduct a larger study, interviewing teachers in Germany about their valuation of content and process concepts in the future.

Our results show that there are significant differences in the valuation of certain concepts between the teachers of those two states. It would be very interesting to investigate the perceptions of those concepts by the teachers, trying to detect if the differences concern only the degree of valuation or even different subject knowledge about these aspects.

Further, it should be considered to incorporate our results in the teacher education programs. The first step could be to analyze the coverage of the salient concepts by those programs. In the case that there are differences, those should be removed. Additionally, there might be some fuzziness in the German standards for teacher education o the KMK regarding those concepts.

10. REFERENCES


APPENDIX

Groups

\(a_1 = \text{BW teachers of computer science}\)
\(a_2 = \text{BY teachers of computer science}\)

Process concepts

Content concepts

\begin{align*}
& b_1 = \text{problem} \\
& b_2 = \text{information} \\
& b_3 = \text{model} \\
& b_4 = \text{algorithm} \\
& b_5 = \text{data} \\
& b_6 = \text{structure} \\
& b_7 = \text{system} \\
& b_8 = \text{computation} \\
& b_9 = \text{process} \\
& b_{10} = \text{software} \\
& b_{11} = \text{program} \\
& b_{12} = \text{test} \\
& b_{13} = \text{communication} \\
& b_{14} = \text{language} \\
& b_{15} = \text{computer} \\
\end{align*}

\begin{align*}
& c_1 = \text{analyzing} \\
& c_2 = \text{classifying} \\
& c_3 = \text{problem solving and posing} \\
& c_4 = \text{generalizing} \\
& c_5 = \text{creating and inventing} \\
& c_6 = \text{finding cause-and-effect} \\
& c_7 = \text{analyzing} \\
& c_8 = \text{classifying} \\
& c_9 = \text{problem solving and posing} \\
& c_{10} = \text{generalizing} \\
& c_{11} = \text{creating and inventing} \\
& c_{12} = \text{finding cause-and-effect} \\
& c_{13} = \text{analyzing} \\
& c_{14} = \text{classifying} \\
& c_{15} = \text{problem solving and posing} \\
& c_{16} = \text{generalizing} \\
& c_{17} = \text{creating and inventing} \\
& c_{18} = \text{finding cause-and-effect} \\
\end{align*}

\begin{align*}
\text{grand means} \\
& \begin{array}{cccccccccccccccc}
3.30 & 2.69 & 2.64 & 2.62 & 2.47 & 2.39 & 2.42 & 2.38 & 2.41 & 2.43 & 2.09 & 2.39 & 2.47 & 2.50 & 2.21 & 1.89 & 2.46 \\
4.57 & 2.67 & 4.00 & 2.86 & 2.90 & 3.67 & 3.43 & 2.52 & 3.18 & 3.29 & 3.14 & 2.95 & 2.95 & 2.05 & 3.10 & 2.14 & 3.09 \\
3.86 & 3.95 & 2.29 & 3.57 & 3.00 & 3.29 & 3.47 & 2.33 & 3.32 & 2.87 & 2.57 & 3.19 & 3.19 & 3.57 & 3.71 & 2.57 & 3.33 \\
4.29 & 3.86 & 3.62 & 3.43 & 2.95 & 4.00 & 4.00 & 3.14 & 3.43 & 3.48 & 2.71 & 3.31 & 3.14 & 3.05 & 2.76 & 2.29 & 2.71 \\
4.05 & 2.52 & 4.43 & 2.00 & 2.48 & 3.14 & 2.90 & 3.43 & 2.62 & 3.14 & 2.38 & 3.00 & 1.57 & 1.48 & 1.76 & 2.24 & 2.70 \\
4.10 & 3.62 & 1.95 & 3.24 & 2.76 & 2.67 & 3.05 & 1.57 & 2.81 & 2.05 & 1.81 & 1.81 & 2.57 & 2.62 & 1.76 & 3.38 & 2.70 \\
4.38 & 3.57 & 2.76 & 3.33 & 2.43 & 3.43 & 3.43 & 2.29 & 3.48 & 3.57 & 3.71 & 2.43 & 2.90 & 2.62 & 2.24 & 2.52 & 2.57 \\
3.43 & 3.05 & 2.48 & 2.62 & 2.29 & 2.76 & 2.52 & 1.90 & 2.38 & 1.71 & 1.95 & 2.33 & 2.29 & 1.86 & 2.48 & 2.10 & 2.45 \\
2.43 & 1.90 & 3.00 & 1.81 & 2.29 & 2.29 & 2.52 & 2.33 & 2.48 & 2.10 & 2.14 & 1.81 & 2.10 & 1.67 & 1.81 & 2.20 \\
3.76 & 2.52 & 2.43 & 2.43 & 2.05 & 2.62 & 2.43 & 1.67 & 2.19 & 3.38 & 2.00 & 2.29 & 2.38 & 1.76 & 2.29 & 2.33 & 2.41 \\
3.05 & 2.29 & 2.90 & 2.19 & 2.43 & 2.10 & 2.00 & 2.14 & 2.81 & 2.71 & 2.38 & 2.43 & 2.43 & 1.81 & 1.86 & 2.05 & 2.17 \\
3.43 & 2.19 & 2.90 & 2.43 & 2.29 & 1.86 & 2.29 & 2.95 & 2.05 & 2.95 & 1.95 & 2.19 & 2.43 & 2.14 & 2.57 & 1.81 & 2.40 \\
3.05 & 2.29 & 2.90 & 2.19 & 2.43 & 2.10 & 2.00 & 2.14 & 2.81 & 2.71 & 2.38 & 2.43 & 2.43 & 1.81 & 1.86 & 2.05 & 2.35 \\
2.67 & 1.76 & 2.29 & 1.67 & 2.19 & 2.76 & 2.29 & 1.95 & 2.14 & 2.81 & 3.00 & 2.00 & 3.71 & 2.95 & 3.38 & 2.10 & 2.48 \\
2.71 & 2.24 & 2.76 & 2.00 & 1.67 & 2.24 & 2.57 & 2.00 & 2.57 & 1.71 & 2.38 & 1.76 & 2.95 & 1.90 & 2.33 & 1.71 & 2.22 \\
2.67 & 2.33 & 2.00 & 2.24 & 2.00 & 2.29 & 2.14 & 1.43 & 2.14 & 2.14 & 1.48 & 1.57 & 2.14 & 1.71 & 2.29 & 2.10 & 2.04 \\
\end{array} \\
\text{grand means} \\
& \begin{array}{cccccccccccccccc}
3.50 & 2.73 & 2.82 & 2.54 & 2.37 & 2.74 & 2.72 & 2.26 & 2.66 & 2.73 & 2.31 & 2.34 & 2.60 & 2.20 & 2.34 & 2.26 & 2.57 \\
\end{array}
\end{align*}

Figure 6. Means for the 2*15*16 split-plot design (\(n_1 = 17; n_2 = 21\))