Primary School Teachers' Beliefs on Computer Science as a Discipline and as a School Subject*

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ABSTRACT

Explicit (i.e. conscious) primary school teachers' beliefs on computer science were gathered through semi-structured interviews and analysed using the grounded theory methodology. Implicit (i.e. unconscious) beliefs were inferred upon while observing computer science lessons given by the interviewed teachers in their classroom on one of the following topics: introduction to programming with the bee-bot®, introduction to programming with scratch®, and cryptography. A pre-post-comparison was conducted with a closing interview. Analysis of the data revealed four distinct views on computer science: media-oriented, mathematical, social, and design-oriented. Furthermore, the study showed that the teachers' beliefs could in some cases be altered by the computer science lessons. Some teachers, however, showed resilience towards conceptual change (belief perseverance). The study was conducted in the state of North Rhine-Westphalia (Germany) and included ten participants for the initial interviews and three participants for the lessons and closing interviews.

*This paper highlights the results of a PhD thesis with the title "Vorstellungen von Grundschullehrpersonen zur Informatik und zum Informatikunterricht" that will be published shortly.

CCS CONCEPTS

• Social and professional topics~Professional topics~Computing education • Social and professional topics~Professional topics~Computing education~Computing education programs~Computer science education • Social and professional topics~Professional topics~Computing education~Adult education

KEYWORDS

Teachers' Beliefs, Computer Science Education, Primary School, Primary Education, Grounded Theory, Conceptual Change, Belief Perseverance, Design-Based Research, Programming, Bee-Bot®, Scratch®, Cryptography

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1 Introduction

Research interest in teachers' beliefs has been steadily increasing since the 1970s [11]. Especially pedagogical psychology as well as mathematics and science education have conducted several studies and theoretical works to define, structure, measure and change teachers' beliefs. Lortie introduced the concept of "apprenticeship of observation" to demonstrate that prospective teachers develop their beliefs throughout their own school years [34]. Teachers' beliefs have been introduced into several models, such as Ernest's model of teaching mathematics [15] or the conceptual framework of TALIS [35, 36]. These developments have also sparked research interest in the computer science education community [5–7, 17, 18] and led to several studies, which cover a broad field of beliefs, such as epistemological beliefs [4, 20] or beliefs about the nature of computer science [26, 41], and different educational stages, such as upper secondary education (ISCED 2011 Level 3) or Bachelor/Master (ISCED 2011 Level 6/7) [28]. Since computer science has only been implemented in primary education (ISCED 2011 Level 1) in very few countries in Europe, "[…] namely in Croatia, Slovenia, the Ukraine, and all the countries of the UK" [46], only sparse research regarding primary school teachers' beliefs has been conducted [21]. These, however, constitute a significant factor for the following developments:

1. Computer Science, either as a distinct school subject or integrated in an existing subject or in a school project, will be taught by primary school teachers. These teachers, consciously or unconsciously, will not only teach their pupils the contents of computer science, but also share their views and beliefs on the discipline and the school subject with them. According to Lortie's concept of "apprenticeship of observation", this will have a cyclic effect on the following generations of pupils and teachers.

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2. Since hardly any primary school teachers have studied computer science [1], it is necessary to develop and offer vocational training concepts and programmes. Studies from other research areas show that the contents of such training concepts are being filtered by the participants based on their pre-existing beliefs [8, 33]. Knowledge about these beliefs is thus crucial in order to develop vocational training programmes that foster a scientific view on computer science on the one hand and take the existing beliefs of the participants into account, strengthen supporting beliefs and "discredit" non-supporting beliefs on the other hand [40].

2 Theoretical Framework

Teachers' beliefs are considered a cognitive mental attribute, which resembles knowledge in certain aspects such as its application towards actions and its contextual nature. So far, however, studies were unable to show distinct differences between these two attributes [22]. The current research thus considers belief-systems and knowledge-systems as intertwined, which differ, however, in some key aspects, such as their consistency or subjective nature [1].

2.1 Defining teachers' beliefs

Kirchner defines them as "subjective, relatively stable, though experience-based changeable, partly unconscious, contextual cognitions of teachers. They incorporate the theory-like, although not without contradiction, thoughts on various interdisciplinary and disciplinary subject areas of teachers' profession." [2] [29]. Abelson states: "By 'belief' I mean a conjectural proposition about some object in the world." [2]. Pajares names 16 characteristics of teachers' beliefs, which include their early formation, their strong connection to knowledge, their filter-function on reality, their connection to other beliefs in a belief-system, their tendency to "self-perpetuate, persevering even against contradictions caused by reason, time, schooling, or experience" or their effect on teachers' behaviour [37]. An incomplete list of definitions has been compiled by Fives and Buehl [19]. Existing definitions, however, differ on some key issues. There is no consensus …

1. … between the relatedness between beliefs and knowledge.
2. … whether beliefs only contain cognitive or also affective or behavioural components.
3. … whether beliefs are explicit (i.e. conscious) or can also be implicit (i.e. unconscious). Fives and Buehl analysed several definitions and favour a belief system that incorporates explicit as well as implicit beliefs [19].

Blömeke states: "Beliefs are, however, not a well-defined construct. Clear distinctions from terms such as attitudes, perceptions or conceptions are rare." [9]. König writes: "There is no clear definition of the term 'teachers' belief" [32].

2.2 Structuring teachers' beliefs

Fives and Buehl inductively defined the following "framework" of teachers' beliefs based on a literature review of approximately 300 peer-reviewed papers using ERIC, PsycINFO and PsycARTICLES [19]:

1. Self
2. Context or environment
3. Content or knowledge
4. Specific teaching practices
5. Teaching approaches and
6. Students

Calderhead distinguishes between the following "areas" [11]:

Beliefs about …

7. … learners and learning
8. … teaching
9. … Subject
10. … learning to teach
11. … self and the teacher role

König only differentiates between [32]:

Beliefs about …

12. … teaching and learning and
13. … professional development.

For mathematics, Ernest defines a model with the following "components" [15]:

14. Conception of the nature of mathematics
15. Models of teaching and learning mathematics
16. Principles of education
17. Model of learning mathematics
18. Model of teaching mathematics

2.3 Function of teachers' beliefs

Beliefs are highly contextual and thus develop when individuals experience certain phenomena which cannot be grasped by any of the beliefs *currently* held by the individual's belief system. Thus, beliefs play a key role in explaining these phenomena, even though no knowledge-based explanation is available at that time. Fives and Buehl see beliefs as a connection between experiences and teacher practices [19]:

[1] For the state of North Rhine-Westphalia (Germany), only 13 out of 31.857 primary school teachers are certified to teach computer science (Informatik) [13].
[2] Her definition in German has been translated by the author of this paper.

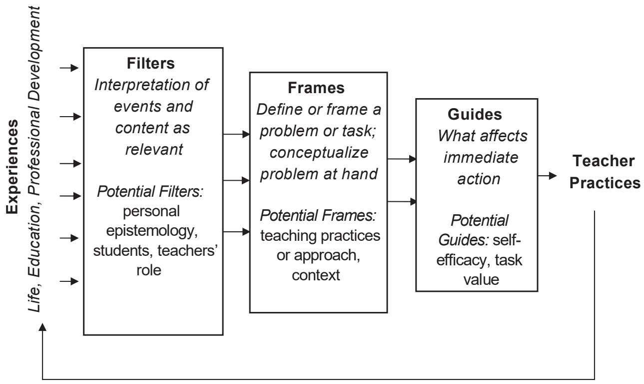

Figure 1: "Beliefs act as filters, frames, or guides"

Beliefs, however, also have a social and collective function. They can be adopted or inherited from family members, peers, or colleagues. Here, beliefs establish an affiliation with a group and can represent a sense of security for its members. Due to the contextual nature of beliefs, these can, however, be volatile and even differ between various group affiliations. On the other hand, if a belief has gained a major centrality in the belief-system of an individual, even the loss of affiliation with a specific group or its breakup does not necessarily have to lead to beliefs being discarded.

2.4 Conceptual change theory

Posner et al. developed the theory of conceptual change in 1982 and defined several requirements for a belief and its underlying concept to change [38]:

1. Intelligibility of a new conception
2. Initial plausibility of a new conception
3. Dissatisfaction with existing conceptions
4. Fruitfulness of a new conception

They define two steps of a conceptual change: at first, an existing concept is applied to a new situation. If the concept does not appear to be applicable to the situation, however, the concept is replaced or reorganised. The first step is called assimilation and the second step accommodation, though no connection to Piaget's theory of cognitive development is intended. Especially the replacement of central concepts, however, is challenging and beliefs that are grounded on these concepts tend to persevere "even after receiving new information that contradicts or disconfirms the basis of that belief." [3].

3 Related Works

Bender et al. conducted expert interviews with 17[3] computer scientists on the following questions [5]: "Which beliefs about the subject computer science do you assume being useful and conducive in this situation?" and "Which beliefs about teaching and learning in computer science enhance students' active learning?" The analysis of the interviews was performed using two of Mayring's content analysis techniques. The authors were interested in beliefs as well as motivational orientations. The latter was not a part of the study presented in this paper. The following beliefs were identified in the data:

1. "Teachers are convinced that superordinate strategies and principles make up the subject computer science and are relevant to all sections of subject"
2. "Teachers are convinced that the core of computer science consists of processes that can always be traced back to relationships between information and data"
3. "Teachers believe that learning in all parts of computer science takes place in the context of the superordinate strategies and principles of the subject"
4. "Teachers are convinced that students are learning in an autonomous way and by critically approaching computer science contents"

Funke, Geldreich and Hubwieser interviewed six primary school teachers in Bavaria (Germany) regarding their opinions on computer science (CS). They report that "the six teachers have no concrete image of computer science in primary schools", yet highlight some important remarks by the teachers [21] regarding the importance of early CS, their willingness to participate in CS courses, the need for teacher training, the need for a more critical view on computers and on "dangers of the world wide web, the functionality of computers and computers in society" as possible topics in a CS course.
Dengel conducted a study with 116 computer science teachers in secondary schools regarding their view on early CS [14]. 67.0% of the respondents agreed that CS in primary schools would be possible and 43.4% perceived it as sensible. Asked about topics of a CS course in primary schools, the five most given answers (multiple choice) were Algorithms (73.5%), Data Integrity and Security (57.1%), Object Orientation (28.6%), Representation of Information (28.6%), Computer Architectures (18.4%) and Networks (14.3%).

4 Method and Design

Four research questions (RQ) formed the basis of the study:

RQ1: Which biographical connections do primary school teachers associate with computer science and computer science education?
RQ2: In the opinions of the teachers, which central computer science terms are relevant for primary schools; why are they relevant and what content do they associate with them?
RQ3: In the opinions of the teachers, where do children of primary school age encounter computer science in their everyday life?

[3] The final results from Bender's PhD thesis are based on 23 expert interviews.

RQ4: Which implicit-unconscious computer science-related beliefs are manifest during teaching a computer science lesson and to what extent does this lead to conceptual changes, belief perseverance and/or resilience?

The study was based on four major methodologies or theories: the grounded theory, the belief-system-theory, the theory of conceptual change, and design-based research.

Phase 1: Three computer science modules were developed in close cooperation with primary school teachers. The modules were developed based on Euler's design-based research-approach, which contains a macro- and a micro-cycle [16]:

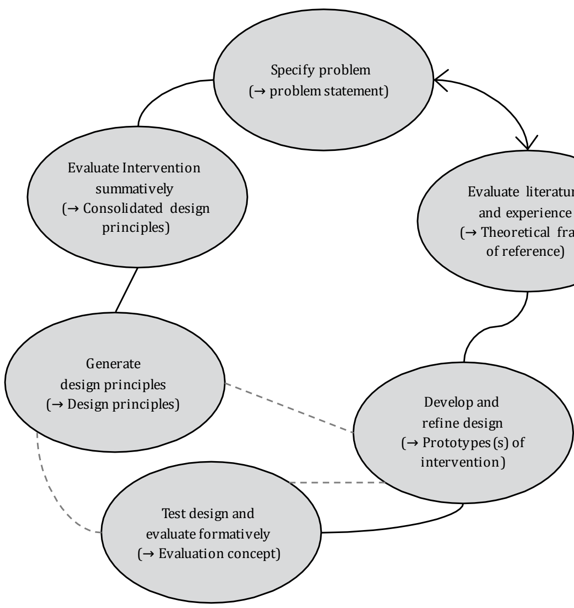

Figure 2: "Research and development cycles in the design research context"

The purpose of these modules was to gain access to the teachers' implicit beliefs. To do so, the computer science lessons the teacher's held were observed in *phase 3* and implicit beliefs were inferred upon. Additionally, the modules were used as instruments to initiate a conceptual change.

Phase 2: The primary instrument to gather data in this phase was a semi-structured interview that contained the following questions for the initial interview:

1. "At the beginning of the interview, I would like to ask you: What do you associate with computer science?"
2. "What tasks would computer science in primary schools have to accomplish?"
3. "Where do primary school children come into contact with computer science?"
4. "On this sheet you will find a randomly assorted set of terms. Which of these terms are important in primary schools in your opinion and what do they mean?"

The following terms were presented to the teachers in a plain textual form and in random order:

Model and implement	Information and data
Reason and evaluate	Algorithms
Structure und interrelate	Languages and automata
Communicate and cooperate	Informatics systems
Represent and interpret	Informatics, man, and society

They form the basis of the competence model for the computer science standards by the German Informatics Society (Gesellschaft für Informatik) for primary education (released in 2019), lower secondary education (released in 2008), and higher secondary education (released in 2016) [10, 23–25].

Participants for the initial interviews were acquired via a questionnaire which included the following items: name, gender, teaching experience in years, favoured class, and favoured subjects. The responses formed the basis for the theoretical sampling which was chosen to identify teachers for follow-up interviews and promised a minimum or maximum contrast to the previous interview.

				Competence estimation		
Pseudonym	Gender	Favoured class	Teaching experience in years	Informatics systems (self)[a]	Informatics systems (pupils)[b]	Overall (pupils)[b]
David	m	3,4	<3	4	4	3
Jonas	m	3	<3	3	3	2
Carla	f	4	6–10	3	3	4
Peter	m	4	3–5	2	1	2
Tim	m	—[c]	—	—	—	—
Jana	f	4	6–10	5	4	4
Barbara	f	2	21–30	4	3	4
Melanie	f	4	11–20	3	3	3
Cornelia	f	—	—	—	—	—
Sabrina	f	—	—	—	—	—

a) Ranking from very low (1) to very high (5)
b) Ranking from very weak (1) to very strong (5)
c) No data available

Table 1: Selected features of the interviewed primary school teachers

Ten teachers agreed to an initial interview. The interviews were recorded, manually transcribed and analysed using the three coding steps of Straussian grounded theory with MAXQDA Analytics Pro 2020: open, axial, and selective coding [45].

Throughout the processes of data gathering and its analysis and interpretation, intensive use of memos was made to annotate the transcripts [12, 45].

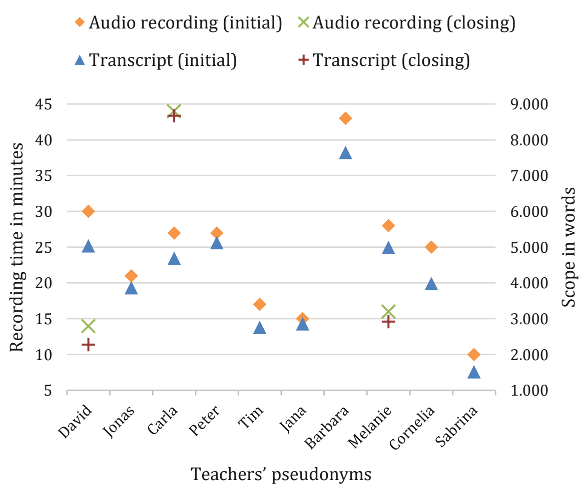

Figure 3: Duration and scope of the interviews ($n_i = 10$; $n_c = 3$)

Phase 3: Three of the ten teachers interviewed agreed to teach a computer science lesson in their class. For the observation of the lesson, a plain protocol was used to log aspects such as verbal, paraverbal and nonverbal communication and activities. Afterwards, a closing interview was held, in which the teachers were confronted with their questions from the initial interview as well as observations from their lessons. The data analysis and interpretation of those interviews resembled the initial interviews. The questions for the closing interview were also similar to those of the initial interview; however, they were enhanced with the following passage: "Back in the initial interview I asked you the following question […]. How would you answer it today?"

5 Teaching Modules

The development of the three modules benefited from the support of the primary school teachers. Their contribution included aspects of the pupil's motivation, of the level of complexity that could be used in the teaching material, the way the material was presented, the complexity of texts and other aspects. The single difficulty for the teachers was to find time to discuss, improve and test the modules.

5.1 Introduction to programming with the bee-bot®

For children of the age of six to eight (classes 1–2 in German primary schools), the bee-bot® was identified as a suitable tool to introduce early concepts of programming such as the sequence, the ideas of a readable and writable memory and of systematic code reuse.

Figure 4: Pupils receiving instructions to model paths for the bee-bot®

The module begins unplugged with the game "we program ourselves". Here, the children use navigation cards to program their partner, acting as a robot. This introduction was chosen so the children could enact the ideas of the sequence and the memory. The cards were designed similarly to the buttons of the bee-bot®, so an easy transfer could be established. The interaction with the bee-bot® included aspects of performance ("Get from point A to point B with as little movements as possible.") and of debugging ("Here you will find a program that should let the bee-bot® move in the shape of an 8. However, some buttons have been mixed up. Can you find the errors and correct them?"). To foster a positive and scientific view of computer science, the experiences that the children made during the lesson were connected to the term computer science.

The feedback from the pupils as well as the teachers was very positive and the unplugged introduction, even though it was not seen as "real computer science" by some teachers, supported the children in their modelling competencies.

5.2 Introduction to programming with scratch®

After an introduction to the scratch® graphical user interface, the pupils could try out several scratch® commands and witness their effect. The scratch® coding cards were used to give the pupils new ideas for their programs. Due to time restrictions, the pupils had only three hours to develop their programs which only made it possible to use a very basic functionality-set of scratch®. This included sequences and iterations. The results were presented by the pupil developer teams and the code was selectively explained to the class.

5.3 Cryptography

This module introduced a simple substitution cipher (Caesar cipher) and a simple transposition cipher using the scytale. In addition to these symmetric-key algorithms, a box, a lock, and a key were used to introduce the concept of the asymmetric-key exchange. Most of the time the pupils worked together as partners. The first step was to capture the idea behind each method and try to decode a given encrypted message as well as to encode a message. The given steps gave the groups the chance to exchange individual encrypted messages. The shortcomings of the two symmetric methods were then demonstrated in a role play in which a thief steals a message and can decrypt it. The role play lead to the asymmetric method, which was also tried out by the pupils. At the end of the lesson, the pupils had to compare the three methods and name their (dis)advantages. Some groups proposed combining the methods to improve security.

Figure 5: Two pupils comparing the Caesar cipher and the "box-lock-key-method"

6 Results

The data analysis and interpretation of *phase 2* led to a first grounded theory that was based primarily on the following four views on computer science. This grounded theory was enhanced with aspects of the implicit beliefs, conceptual changes, and belief perseverance from *phase 3*.

6.1 Explicit beliefs

The primary school teachers' beliefs on computer science as a discipline and as a school subject were formed either during their years in school as pupils or as teachers. Family or teacher training had no major influence on their beliefs. In accordance with the insider-outsider-dichotomy discovered by Knobelsdorf, the teachers strongly believed that computer science could only be understood by gifted pupils, teachers etc. and could hardly be comprehended by others [30, 31, 44]. This dichotomy included all domains, such as the pupils, the teachers, colleagues, parents etc. Computer science was associated with cooperative teaching methods, such as partner or group methods. The explicated beliefs showed four distinct views on computer science:

The media-oriented view: These teachers considered that computer science includes teaching the use of specific software applications. This included the use of word processors or the use of web browsers. Computer science provides the pupils with these competencies, so that other subjects can use computers and specific applications, search for subject-related content on the internet, write essays in a word processor or use software for presenting a specific topic in class. These teachers had little to no contact with computer science in their own school years and did not participate in related vocational training programmes.

The mathematical view: These teachers saw a strong connection between computer science and mathematics. Especially algorithms, but also modelling was important to them. For these teachers, computer science posed as a supporting discipline for mathematics that deals with methods to implement mathematical problems by using computers. Some of these teachers attended computer science lessons at secondary school but did not continue attending the course due to missing everyday application.

The social view: These teachers saw computer science as part of a social science continuum in which the effects of computers on society are discussed, evaluated, and interpreted. Every detail about the application and the principles of computer science was evaluated on a benefit-harm-axis. The teachers did not attend computer science courses at secondary school and showed interest in the social sciences, humanities, languages, and politics.

The design-oriented view: These teachers associated computer science with the development of software based on a given hardware structure. They referenced the binary system, programming, or the need to save, change, store, and secure data. They attended computer science courses at secondary school. The reasons, they did not continue the course were either the focus put on using computers rather than understanding their principles in order to design (i.e. program) them or too much focus on algorithms with no real application to real world problems.

Pseudonym	Gender	View on CS
David	male	design-oriented
Jonas	male	media-oriented
Carla	female	mathematical/ media oriented
Peter	male	mathematical
Tim	male	media-oriented
Jana	female	social
Barbara	female	media-oriented
Melanie	female	social
Cornelia	female	media-oriented
Sabrina	female	social

Table 2: Views on computer science held by the teachers

While teachers who can be assigned to the media-oriented and the social view focused on functional aspects of digital artefacts [42, 43], teachers from the mathematical and especially design-oriented view focused on structural aspects.

6.2 Implicit beliefs

During the computer science lessons, no major dissonance between the explicated beliefs from the initial interview and the teachers' actions in the classroom was apparent. The explicated beliefs about the insider-outsider-dichotomy regarding the pupils, however, was not visible during the lessons. The teachers supported all the pupils when they had questions and were surprised that by the end of the lessons, they were able to solve the given tasks. Before the lessons, some teachers even pointed out that their class was not very performant and they would be surprised if any of the students were able to solve the tasks. In one case ("Melanie"), during the initial interview many references to computer science as too theoretical with too few possibilities of application in everyday life were made. During the lessons, however, this point was not raised.

6.3 Conceptual change

The use of unplugged materials had a clear impact on teachers, who believed that computer science and the use of computers mutually depended on one another. The fact that topics from computer science could, on the one hand, be presented without computers and were successfully used by the very same teachers in their classrooms during the CS lesson indicates, on the other hand, that their beliefs entered a transitional stage in their belief-system. For most teachers, the central belief of the computer as the essential artefact for computer science was shattered and thus lost its previous centrality, which caused the entire reorganisation of their belief-system. While most teachers entered this transitional stage due to the CS lesson, there was one teacher ("Carla") who had already entered this stage prior to participating in the initial interview and the CS lesson. For Carla, her then central belief that computer science was a synonym for using computers was superseded by her participation in the Bebras Challenge, which was opened for classes 3–4 of primary schools in Germany in 2015. The search for a new central belief in her computer science belief-system led her to algorithms which she was familiar with from mathematics. The development and implementation of mathematical algorithms, for example for addition or subtraction, as central concepts for computer science gained major centrality in her belief-system. Also, the classroom lessons that Carla gave showed exceptional outcomes compared to those of other teachers. Carla decided on the plugged module "introduction to programming with scratch®", resulting from an opportunity to use a "computer room" for the lesson. Throughout the initial interview, it became apparent that Carla had developed a new computer science belief-system which did not contain her previous central belief of the computer as the fundamental element of computer science. However, up to the time of the closing interview, no new belief was established in her new belief-system concerning the role of computers in computer science. Her activities during the lesson and even more so her comments in the closing interview showed that she was partly reverting to her old CS belief-system to solve this issue. Her remarks in the closing interview showed many more characteristics of the media-oriented view than the mathematical view from her initial interview. In addition, only very few remarks regarding her experience with the Bebras Challenge appeared in the closing interview.

6.4 Belief perseverance

Especially the younger teachers with less teaching experience showed hardly any signs of belief perseverance. The teacher "David", for example, chose the unplugged module on cryptography and therefore added to his previous beliefs of computer science being related to data security, data storage and data encryption. Especially the older teachers with more teaching experience, although they perceived the lessons positively, tended towards belief perseverance. An example is the teacher "Melanie", who also chose the cryptography-module. For her, computer science in primary school should be combined with an established subject. The reason for this belief was her own experiences with computer science in secondary school, which she considered to have very little application to everyday life and in her opinion was based on pure theoretical problems. This belief led to her opinion, that computer science in primary school had to be connected to topics from another subject. The medium to connect the two subjects was the computer. Since Melanie attended a computer science course in secondary school, she did not experience that computer science consisted solely on using a computer but also referenced programming environments or the modelling and implementation of algorithms as essential for using computers in computer science. Although her activities and the results from her closing interview indicate that she enjoyed the CS lesson, she criticised the lack of computer usage and that there was no "real" connection to computer science. In Melanie's case a belief change did not occur, due to belief perseverance in the explained case. Not even the positive experience of the CS lesson caused her to change her belief of CS as being too theoretical to lose centrality and eventually initiate a reorganisation of her CS belief-system or even the formation of a completely new system, such as in Carla's case.

7 Constraints

The number of conducted interviews ($n = 10$), even though they partly produced a considerable quantity of data, must be considered as a first step towards gaining greater insights into the primary school teachers' beliefs on computer science and computer science education. Consequently, the four views on computer science presented here by no means represent the final status and will most likely be adjusted when more interviews are conducted in the future. A first step, using online questionnaires, has been taken by Gude in her master thesis with a sample of 56 primary school teachers [27]:

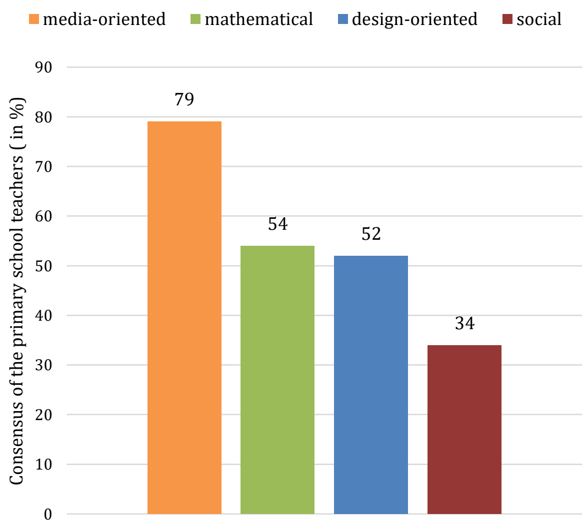

Figure 6: Consensus of primary school teachers ($n = 56$) towards the four views on computer science (multiple choice)

The results also indicate that certain views are more prevalent than others; however, further research needs to be carried out in this area and on the distinctiveness of these views.

8 Conclusion and Outlook

The teacher's biographies did not differ on many key issues, but the experiences they made during their own school years or in their professional life as a teacher were interpreted in different contexts; they were filtered differently due to existing beliefs and were arranged differently in their CS belief-system with specific central and less central beliefs. The computer, however, plays a central part in most teacher's CS belief-systems. The role of the computer in CS, however, is either perceived as a mere tool (media-oriented view), as a social artefact (social view) or as a medium for creativity (design-oriented view). The tendency for a belief's perseverance can be explained by two factors: the duration in the teacher's belief-system and the centrality of the belief in it. In Melanie's case, both factors caused the witnessed perseverance. In Carla's or David's case, however, conceptual change occurred because none of the connected beliefs had a high centrality or were part of the belief-system for a long time.

Initiatives and activities to implement computer science in primary schools are by no means trivial. Apart from constructing curricula etc. it is vital for the teachers to foster a view on computer science in their pupils that views computer science as a discipline and school subject that deals with understanding the basic principles that are required to model and implement software. For this, it is necessary to install teacher training programmes because most primary school teachers have little to no knowledge about computer science. These teacher-training-initiatives, however, should take the pre-existing beliefs as requisites into account [47]. Beliefs that support the above view on computer science should be fostered, while beliefs that solely draw a connection between computer science and the use of computers should either be changed or "discredited". Such techniques have already been developed, such as Savion's super active learning approach [39] and could be transferred to teacher training and computer science education.

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