Chemistry Pre-service Teachers' Mental Models of Science Teaching and Learning in Malaysia

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1 Introduction

A mental model is a cognitive construct that describes a person's understanding of a particular content domain in the world. Mental models are cognitive representations of reality, or ways in which reality is codified in terms of how one understands it. It is an explanation of someone's thought process for how something works in the real world. Mental models are the *internal* representations of situations, both real and imaginary (Johnson-Laird & Byrne, 2002), that people use to understand specific phenomena. Johnson-Laird (1983) proposed that mental models are the basic structure of cognition and "play a central and unifying role in representing objects, states of affairs, sequences of events, the way the world is, and the social and psychological actions of daily life" (p. 397). Mental models affect what we see in situations and create reinforcing patterns of behavior.

According to cognitive schema theory, people draw from their prior experiences, training and instruction to develop mental models that provide the framework for understanding events (Anderson, 2004; Norman, 1988). The mind constructs mental models as a result of perception, imagination and knowledge, and the understanding of discourse. Mental models represent our assumptions and beliefs about how the

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world around us works and influence a person's judgment and decision making. Gentner and Stevens (1983) noted that these internal models provide predictive and explanatory power for understanding interactions with the world around us. Mental models allow people to describe and understand phenomena, draw inferences, make predictions, decide which actions to take, and experience events vicariously (Johnson-Laird, 1983).

Barnes (1992) suggested that one's mental model is organized in "frames" or clustered sets of expectations. Teachers' professional frames are both individually and socially derived – shaped by experiences as well as expectations and values (from the outside as well as the inside). These clustered sets of expectations or frames, similar to mental models, may provide valuable insights into the beliefs that teachers hold about the teaching and learning of science. Norman (1983) suggested that mental models may represent one's belief system, holding predictive and explanatory power. An organized collection of individual beliefs can be viewed as forming a mental model (Chi, 2008). The visible part of the cycle, behavior, reinforces the invisible part, the beliefs or mental models.

Mental model formation depends heavily on the conceptualizations brought to a task and includes our views, beliefs, and attitudes concerning the world, ourselves as learners or teachers, our capabilities and prior experiences, the tasks we undertake, the issues we confront, and the strategies we employ. Our mental models (or schemas) affect how we interpret new concepts and events. As such, mental models are important because one's beliefs, expectations, and interactions with those systems profoundly influence one's ultimate actions with regard to those systems (Norman, 1983). Hence, mental models are dynamic and can be changed by experience or expectations.

Because mental models are developed through particular interactions with a system, individuals' unique experiences will result in interaction-specific or functionally idiosyncratic mental models. Studies by Calderhead and Robson (1991) reported that pre-service teachers held vivid images of teaching from their experiences as students. These images may affect teachers' interpretations of course experiences and powerfully influence the translated knowledge and projected practice they would apply as teachers. Students need to develop good-quality mental models about teaching and learning, because those mental models will inform their plans and actions in their prospective classrooms. Kerr (1981) proposed that good-quality teaching actions are informed by good-quality intentions and plans, which are in turn informed by good-quality knowledge about teaching and learning. Studies have shown that learners with access to good mental models demonstrate greater learning outcomes and efficiency compared with those with less adequate models in various domains (e.g., Mayer, 1989; White & Frederiksen, 1989).

To assess mental models, researchers often rely on learners' construction of external representations (e.g., concept maps) as a proxy for what resides inside the learner's head. Thomas, Pederson, and Finson (2001) developed and validated the Draw-A-Science-Teacher Test Checklist (DASTT-C) to explore mental models and teacher beliefs of pre-service teachers in the beginning of their science methods course. The DASTT-C includes both illustration and a narrative data component to provide a clearer picture of pre-service teachers' self-perceptions of themselves as science teachers. Inasmuch as oral interviewing of each pre-service teacher is considered impractical, a written narrative component was developed as an alternative. The tool could be used to help teachers recollect memorable episodes within their beliefs about how to teach science, consider alternative methodological approaches, and develop a preferred image of themselves as science teachers.

Markic (2008) modified the Draw-A-Science-Teacher-Test Checklist to achieve a more open and explorative questionnaire. The approach tries to uncover more information from pre-service teachers' drawings and their descriptions of their teaching objectives. The approach towards the teaching situation is illustrated in their drawings. These drawings that science pre-service teachers make are considered an important package of information that can be read and decoded. Data analysis based on Grounded Theory (GT; Glaser & Strauss, 1967; Strauss & Corbin, 1990) consists of three steps: open, axial, and selective coding. This approach to data analysis allows for a richer description of the pre-service teacher beliefs about classroom organization, teaching objectives, and epistemological beliefs (Markic & Eilks, 2008). The articulation of the pre-service teachers' beliefs is made more accessible through a graphic approach using three-dimensional (3D) diagrams.

2 Purpose

The purpose of this chapter is to investigate chemistry pre-service teachers' mental models of science teaching and learning.

3 Methodology

The sample consisted of 43 pre-service science teachers who were in their third year of the Science with Education Degree Program at the Universiti Sains Malaysia. These pre-service science teachers were enrolled in the chemistry teaching methods course, which is a required course for all chemistry majors and minors. Out of the 43 pre-service science teachers involved, 10 were chemistry majors while the remainder minored in chemistry. Data were collected through the Draw-A-Science-Teacher-Test Checklist (DASTT-C), which was administered to the pre-service science teachers during the first meeting of the course. The following instructions were given by the instructor:

Select a class stage, to which your thoughts refer and indicate the stage (Form 4 or Form 5). Draw yourself and pupils during instruction. In the design you should play a role as teacher, the pupils, media, the area or other device. Explain your drawing by answering the following questions:

1. What is the teacher doing? Describe your activity as teacher in this instructional situation.
2. What are the students doing? Describe the activities of your pupils in this instructional situation.

Table 1 Evaluation pattern

Beliefs about classroom organization	*−2*	Strongly teacher-centered: The teacher is in the centre of any activity; dominates activity; lectures; uses media to focus students' attention
	−1	Rather teacher-centered: The teacher is in the centre of the activity, but interacts with the students; (s)he requires short answers from students, but dominates and directs every activity in the classroom.
	0	Neither … nor: Teacher- and student-centered activities are in balance, the teacher shifts from teacher- to student-centered teaching.
	1	Rather student-centered: Students' activities are at the core, but teacher initiates and controls students' activities.
	2	Strongly student-centered: Students' activities are at the core; students are at least partially able to choose and control their activities.
Beliefs about teaching objectives	*−2*	Exclusively content-structure focused: Learning content is the central objective.
	−1	Rather content-structure focused: Learning content is in the fore-ground; but some non-cognitive objectives are targeted.
	0	Neither … nor: Learning of contents and applications/non-cognitive objectives is in balance; or motivational objectives are the core.
	1	Rather scientific literacy oriented: Learning of competencies, problem solving, or thinking in relevant contexts and other affective outcomes are important.
	2	Strongly scientific literacy oriented: Learning of competencies, problem solving, or thinking in relevant contexts and other affective outcomes are the main focus of teaching.
Epistemological beliefs	*−2*	Learning is receptive: Learning is passive and over-directed; learning is a dissemination of information.
	−1	Over-directed learning with student-active phases: Learning follows a storyboard written by the teacher; conducted by the students, but organized and directed by the teacher.
	0	Over-directed learning with elements of constructivism: Learning is directed by the teacher taking into consideration students' preconceptions or problem solving, but the learning process stays over-directed.
	1	Rather constructive learning: Learning is an autonomous and self-directed activity, but is initiated and partially directed by the teacher.
	2	Strongly constructive learning: Learning is an autonomous and self-directed activity, starting from students' ideas and initiatives.

Markic & Eilks (2008)

3. What goals are pursued (trying to be achieved within the given time) by the teacher in the instructional situation?
4. What preceded the drawn situation? Explain your approach to achieve your goals.

The measurement of the beliefs is quantified using the scales and description of the codes from selective coding developed by Markic and Eilks (2008), presented in Table 1.

4 Results and Discussion

Two examples (diagram 1 and diagram 2) of the pre-service science teacher drawings are presented in Fig. 1. The drawings were chosen because they illustrated the range of values (−2,−2,−2) and (+2,+2,+2) used in coding the drawing of the science teaching as well as the diversity of personal beliefs held by the pre-service science teachers. Diagram 1 shows a typical arrangement in the Malaysian classroom where pupils are seated facing the teacher in the front. The teacher is truly the "sage at the center of the stage." Diagram 2 shows the opposite atmosphere to diagram 1, where the class is held outside and pupils were depicted to be exploring the environment. The diagram illustrates a constructivist approach to learning where students have to discover and build their own understanding of the knowledge.

The findings from the data collected showed that none of the drawings by pre-service science teachers who majored in chemistry scored the combined codes of (+2,+2,+2). However, two of the drawings by the chemistry majors scored a combination code of (−2,−2,−2) as shown in diagram 1 (see Appendix 1). Figure 2 (diagram 3) shows an example of the best drawing by a chemistry major pre-service teacher. The scores given for this diagram were (+2,+2,+1), which means that this pre-service science teacher was strongly student-centered, believed strongly in attaining scientific literacy, and believed teachers still have some say in the teaching and learning process. The drawing illustrated a typical laboratory environment where students could be seen working together on an activity at their respective tables.

Figure 3 shows the codes assigned to the drawings of all the pre-service science teachers according to the three categories (Table 1): beliefs about classroom organization, beliefs about teaching objectives, and epistemological beliefs. The results showed quite a homogenous distribution within the codes $-2 \rightarrow +1$ for the beliefs about classroom organization, with less than five pre-service science teachers receiving a code of +2. This finding shows that the pre-service science teachers were strongly teacher-centered and only somewhat student-centered. In a strongly teacher-centered classroom organization, the teacher dominates and lectures form the major activity, with media used to focus student attention. The teacher may occasionally plan for a student-centered classroom organization; however, the teacher still initiates and controls the activities that are reflective of the teacher-centered classroom organization. It is possible that at this stage pre-service science teachers still lack knowledge about what constitutes a teacher-centered and student-centered classroom. It is also possible that their view about classroom organization is still being influenced by their prior experiences as students, where the teacher was more traditionally the "sage at the center of the stage."

One example as written:

Teacher activities*:* The teacher teaches to their student about the effect of the catalyst on the rate of reaction. **The teacher asks the student** to draw a diagram of the rate of reaction before and after the catalyst is added. **The teacher also asks the student** to conduct an experiment to show the effect of the catalyst on the rate of reaction.

Student activities: Students focus on what the teacher teaches them. They also **follow their teacher's instruction when** the **teacher asks** them to draw.

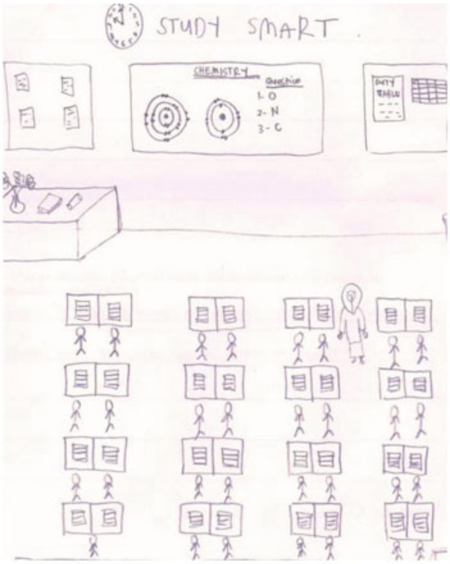

Diagram 1: Example of drawing (-2,-2,-2)

Teacher's activities
Teacher is observing the students. After giving questions to students, teacher facilitates and observes the students.

Student activities
Students are trying to answer the questions given. Students ask teacher when they need help to answer the questions.

Objectives of the drawn situation
The goals are to make sure students understand how to draw the orbital of an atom and to calculate the electrons.

Approach toward drawn situation
Mastery learning, teacher make sure students master the concept before teaching another concept.

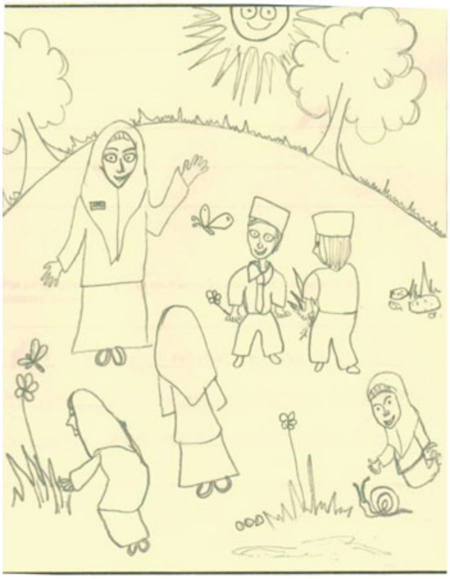

Diagram 2: Example of drawing (+2,+2,+2)

Teacher's activities
The teacher bring the students to observe the school field and classify between living organism and nonorganisms.

Student activities
Students are busy observing organisms at the school field. They explore and experience individually the unique characteristics between organisms.

Objectives of the drawn situation
To differentiate between living and nonliving organisms.

Approach toward drawn situation
Teacher provide the student with real organisms/surrounding so that student will discover the most from the inquiry

Fig. 1 Example of the pre-service science teacher's drawing

The beliefs about teaching objectives are distributed in the range of −2 to +1. Only a few of the pre-service science teachers received codes 0 and +2. The lowest code, −2, illustrates that participants preferred to be exclusively content-structure focused, with learning content as the central objective.

The distribution for the epistemological beliefs showed that most of the pre-service science teachers were assigned a code of −1 followed by +1, −2 and 0.

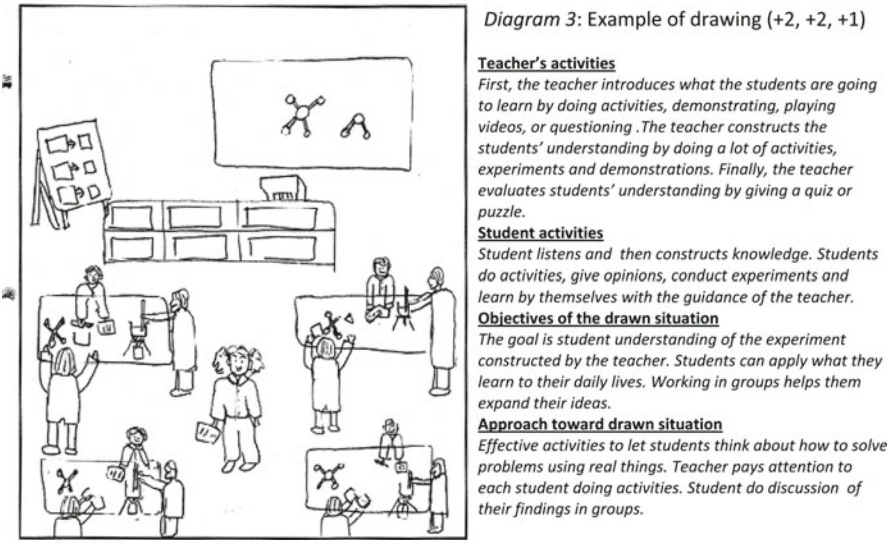

Fig. 2 Example of a chemistry pre-service teacher's drawing

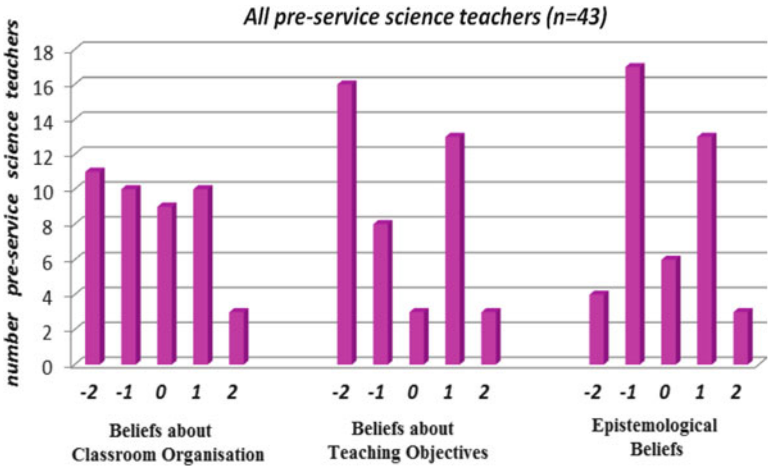

Fig. 3 Codes for all of the pre-service science teachers (n = 43)

A code of −1 indicates that the teacher is still the director of the teaching and learning process while the students are the active participants in the process. The teacher dictates the flow of the activities while students are responsible for completing all the assigned tasks and activities. About four of the chemistry pre-service teachers held a rather constructive perspective of learning while none subscribed strongly to the constructive perspective.

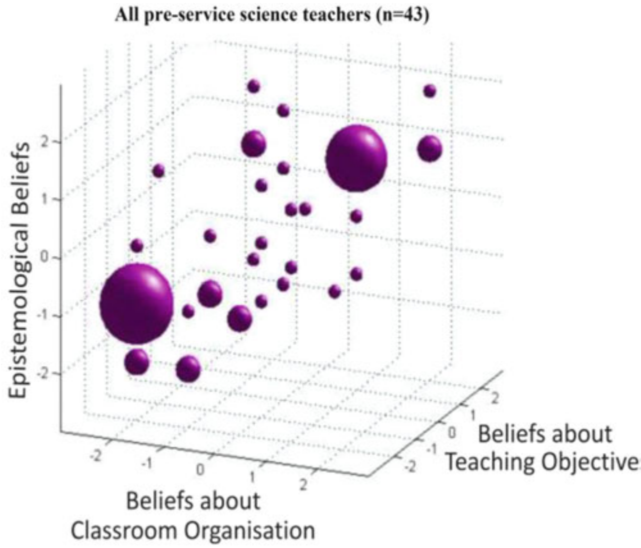

Fig. 4 Joint representation of the data from the three dimensions within one single diagram. The size of the spheres represents the number of the pre-service science teachers

The three categorical beliefs can be connected together and represented in 3D diagram (Markic & Eilks, 2008). The 3D diagram is considered an elegant and sophisticated form of data analysis because the three categorical beliefs can be depicted visually. The sphere represents the number of pre-service science teachers with the joint categorical beliefs. Figure 4 shows the joint representation of the three categorical beliefs held by the chemistry pre-service teachers. The size of the spheres corresponds with the number of pre-service science teachers with the joint codes for each categorical belief: beliefs about classroom organization, beliefs about teaching objectives, and epistemological beliefs. The figure shows heterogeneous spheres, with the two largest spheres at the diagonal (–2,–2,–1) and (+1,+1,+1) and others distributed diversely along the axes. The findings indicate that the beliefs of all the pre-service science teachers in this study were mostly in traditional teaching, with some moving towards modern constructivist teaching. The chemistry pre-service teachers believed in teacher-centered classroom organization rather than a student-centered classroom. Most of the chemistry pre-service teachers preferred teaching with an exclusively content-structured focus with learning content as the central objective. The findings are similar to the findings by Markic and Eilks (2008) from their study on German first-year chemistry student teachers' beliefs about chemistry teaching and learning (Figs. 5, 6).

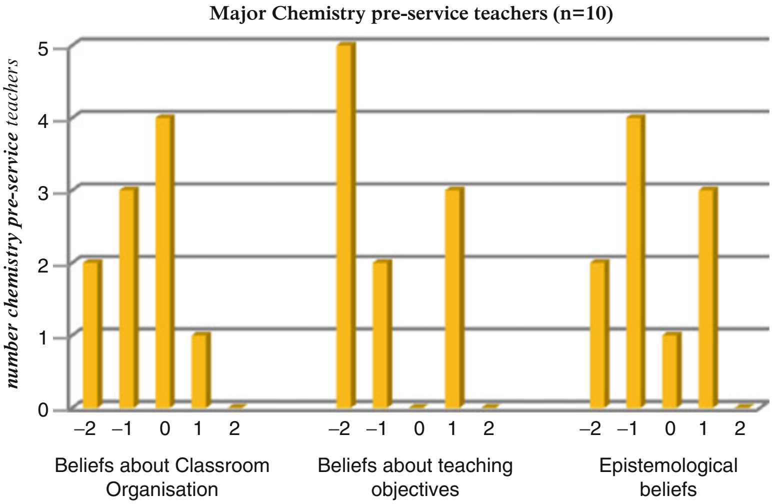

Fig. 5 Codes for the chemistry pre-service teachers (n = 10)

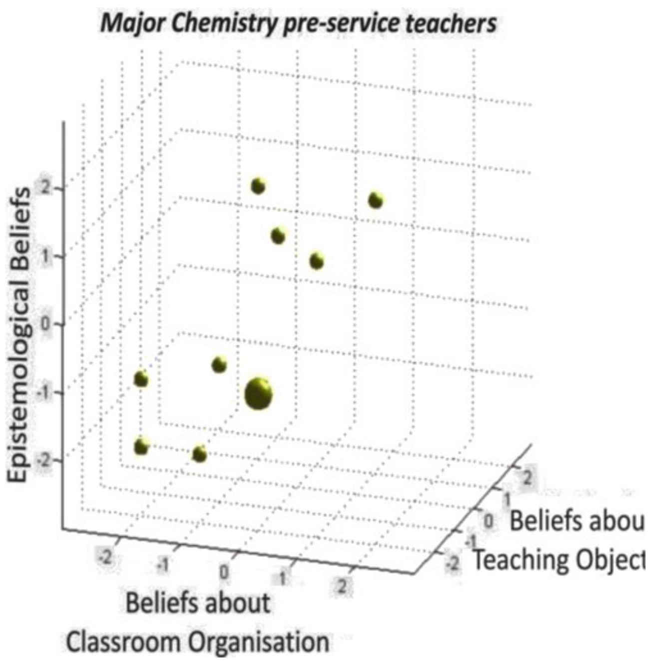

Fig. 6 Joint representation of the data from the three dimensions within one single diagram. The size of the spheres represents the number of the major chemistry pre-service teachers

5 Conclusions and Implications

A learner's mental model is highly individualized and constantly changing as more input and learning take place. Learners construct new knowledge and modify existing knowledge as they experience situations, problems, circumstances, and other events in learning settings. The models continue to change as more knowledge is gained. A person must have a working model of the phenomenon in his or her mind in order to understand a real-world phenomenon. Authentic learning environments have the potential to provide an environment that allows students to experience learning in situated contexts, and these experiences enrich and change their mental models. Hence, understanding the mental models in teaching and learning science is crucial at the beginning of the methods course in teaching chemistry. This understanding can help teacher educators to improve and support teaching and learning experiences in the methods course and the teacher education program. As evidenced in the representations, the chemistry pre-service teachers in this study still held traditional beliefs about teaching and learning. Teacher educators need to consider the existing mental models held by pre-service teachers and plan a teacher preparation program to shape these mental models according to the current educational theory in teaching chemistry. Instructors who are more aware of the role that mental models play in learning ill-structured knowledge are more likely to succeed in supporting learners' experiences (Eckert & Bell, 2005). Visualization of mental models can help both instructors and students understand the knowledge-building process (Yehezkel, Ben-Ari, & Dreyfus, 2005).

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Appendix A

Numbers and percentage of the pre-service science teachers in the respective categories. The categories refer to Table 1 in the sequence Classroom Organization, Teaching Objectives, and Epistemological Beliefs. For single students not all codes were given in every category.

Code combination	All Science (n=43)	Chemistry (n=10)	Code combination	All Science (n=43)	Chemistry (n=10)
(−2,−2,−2)	2 (4.7%)	1 (10.0%)	(0,0,+1)	2 (4.7%)	
(−2,−2,−1)	6 (14.0%)	1 (10.0%)	(0,−1,+1)	1 (2.3%)	1 (10.0%)
(−2,−2,0)	1 (2.3%)		(0,−1,−1)	1 (2.3%)	
(−2,−1,−1)	1 (2.3%)		(0,−1,0)	1 (2.3%)	
(−2,−1,+1)	1 (2.3%)		(0,−2,−1)	2 (4.7%)	2 (20.0%)
(−1,−2,−2)	2 (4.7%)	1 (10.0%)	(0,+1,0)	1 (2.3%)	1 (10.0%)

(continued)

(continued)

Code combination	All Science (n=43)	Chemistry (n=10)	Code combination	All Science (n=43)	Chemistry (n=10)
(−1,+1,+1)	1 (2.3%)		(+1,−2,+1)	1 (2.3%)	
(−1,−2,−1)	1 (2.3%)		(+1,−2,0)	1 (2.3%)	
(−1,−1,−1)	2 (4.7%)	1 (10.0%)	(+1,0,−1)	1 (2.3%)	
(−1,−1,0)	1 (2.3%)		(+1,+1,−1)	1 (2.3%)	
(−1,+1,+2)	1 (2.3%)		(+1,+1,+1)	5 (11.6%)	1 (10.0%)
(−1,+1,0)	1 (2.3%)		(+2,+2,+1)	2 (4.7%)	
(−1,+1,+1)	2 (4.7%)	1 (10.0%)	(+2,+2,+2)	1 (2.3%)	
(0,0,+2)	1 (2.3%)				

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