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Application of a Knowledge-in-Pieces perspective to students' explanations of water springs: A complex phenomenon pertaining to the field of physical geography

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Abstract

This in-depth explorative qualitative study provides an empirical analysis of students' understanding of the concept of water springs based on the theoretical framework of Knowledge-in-Pieces (KiP) by diSessa (1993). KiP is an epistemological perspective that views knowledge as a complex system of many types of knowledge elements. These include the so-called explanatory primitives (e-prims), that is, intuitive knowledge elements that people use when interpreting the world. The aim of this study was to gauge the potential of KiP in the field of research on pre-instructional conceptual knowledge in the geosciences by analysing conceptions of the complex hydrological issue of the formation of water springs. When probing student explanations of springs for e-prims in two case studies involving 12-year-old boys, we identified two explanatory primitives not previously documented. We named these "stuff in motion has force" and "hard stuff blocks, loose stuff lets something through.

Keywords

Knowledge-in-Pieces; intuitive knowledge; explanatory primitives; complex hydrological concepts; water springs

1 Introduction

The motivation for the present study derived from the fact that, while the approach of Knowledge-in-Pieces (KiP) has proved fruitful for learning in various fields of science learning, it has so far received little attention in geography and earth science (hereinafter referred to as geosciences). KiP is an epistemological perspective that views knowledge as a complex system of many types of knowledge elements, including intuitive knowledge elements (diSessa, 2018, p. 67). This explorative study analyses 12-year-old secondary school students' explanations of a hydrogeological phenomenon, namely the formation of water springs, from a KiP perspective (diSessa, 1993). The relevance of water springs as a hydrological topic is attributable to the fact that they are an indispensable source of drinking water for mankind. The quality of spring water is, in turn, very much dependent on the conditions under which a spring is formed (Hölting & Coldewey, 2009). The prerequisites for the formation of springs, however, are complex and invisible. Therefore, novices can explain the occurrence of water springs only with the help of everyday experience and an intuitive understanding of the physical world. When students who have no formal knowledge of water springs are asked how springs are

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formed, they frequently express the following idea: “Groundwater is stored underground, often in large subsurface openings such as caves, lakes, or channels. Due to its force, the water rises to the surface against gravity to form a spring” (Reinfried, Tempelmann, & Aeschbacher 2012b). From the perspective of formal hydrogeology, such notions are mostly erroneous. They constitute common-sense science knowledge, which is also referred to as prior knowledge or intuitive knowledge acquired prior to formal instruction (e.g. diSessa, 2018; Hammer, 1996; Sherin, 2006). We chose the KiP perspective for this research project because it appeared to be particularly suited for capturing intuitive knowledge. Our goal was to identify intuitive knowledge elements upon which students draw when explaining water springs and to discover how students make sense of these elements to arrive at a conclusive explanation of this phenomenon.

2 Pre-instructional knowledge conceptualised as Knowledge-in-Pieces

Knowledge-in-Pieces (KiP) is an epistemological perspective on science learning developed by diSessa (1993). It belongs to the field of conceptual change (Vosniadou, 2013), a learning theory close to constructivism, which examines particularly difficult learning processes. KiP has provided a deeper understanding of the phenomenon of “prior conceptions”, a term used to describe students’ intuitive, common-sense, everyday, pre-instructional ideas of phenomena of the natural world (diSessa, 2018, p. 67). Using KiP, students’ explanations of the physical world are taken to be spontaneous constructions. These constructions result from the activation of fine-grained intuitive bits of knowledge, termed psychological primitives, or p-prims (diSessa, 1993, p. 112). The term “intuitive” is used loosely and informally to describe students’ commonly held prior conceptions. P-prims are defined as micro-generalisations that people abstract from their experience. They are closely linked to familiar phenomena and are used in everyday life in a wide variety of situations. They are spontaneously activated in a given situation and organised in such a way as to help people interpret what they experience. The individual is not aware of their existence, as they are non-verbal and lie outside the realm of conscious deliberate recall. P-prims are therefore always context-dependent and are activated only in response to a particular situation or by associative knowledge structures (diSessa, 2008). P-prims are elements of intuitive knowledge that constitute people’s “sense of mechanism” by which they assess occurrences as obvious, plausible, or implausible and explain or refute real or imagined possibilities (diSessa, 2018, p. 69). Once p-prims are established on the phenomenological level, they become internalised resources that can be called upon at any time to render later experiences intelligible. This sense-making process takes place at a very deep cognitive level, which explains why learners are largely unaware of the basis of their understanding (Southerland, Abrams, Cummins, & Anzelmo, 2001, p. 329). In other words, p-prims are fundamental knowledge elements that learners understand without explanation because they function as implicit presuppositions of how the physical world works (Ueno, 1993). Since, according to diSessa (2018), single pieces of knowledge are not interconnected but remain *isolated*, contradictory pieces of knowledge can *coexist* without learners being aware of the contradictions.

Because the use of those p-prims that formal science would classify as incorrect often proves useful in real-life contexts, elements of knowledge are inherently neither correct nor incorrect from a KiP perspective. They only become correct or incorrect in their application. The p-prim “closer means stronger” (Sherin, Krakowski, & Lee, 2012) offers an illustrative example. If this p-prim is used to state that it is hotter in summer because the Earth is closer to the Sun than it is in winter, this is wrong from the perspective of formal astronomy. Conversely, if the same p-prim is used to explain why a lit candle gradually feels hotter as one ventures closer to it, the conclusion is correct. Once established, p-prims do not disappear and are not replaced. They belong to the individual’s intuitive knowledge of how the world functions. P-prims are reinforced by daily experience and, thus, have a high cueing priority. In the course of learning processes, p-prims are not substituted but expanded in their scope of application. For this reason, learning, from a KiP perspective, is viewed as conceptual development based on the reorganisation and re-contextualisation of initially piecemeal, loosely connected, incoherent (sub-)conceptual knowledge elements of a learner’s individual knowledge repertoire into a better organised, stronger, and more complex knowledge system (diSessa, 1993, 2008). Since p-prims are general abstractions from experience, they should not be domain-specific, because their activation in the cognitive system will occur prior to any assessment of a phenomenon of a particular knowledge domain (diSessa, 1993; Hammer, 2000; Louca, Elby, Hammer, & Kagey, 2004; Sherin, 2001). In a 120-page long analysis, diSessa (1993) describes over 30 p-prims, which have since been supplemented by further examples (e.g. by Hammer, 2004; Sherin, 2006). Some well-known examples of p-prims are “continuous force” (the intuitive schematisation of an agent perpetually acting on an object), “Ohm’s p-prim” (increased effort or intensity of impetus leads to more of the result), “overcoming” (one force or influence overpowers another), and “blocking” (an object's tendency towards motion is thwarted by another object in its path). All examples were taken from diSessa (1993, p. 217ff).

Kapon and diSessa (2012, p. 266) expanded this approach by developing the construct of explanatory primitives. In their view, explanations are formed by reducing each phenomenon to a certain set of functional knowledge elements, which they term explanatory primitives, or e-prims. They have the characteristic of being self-explanatory and are encoded in people’s minds. While p-prims relate to abstracted experiences of the physical world, e-prims are self-explanatory units that reflect “the way things are”. They result from social interaction, language (metaphors), or explicit instruction. E-prims *may* possess properties of p-prims, but they do not necessarily possess properties of p-prims. They are therefore seen as a category of knowledge elements superordinate to p-prims, but in terms of their function, they do not differ from p-prims. In other words, as e-prims and p-prims are self-explanatory, every p-prim is by definition an e-prim, but not all e-prims are p-prims. P-prims have very specific properties on account of their source, encoding, developmental history, and systematicity (diSessa, 1993), whereas the e-prim category can be far more varied (Kapon & diSessa, 2012, p. 266; Kapon, 2016).

According to KiP, the stability of some students’ conceptions can be explained by the fact that the e-prims activated are responsible for whether an explanation is viewed as being acceptable or instead triggers surprise in the individual. Explanations that are consistent with activated e-prims are judged by diSessa (1993) and Kapon and diSessa

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(2012) as being more plausible. These researchers suspect that every e-prim has a reliability priority, which is based on recurring confirmations of the e-prim in everyday life situations and reinforces or reverses the original cue. The reliability priority reflects the amount of confidence a person has in a particular e-prim in a specific thought context. Kapon and diSessa (2012, p. 272ff) developed a set of criteria for identifying e-prims in explanations. For this purpose, they operationalised the content components of the intuitive knowledge dimension. When we conducted our data analysis, we used these criteria to identify e-prims and p-prims in student explanations (see section 4.2). In terms of e-prims, the following have so far been documented in the literature: “Gravity pulls things down” is used to explain why objects fall downward (Kapon & diSessa, 2012, p. 267); “things tend to be as they appear” conceptualises items based on everyday experience, such as a “flat Earth” (Kapon & diSessa, 2012, p. 281).

In a nutshell, the important explanatory advantage of KiP is that it views inconsistencies in physical (diSessa, 2018, p. 66), epistemological (Hammer & Elby, 2002), and pedagogical beliefs (Ohst, Fondu, Glogger, Nückles, & Renkl, 2014, p. 2) from the perspective of human mental resources, such as p-prims and e-prims, that are activated in different contexts. They can be identified by small-scale, in-depth analyses; thus, they can reveal the structure of prior conceptions and thereby explain differences in students’ prior knowledge about one and the same phenomenon as well as differences in the stability of this knowledge. Herein lies the motivation for the present study, which is namely to transfer the methodology of KiP research to the field of education in geoscience in order to identify knowledge elements that are activated in students' cognition when they are called up to explain phenomena related to geoscience.

3 Previous research and research question

KiP was first applied to physics education (e.g. diSessa, 1993; Redish, 2004), with the particular aim of providing a deeper understanding of the intuitive conception of force, and has since penetrated other areas, such as mathematics (e.g. Iszak, 2005; Wagner, 2006), chemistry (e.g. Taber & García Franco, 2010), biology (e.g. Southerland et al., 2001), computer science (e.g. Chao, Feldon, & Cohoon, 2017; Masson & Legendre, 2008), and even race and racism (Philip, 2011). In the past decade, KiP has also gained a foothold in the educational sciences, where “incorrect” intuitive pedagogical knowledge has increasingly been conceptualised as pedagogical knowledge in pieces (Ashe & Bibi, 2011; Orrill & Eriksen Brown, 2012; Harlow, Bianchini, Swanson, & Dwyer, 2013). Goodyear, Markauskaite, and Kali (2009, p. 16), for instance, assume that there are pedagogical p-prims, in the form of encoded experiences of learning and teaching, that are used in pedagogical sense-making. Just as p-prims that result from interaction with the physical world can be subsumed under "naive physics", p-prims that result from experiences of learning or teaching could well constitute the building blocks of "folk pedagogy" (Goodyear et al., 2009, p. 16).

Intuitive knowledge elements in geoscience conceptions have so far rarely been analysed. Research in this field has generally focused on the identification of “misconceptions” or erroneous conceptions related to natural phenomena, such as the greenhouse

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effect and global warming, tropical cyclones, volcanic activities, and glaciers (e.g. Cheek, 2010; Lane & Coutts, 2012). A few studies have looked for the underlying reasons for erroneous conceptions, but they have not used the KiP approach (cf. Conrad, 2015; Niebert, Marsch, & Treagust, 2012; Reinfried, Aeschbacher, & Rottermann, 2012a; Felzmann, 2013). KiP research in the geosciences is available from Barth-Cohen and Braden (2018), who studied the relationship between observation and knowledge in field geology. Parnafes (2012) describes the process of developing understanding of the phases of the moon. Shelton and Stevens (2004) analysed student learning about the Earth-Sun relationship. Rosenberg, Hammer, and Phelan (2006) examined epistemologies of students discussing the rock cycle. Many more studies, however, are needed to fully penetrate the origins and nature of the whole range of intuitive knowledge in a novice's grasp of geoscience concepts. The goal of the research presented here was therefore to explore the foundations of the intuitive knowledge that characterises students' explanations of springs. This broad focus was addressed through the following, more specific, research question:

Can p-prims and e-prims be identified in student explanations of the formation of water springs?

Using the topic of springs as an example, we wanted to determine whether KiP holds similar potential for geosciences education as for other areas of discipline-based education to interpret learners' thinking in comprehensible and detailed models of small intuitive units of knowledge. Success in this endeavour would mean that geography didactics could contribute its own concrete illustration of the KiP perspective in geography teacher education.

4 Method

4.1 Data collection

The data used in this project originates from a larger qualitative research project, which we describe briefly here. The project was a pilot study that investigated the conceptual development of students' spring concepts, using learning path analyses (Reinfried, 2015). Ten 12-year-old students from a Swiss secondary school were involved in the study (five girls and five boys, with an average age of 12.4). We selected the students from two seventh-grade classes (n = 41) from a school near Lucerne, a partner school of our university, using profile sampling (Reinders, 2005, p. 143f.). In profile sampling, test subjects are selected on the basis of data already obtained. This data consisted of drawings of and texts about springs produced by all 41 students prior to instruction. To achieve the greatest possible heterogeneity of information, we selected 10 maximally contrasting documents from the total sample. Participation in the project was voluntary. Participants were guaranteed confidentiality and informed that they could withdraw their data from the study at any time without adversely affecting their relationship with the researchers or their teacher. The seventh grade was chosen because students in Switzerland do not receive formal instruction in the geosciences until they are in the seventh grade. All 41 students were taught by the same teacher in geography and in the

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sciences, and no academic knowledge of springs had been previously provided at the time of the study.

The 10 selected students were asked to explain their ideas about water springs in semi-structured clinical interviews and knowledge tests before and after an intervention with learning materials. The learning materials had been specially developed to improve the students' conceptual understanding of springs and support conceptual change (Reinfried, Aeschbacher, Kienzler, & Tempelmann, 2013). The knowledge development of the learners was monitored through pre-, post-, and follow-up tests. The present study is, however, an original research work in its own right, as the KiP approach was not incorporated into this prior research project. Although we already suspected at the time of this prior research project that p-prims could play a role in the students' prior conceptions (see Reinfried, 2015, p. 127 and p. 131), it was only after the publication of the study that we started to deal intensively with the KiP approach. The reason for our impression that p-prims could have been playing a role in the students' prior conceptions was that, although the students had worked with our learning materials, not all students had given up their ideas of underground water bearing cavities. We wanted to determine whether the KiP perspective could provide a starting point for a better understanding of this observation. We decided to re-examine part of the data using a fine-grained in-depth analysis with the aim of discovering in the students' pre-instructional spring conceptions those intuitive knowledge elements that Kapon and diSessa (2012) had described as e-prims. The data collected prior to the intervention constituted the most appropriate documents for these purposes. They included several student utterances, namely verbal interview data, student gestures, and self-generated written explanations and drawings.

The interview data had been obtained as follows. Each student was interviewed individually by either the first author or a trained member of her research group. The interviews lasted around 10 to 15 minutes. The interviews were conducted face to face in German. The students were asked to explain their notions verbally using the drawings and written explanations they had produced before the interview. The interviewer asked questions to clarify what the students meant or to provide them with a cue for explaining the processes underlying their notions of spring formation. The students' statements were analysed using the literally transcribed video interviews. We focused on the students' spoken words, including the gestures they had used to underline their explanations (see Appendix). Additional data were provided by the students' annotated drawings and their short texts. According to Flick (2009, p. 261f), such products are to be understood as valuable means of communication that provide supplemental information to the interview data. As products developed by the students to explain their ideas, they can help researchers to reconstruct the mental representations of their test persons. The use of different data sources relating to the same phenomenon can provide a richer picture of the empirical reality. Patton (2002) considers the use of different data sources concerning the same phenomenon as a form of data triangulation that serves to make the results of qualitative studies as robust as possible, to confirm the results, and to increase the validity of studies.

4.2 Data analysis

The data were analysed by the two authors. As a research method, we applied latent content analysis (Bengtson, 2016; Stamann, Janssen, & Schreier, 2013), a qualitative analytical approach to coding and interpreting data, which is characterised by techniques applied in grounded theory (Glaser & Strauss, 1967; Strauss & Corbin, 1998). Latent content analysis is used to explore the deeper meanings of communication information. For the analysis of the students' moment-to-moment reasoning during the interviews, a microanalytic approach was used. Microanalytic coding selects for analysis short segments of thinking out of a fuller corpus of thinking and looks at these segments with high conceptual resolution (diSessa, Sherin, & Levin, 2016, p. 42). An analysis unit consisted of one student statement interposed between two interviewer questions or remarks and could comprise one or more sentences. When interpreting and coding the transcripts, we were aware of the danger that a student's phrasing might lead to a mistaken reading of the underlying way of thinking because intuitive knowledge elements operate well below the level of spoken language. For this reason, we took the wider context of the dialogue into consideration when interpreting and coding the individual utterances. This was done by including explicative information, such as the students' gestures, drawings, and texts.

In the first step, we searched for p-prims in the transcript sections. We used the list of p-prims published by diSessa (1993, pp. 217-225). In most cases, one p-prim—and, less often, several p-prims—could be assigned to the pupil's statements. An example is Benni's statement in turn B26: "Um, I am sure that there are caves where the water just stays there, **but the water eats further into the stone** and at some point it will then just come out." We assigned "Ohm's p-prim" to this statement. With this procedure, certain p-prims—such as "Ohm's p-prim", "continuous force", "overcoming", and "blocking"—could be identified particularly frequently. On the basis of these classifications, we hypothesised that e-prims with the following kinds of meanings could form part of the students' way of thinking: "moving water has force" and "hard material blocks something".

In the next step, we analysed the students' statements using the criteria for the identification of e-prims developed by Kapon and diSessa (2012, p. 272f).

(1) Functionality: The knowledge element is explanatorily useful to the goal of reasoning and responsive to the context in which this reasoning takes place.

(2) Obviousness: The knowledge element is referred to by the student with explicit statements or with unelaborated confidence and acceptance.

(3) Development history: The knowledge element can be related to familiar experiences from which it could have been abstracted.

(4) Triangulation of expression: The knowledge element reappears frequently in a variety of manifestations during the reasoning process.

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(5) Triangulation of form and content: The knowledge element matches a documented p-prim or other documented intuitive notion with respect to all the relevant components of the situations in which it is used. This criterion cannot always be satisfied, but when it is satisfied, the interpretation can be considered to be on a safer ground.

In the analysis, this list had the function of a coding guideline. Its criteria served as deductively generated codes. The students' gestures and their written and drawn forms of communication were used to verify the fourth criterion, *Triangulation of expression*. The results section contains the student utterances assigned to the criteria in detail. To guarantee the quality and trustworthiness of the results, we conducted the analysis iteratively. The two authors first analysed the material separately; they then discussed their results and clarified cases of doubt. To avoid misinterpretations, they compared these initial results with the theoretical foundations and the examples used in the KiP literature. The data material was then subjected to a second critical review by the two authors, and the results were discussed until a consensus was reached between the two researchers.

5 Results

The results of the analysis are presented below, using the example of two case studies selected according to the method of maximum contrasts (Glaser & Strauss, 1967, pp. 51-83; Kleemann, Krähnke, & Matuschek, 2009, p. 26). The contrast refers to the prior knowledge of the two cases. Thus, they do not contrast with each other in an absolute sense, but they contrast with each other relationally with respect to the prior knowledge comparison criterion. The two selected cases concern the two 12-year-old boys, Andi and Benni (the names are pseudonyms), who differed the most from each other and from the other test subjects in terms of their prior knowledge. Benni had already seen a spring in nature, although this was the special case of the karst spring, and constructed his idea of springs on the basis of his observations. Andi had never seen a spring before and constructed his explanations by using his everyday knowledge.

The excerpts from the interviews with Andi and Benni (see Appendix) can be read as two distinct self-generated narratives of the phenomenon of water springs based on the boys' personal history and experiences. The word "spring" in the first interview question, "How do you imagine a spring is formed?", acts as a key stimulus and cues implicit intuitive and explicit knowledge, visual memories, feelings, and contexts based on previous experience of the world. Andi explains that a spring is a pool filled with water deepened into solid rock by swirling water (Fig. 1). The water originates from river water that seeped into the earth's interior, where it was heated up to boiling point and then rose up in the form of water vapour, pushing or grinding earth particles away to force its way to the surface. Benni explains that a spring is an outlet of water from a cave drilled into hard rock by the water (Fig. 2). Here, the water originates from percolated glacial meltwater that flows underground at high velocity in self-created channels.

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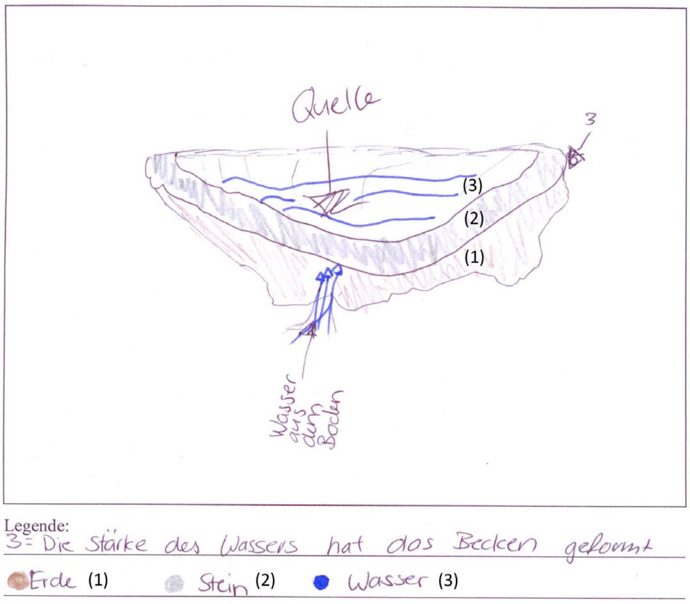

Fig. 1: Andi's drawing (Legend: Quelle = water spring; Wasser aus dem Boden = water from underground; Die Stärke des Wassers hat das Becken geformt = the strength of the water has shaped the pool; Erde = soil; Stein = stone; Wasser = water). The numbers (1), (2), (3) have been inserted by the authors to make the drawing easier to read.

Fig. 2: Benni's drawing: (Regen = rain; Berg = mountain; Hölle [= spelling mistake, he means Höhle] = cave; Fluss = river; Wasser von einem Gletscher = water from a glacier).

We argue that, in spite of the differences between the two, both narratives are based on the same intuitive core elements of knowledge, namely the e-prims provisionally referred to in section 4.2 as "moving water has force" and "hard material blocks something". Both meet all the requirements for e-prims defined by Kapon and diSessa (2012), as is demonstrated below. To express their character of elementary, universal, and domain-independent knowledge building blocks as clearly as possible, we have definitively named them as "stuff in motion has force", where "stuff" in the context of springs means water in its liquid and gaseous state, and "hard stuff blocks, loose stuff lets something through", where "hard stuff" means rocks and "loose stuff" means earth, both in the context of springs. These e-prims are the result of our fine-grained analysis of the students' utterances and are substantiated in the following subsections with concrete examples from the interview transcripts.

Stuff in motion has force

In turns A16, and A20 (see Appendix), Andi explains that the water has made a pool with its own power. The expression "with its own power" reflects the idea that the force is inherent to the water. The same idea is contained in Benni's self-generated explanation that "the water had drilled its way" (turn B10) and "that the water eats further into the stone" (B26). When asked how water can drill, Benni answers, "Through the ((…))[1] well, the movement again and again" (turn B30) and "It just hits the wall again and again and drills further" (turn B36). What made this explanation so plausible in the boys' pre-instructional reasoning? We argue that the e-prim that "stuff in motion has force" lies at the core of their reasoning. This e-prim was cued in their knowledge system, supporting their sense of understanding. "Water in motion has force" means that water exerts an inherent power enabling it to grind down hard rock. In nature, water in motion abrades rock with high erosion resistance, mostly mechanically, by flowing at increased flow velocities and carrying fine silt or sand particles, which are usually not visible to the naked eye and act like abrasive paper. The influence of chemical weathering in combination with water pressure is of secondary importance under the given conditions. Abrasion is the result of rock surfaces being mechanically scraped due to friction between the rock surface and moving particles carried by running water.

"Stuff in motion has force" fully conforms with the operationalised definition of an e-prim:

(1) Functionality: "Stuff in motion has force" explains why the water is able to move forwards underground. It also explains the existence of underground caves and channels. The e-prim that water needs to be in motion to have force is expressed in Benni's reply to the question of how water can drill: "Through ((…)) well, the movement" (turn B30). Andi wrote in his explanatory text that the force of bubbling water causes it to create its upward path and the basin at the surface. When asked what he means by the force of the water, he says, "Well, the quickness" (turn A22), which is also linked to the idea that water has be in motion to exert an effect.

(*2) Obviousness:* Both boys think it obvious that the e-prim "stuff in motion has force" (which is subconscious) is true and express this through explicit statements and unelaborated confidence and acceptance. By way of example, in answer to the question of how he can tell that water drills, Benni responds with the words "there is a huge hole, basically, where the water then flows down" (turn B12) and then recounts a visit to a cave with an underground channel embedded in limestone. The water was rushing down the channel at high velocity, causing a lot of turbulence and noise. The sides of the channels showed impressive signs of abrasion. He adds, "I've been to Lucerne, to the Glacier Garden; there it's also ((…)) like it [the water – authors' note] digs" (B14). He is referring in this answer to the Glacier Garden in Lucerne, a nature park where Pleistocene glacial potholes are visible in situ and visitors are told that these potholes were formed by glacial meltwater flowing at high velocity. Andi explains that he has heard about the force of water in the Swiss canton Ticino: "Because here rivers also use their own power to form pools themselves" (turn A20). His answer pertains to a well-known peculiarity of the rivers in the southern part of Switzerland, where turbulent high-velocity rivers laden with sediment have formed fluvial potholes in the rocky river beds. It is noteworthy that the students were not aware that it is, in fact, the process of mechanical abrasion that is responsible for the rock shaping.

(3) Development history: A familiar experience of running water that seems to have "force" is that of a faucet turned wide open, from which the water shoots and washes away dirt. The knowledge element that “stuff in motion has force” could also have been abstracted from linguistic sources. An example is the metaphor “constant dripping wears the rock away”, which reflects this idea.

(4) Triangulation of expression: The e-prim “stuff in motion has force” is expressed verbally several times in the interviews using different wording and is also evident from the gestures and written text: (a) in spoken wording in A4, A16 (water forms), A46 (water or water vapour pushes, grinds), B10 (water digs and drills), B20 (water rounds out), B26 (water eats), and B32 (water smacks); (b) in gestures in B12, B14 (digging), B20 (rounding out), B36 (beating and drilling); (c) in written texts. Andi explains in his written account that “a long time ago, water started to bubble up. The force of the bubbling up has formed the path to the surface and the basin. The strength (German: Stärke) of the water has formed a basin.” Elsewhere he writes, “The water is somehow heated up and forms its own path due to the strength of the water.”

(5) Triangulation of form and content: “Stuff in motion has force” is expressed by both boys. The notions that “force is a property of objects” and that “animate or active objects contain and/or exert force” are common intuitive conceptions in physics, which have been explored in numerous studies (Brown, 1989; McCloskey, 1983; Watts & Zylbersztajn, 1981). In the context of spring formation, water is seen as a causal agent that creates impetus and transfers it to other objects. Velocity is seen as the cause of the force. Common-sense concepts that match this notion are “motion implies active force” or “motion requires force” (Clement, 1984) (see Andi’s idea that bubbling water has strength in turns A4, A8, and A42) and “velocity is proportional to applied force” (Daehler, Shinohara, & Folsom, 2011). Other p-prims underlying “stuff in motion has force” are “continuous force” and “Ohm’s p-prim” (diSessa, 1993). “Continuous force” is the intuitive schematisation of an agent perpetually acting on an object. It is expressed by Benni in turn B36, when he states that water exerts a continuous force on the rock walls, and by Andi in turn A46. According to diSessa (1993, p. 218) “continuous force” accounts for the misunderstanding that motion requires force. “Ohm’s p-prim” is the intuitive schematisation of the idea that “an agent or causal impetus acts through resistance or interference to produce a result” (cit. diSessa, 1993, p. 217). We identified it in Andi’s explanation in A46 and in Benni’s idea in B36. The p-prim “overcoming” (diSessa, 1993, p. 222), which is the intuitive schematisation of one force overpowering another, is expressed in Benni’s suggestion that the resisting rock wall gives way to the force of the water (B36) and in Andi’s idea that the “strength” of the water is able to grind part of the rock away (A16, A46).

Hard stuff blocks, loose stuff lets something through

Both boys assume that the ground below the surface is made up of layers (turns A26, A30, B18, and B38), but they have conflicting ideas about the structure of the Earth. According to Andi, the Earth consists of hard rock on the surface and loose soil underneath (turn A26). Benni thinks that there is rock underneath the soil, which becomes increasingly hard the deeper one goes. Below that is molten rock (turns B40). Both students consider hard rock to be impermeable, as reflected in Benni's response to the interviewer's question about why water entering the cave does not seep lower down: "Because the further down you go, the harder the stone becomes" (turn B24) and does not let any water through ("It just stops the water", turn B42). Soil, by contrast, consists of little balls that water can flow through (B44). Andi expresses this idea another way in his drawing (Fig. 1). The latter depicts a water-filled basin embedded in hard rock, lying on soil. Water that originates from below is flowing into the basin. Andi thinks that the rock becomes softer deeper down (turn A34: "There can't really be just stone under the mountain, because there must also be earth underneath there", because "not everything can be made of stone, otherwise, you wouldn't be able to get under there, like by drilling" (A36). In other words, rock is hard and impermeable, whereas soil is loose and permeable. We argue that these ideas are derived from the e-prim that we refer to as "hard stuff blocks, loose stuff lets something through". This e-prim is based on experience but does not correspond to the petrographic properties of rocks, which can be permeable to water despite being hard and not showing macroscopic voids. Hard rocks can have pore spaces (i.e. microscopically small voids), usually not visible to the naked eye, that can be filled with water provided that the pores are interconnected (Owen, Pirie, & Draper, 2011).

The knowledge element "hard stuff blocks, loose stuff lets something through" fully conforms with the operationalised definition of an e-prim:

(1) Functionality: "Hard stuff blocks, loose stuff lets something through" explains why water is impeded by rocks but seeps into the soil. Andi thinks that the Earth's surface is covered with an impervious layer of hard rocks, in which water has hollowed out a pool, while loose soil underneath the rock layer contains passages and tubes that let river water seep in and allow water (and water vapour) to rise (turns A6, A30, A44, and A46). Benni explains this idea as follows: "Earth is made of lots of little balls ((…)) and then it can flow through, the water, and … the further you go under … there is harder stone there, then it can't flow through any more" (turn B44). When asked why percolating water does not seep further down into the Earth's interior, Benni replies that "there's harder stone underneath, and it just stops the water" (turn B42).

(2) Obviousness: Benni states explicitly that water cannot seep through hard rock (turns B24 and B44), and Andi expresses this idea in his verbal account in turns A34 and A36: "There can't really be just stone under the mountain, because there must also be earth underneath there … otherwise, you wouldn't be able to get under there, like by drilling." He is convinced that rocks, which are hard, unlike loose soil, do not allow passage.

(3) Development history: The knowledge element that “hard stuff blocks, loose stuff lets something through” is an abstraction of a concrete physical phenomenon frequently observed in the natural world. Whenever it rains or liquids are spilled, children notice that surfaces made from hard materials, such as asphalt or floor slabs, do not let water through, unlike loose materials such as soil, gravel, or sand.

(4) Triangulation of expression: The e-prim “hard stuff blocks, loose stuff lets something through” is expressed several times in the interviews using different wording and is also evident from the drawings and gestures: (a) spoken wording in turns A34 and A36 (Andi) and in turns B24, B42, and B44 (Benni); (b) gestures in turn B36 (Benni); (c) drawings by Andi and Benni (Fig.1, Fig. 2).

(5) Triangulation of form and content: The e-prim that “hard stuff blocks, loose stuff lets something through” matches the documented p-prim “blocking” (Hammer, 2004; diSessa, 1993; Sherin, 2006). “Blocking” is the intuitive schematisation of the idea that “a force or an object's motion (here, water) is directly impeded by another object (here, hard rock) in its path” (Sherin, 2006, p. 540). Both boys activate “blocking”: Andi in turn A36 and Benni in turn B44. Another knowledge element that matches “hard stuff blocks, loose stuff lets something through” is “two objects cannot occupy the same place at the same time” (Spelke, 1991). This can justify the idea that a solid rock mass and water cannot occupy the same space simultaneously. Given that rocks consist entirely of “stone substance”, there is no room for water, because all matter, including fluids, take up space (Hammer, 2004). A liquid cannot be contained in solid matter lacking (noticeable) voids. With such a primitive in place, no further explanation is necessary.

6 Discussion

The aim of this study was to analyse core components of seventh-grade students’ understanding of a complex hydrogeological phenomenon, the formation of springs, which usually cannot be directly observed. In concrete terms, the search was for explanatory primitives (e-prims) embedded in scientific thinking. The case studies of two 12-year old boys, Andi and Benni, who explained their understanding of water spring formation in interviews, were used as examples. Our analysis revealed two intuitive knowledge elements matching existing abstractions from prior experience. We consider these knowledge elements to be explanatory primitives (e-prims) that are domain-independent and universally valid: “stuff in motion has force” and “hard stuff blocks, loose stuff lets something through”*.* Interestingly enough, both boys drew on the same e-prims, which made sense to them in the context of springs. We consider this an indication that the KiP theory can be generalised beyond the disciplines to which it has been applied so far. The study presented here provides proof that the KiP perspective can lend insight into students’ self-generated explanations in the geosciences, thus demonstrating that important knowledge components are not tied to physics, mathematics, biology, or the other science areas mentioned in section 3.

The e-prim “stuff in motion has force”, activated by the students in the context of moving water or water vapour exerting a force that overcomes the resistance of hard material and creates water passages, is indicative of an intuitive sense of mechanism. This

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sense of mechanism allows people to judge the plausibility of a physical event and to make predictions (Sherin, 2006, p. 539). It plays a crucial role in the construction of intuitive explanations concerning mechanically induced situations in which one event necessarily results from the previous event. In the example discussed here, spring formation results from the moving water, which has to act upon a hard substance, a rock or hard soil; this is not the case in nature, as spring formation depends on a number of hydrological, geological, and geomorphological prerequisites that interact.

The e-prim "hard stuff blocks, loose stuff lets something through" is used by the students to make sense of the nature of things (Hammer, 2004; Taber & Garcia-Franco, 2010, p. 123). The pattern that rocks have inherent properties, such as hardness and the ability to block water, is useful in many macroscopic contexts. The hardness of rocks, however, does not depend on their position in the Earth's crust, as assumed by Andi in turn A26 and Benni in turn B24. It is a physical material property resulting from the rocks' petrography, that is, their mineral content and contextual relationship within the rock. Hardness is the mechanical resistance of a material to mechanical penetration by another body and is not an indicator of impermeability. In everyday life, most materials (e.g. table tops made from granite or washbasins made from marble) are usually thought of not in terms of being composed of smaller composites (e.g. minerals) that determine their properties but rather in terms of their functions in relation to people (e.g. to eat on it or to pour water in it). That hard materials such as rocks are considered impermeable while loose materials such as soil are considered permeable conforms with the physical experience of human beings, and there is no evidence in everyday life that contradicts these ideas.

In Benni's and Andi's explanations, the two e-prims interact. To form a spring, an active agent, namely the moving water, is needed to change a hard blocking substance, namely the rock or hard soil, in order to create openings for the water to seep or flow through the substances. The boys were drawing upon their intuitive knowledge of how the world seems to work and doing their best to make sense of concepts such as water springs within this framework. They considered the formation of springs based on their sense of the nature of things and their sense of physical mechanisms, which prove useful in many other contexts.

7 Conclusions and implications

We have presented two examples that illustrate how the description of a real-world phenomenon, the formation of water springs, can be informed by psychological primitives. These are part of the knowledge system, which consists of a diversity of context-sensitive, fine-grained, coexisting knowledge elements and other knowledge resources, such as learned facts, adults' explanations, or hearsay. When the role of implicit knowledge in student thinking is acknowledged, the far-reaching significance of primitives for the teaching and learning of geoscience topics in a wider context becomes apparent. We illustrate this with three examples.

(1) We assume that the e-prims described in this article might also play a role in other geoscience topics, even if research on these topics is still missing. The e-prim "stuff in

motion has force" might be cued in novices to explain the erosional effects of wind and glacial ice. Similar to the erosional processes of water, however, the eroding effects of wind and glacial ice are based on sediment additions (Glawion, Glaser, & Sauer, 2009, p. 180 and p. 225). In the case of wind erosion, these are small grains of silt and sand; in the case of glacial erosion, these are rock fragments frozen in the ice. The e-prim "hard stuff blocks, loose stuff lets something through" is applied to all kinds of materials in everyday life, independently of the properties they have in reality. Examples, besides rocks, are unglazed ceramic products (terracotta) and wood, which are hard but permeable. Knowing that hard rock can be permeable is not only important to understanding how a spring functions, but it also helps to understand that petroleum and natural gas are also deposited in the pore spaces of permeable rocks. This knowledge is also important to grasp the new technology of carbon capture and storage (CCS), a process whereby CO_2 is "captured" from the air and then transported to a storage site, which may well be a permeable rock (Haszeldine, 2009).

(2) The curricula for the school subject of geography explicitly require that references to education for sustainable development be taken into account when teaching the subject's contents (DGfG, 2015; D-EDK, 2015). Groundwater resources are under increasing pressure (IGRAC, 2018) requiring people to be more committed to groundwater protection. The intuitive idea that spring water originates from underground caves and rises upwards due to its "internal pressure" is not helpful in understanding the effects of widespread surface pollution on groundwater and spring water as sources of drinking water. The intuitive notion would suggest that groundwater pollution is a local problem, whose effects remain restricted to where the "underground lake" or "water vein" is situated. In reality, however, groundwater pollution can affect large areas and, in consequence, a large number of residents who share the same aquifer underlying the area (Tarbuck & Lutgens, 2009).

(3) Water springs form an interface between underground and surface subsystems of the water cycle. The water outlets at the earth's surface are visible, but the underground parts of springs are not. They can only be understood if their microscopic dimension is considered. Our findings indicate that learners in the geosciences interpret natural phenomena, which are the result of microscopic conditions, on the basis of macroscopically observable properties. Not knowing the differences between the macroscopic level and the microscopic level is widely recognised as a major source of conceptual misunderstandings, as reported from other science disciplines (Harrison & Treagust, 2002; Taber, 2001). The topic of springs provides an illustrative example to demonstrate how microscopic and macroscopic structures interact and thereby determine the properties of a natural phenomenon.

As far as instructional interventions are concerned, they should start from the principle that fine-grained pieces of knowledge in students' explanations are neither right nor wrong but should rather be understood as elements that can be applied either appropriately or inappropriately. Offering students a seemingly "better" (= the normative) explanation than their intuitive explanation without engaging the conceptual resources the students readily access when needed is unlikely to contribute to achieving the educational goal of the envisaged conceptual development. Since, according to the KiP perspective, conceptual development means reorganisation and re-contextualisation of a learner's individual fragmented knowledge repertoire into a better organised, stronger, and more complex knowledge system (diSessa, 1993, 2008), instruction should nurture students' intuitive ideas. They should be incorporated in a kind of learning that guides learners to continuously evolve their grasp of the subject matter from intuitive understanding to sophisticated understanding. The KiP researcher Parnafes (2012) uses the theoretical constructs *resolution* and *range* for this process of gradual knowledge progression. Resolution means the increase of elaborated ideas, and range concerns the extent or scope of the contexts that an explanation covers. What this means is that learners should construct their own explanations by exploring details and broadening their boundaries of comprehension, thus following their own paths to reconfigure and improve their explanations (Parnafes, 2012, p. 400). The instructor plays an important role in this process by helping students to focus on fruitful directions from among the many available options. The constructs of resolution and range can be applied to water springs by helping learners to interpret macroscopic geoscience phenomena in microscopic terms. The concept extension has to take place in two ways: first, by understanding that water can dissolve rocks, such as carbonate rocks, chemically and can thus create cavities without crushing the rock to form voids; second, by mentally shrinking the notion of large rock cavities to microscopically small interconnected holes in order to arrive at the concept of porous and permeable rocks. The idea that liquids in rocks can occur in large cavities is not fundamentally wrong, but it has to be recognised as a special case and has to be extended by other examples. From the perspective of KiP theory, these conceptual extensions could lead to the e-prims "stuff in motion has force" and "hard stuff blocks, loose stuff lets something through" being weakened or even losing their explanatory priority in hydrogeological contexts.

Finally, it is important to acknowledge the particular limitations of the study we have presented. We have provided data collected from only two cases through qualitative methods, the findings of which cannot be extended to wider populations with the same degree of certainty as quantitative analyses. Nevertheless, this article illustrates the importance of fine-grained in-depth analyses of students' prior conceptions to assess the meaningfulness of their statements in reference to a geoscience concept. The understanding of e-prims involved in the formation of explanations can provide teachers in all scientific domains with deeper insight into the fundamentals of their learners' thinking and knowledge construction. It would therefore be worthwhile to further explore the nature of intuitive knowledge elements in geography and other disciplines relevant to education and to test the practical application of this research in teaching.

Notes

[1] ((…)) = Omissions in the interests of readability and conciseness; full text is cited in the excerpts in the appendix.

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Appendix

1 Excerpts from the Interviews

The following section includes excerpts from the video transcripts (translated from German to English), in which the students explain how water springs form. Excerpt A contains conversational turns related to Andi's explanations, and excerpt B conversational turns related to Benni's explanations; "Int.1" denotes the first interviewer (Reinfried), and "Int. 2" a member of her research group.

Transcription conventions:

1. "(#)" - Numbers in italics in parentheses indicate length of pauses in seconds.

2. "..." - Three dots indicate an untimed pause.

3. "[...]" - Three dots in square italic brackets indicate that some material contained in the original transcript has been omitted.

4. "=" - The equals sign indicates two utterances voiced in sequence without any perceptible pause.

5. "((*the water*))" - Italic text in double parentheses provides extra-linguistic information such as references to related bodily movements or students' utterances.

1.1 Excerpts from the interview with Andi

A1 Int1: How do you imagine a spring is formed?

A2 Andi: Well, I think that *((speaks Swiss-German dialect; Int1 interrupts))*.

A3 Int1: Could you speak High-German, then it's easier to typewrite it later.

A4 Andi: Well, I think that, um, that the water comes from below and from the earth-, so yeah, it's heated by the Earth's core and then it somehow bubbles (German: *sprudelt*) to the top *((moves left hand over the drawing))*. And then it makes its pool, like, on its own. Yes.

[...]

A5 Int1: And so how does the water that is heated there get there?

DOI: pending

A6 Andi: *[##]* Well, I think, that it sort of, for example in rivers, it sort of goes under the ground ((*means: seeps into river beds; A6 makes eye contact with Int.1*)). Then it somehow goes through passages or something. Then it gets heated up again down there and bubbles (*sprudelt*) to the top again *((makes eye contact)).*

A7	Int1:	=So in rivers it seeps through passages and that's how it gets down below, then it's heated and why does it come to the top again when it's heated?
A8	Andi:	=Well, because it, I think because it bubbles (*sprudelt*) up again.[1]
A9	Int1:	=Mmm, and what might be the reason for that?
A10	Andi:	=Well, I just think that it *((the water))* becomes steam and then it rises up.
A11	Int1:	What makes you think that?
		[...]
A12	Andi:	=Well, I was actually just thinking of a pot, because you also heat water in it, and steam is given off too *((makes eye contact))*.
		[...]
A13	Int1:	And then the cooker would be, so to speak, the earth's core?
A14	Andi:	Mmm ((*agreeing)*).
A15	Int1:	=And, um, this spring basin, or the "pool" *((moves left hand over the drawing))* that you described in your text, how should we imagine that?
A16	Andi:	=Well, for example, it can be on a mountain or just on the ground, on bedrock, where the water with its own power has somehow formed a pool like this *((Makes an anticlockwise circular movement with a cupped hand)).*
A17	Int1:	Hmm, and what makes you think that?

[1] The word "bubble" (*Sprudel*) is used in German in a geoscience context to describe water released from bubbling springs, fountains or geysers. Here, Andi really means bubble in the sense of surge, simmer, boil because he used the analogy of a steaming pot filled with hot water. However, in A20 he uses the analogy of fluvial potholes to explain his spring pool. Fluvial potholes are the result of vertical river eddies. In colloquial German river eddies are Wasser-Strudel and fluvial potholes are Strudel-Löcher. Because the terms Sprudel und Strudel are very similar it is not clear whether Andi was aware of the fact that the words mean different things in a geoscience context.

DOI: pending

A18	Andi:	=I don't really know *((smiles and shrugs shoulders)).*
A19	Int1:	=Just an idea? *((encouraging smile*)). *[…]* Or have you maybe seen something like that before? Or maybe heard about it in school in a different context?
A20	Andi:	[####] Well, for example, the bit about the water power, I heard about that in Ticino for example, because here rivers also use their own power to form pools themselves, for example.
		[...]
A21	Int1:	You've described that here in writing as, you've written it as, um,... so you think it's with the strength of the water ((*points to the student's sentence "The strength of the water has formed the pool)).* What do you mean by "strength"?
A22	Andi:	Well just, well the quickness.
A23	Int1:	Hmm, so the speed, is that? Yes?
A24	Andi:	Mmm (*agreeing*).
A25	Int1:	Then here ((*points to the student's drawing))* we have the earth and stone ... So there the rock is on the soil.
A26	Andi:	Hmm, well just the earth is underneath and then above it, a layer of stone starts *((makes horizontal movements with hand)).*
A27	Int1:	=And so what is the earth for you? Here?
A28	Andi:	=Well just the normal ground.
A29	Int1:	=So we have to imagine that the top soil would be here *((points to the drawing)).* And the stone, the rock, is on top of it?
A30	Andi:	Mmm *((agreeing)),* so it's a layer of stone on top. Just not all of it *((the whole of the Earth's crust))* is made of stone.
A29/31	Int1:	Hmm. Have you seen something like that in nature before? *((points to the drawing))*
A30/32	Andi:	No ... not really.
A33	Int1:	And what makes you think that?
A34	Andi:	=Well there can't really be just stone under the mountain, because there must also be earth underneath there.
A35	Int1:	=And why?

A36	Andi:	Well, because not everything can be made of stone *((smiles and makes eye contact with Int1)),* otherwise you wouldn't be able to get under there, like by drilling or something.
A37	Int1:	Ah, yes *((sympathetic smile)).* Now, so we've already talked about where the in the hollow shape comes from. You said it comes from the earth. *[…]* And then you wrote, I believe it's on the next page ((*ruffles through the documents)*), ah, no here "the path up and the pool are formed by the power of the bubbles (*Sprudel*)" *((points to the student's text.*)). So, what do you mean by "bubble" here?
A38	Andi:	=Well, just *((shrugs shoulders and glanced briefly at Int1))* the steam comes up too, and yeah.
A39	Int1:	=That would be the steam, the bubble *((points to student's drawing))*?
A40	Andi:	Mmm *((agreeing)).*
A41	Int1:	=And it has, so to speak, made space to rise, err, and after, then... The steam has also made the pool? *((points to student's drawing))*?
A42	Andi:	=Well, no, it ((*the water*)) actually did it in the pool.
A43	Int1:	Hmm, yes *((nods)).* And, um, how should we imagine the rising area?
A44	Andi:	=Well, I think, they're just very very small like little tubes that just rise up.
A45	Int1:	Ah, yes. And how can the power of the bubbles manage that then? What exactly happens?
A46	Andi:	=Well, I think, well it just needs a long time and then a little bit of rock keeps getting pushed away. Well no, not pushed away, just like grinded away and at some point it *((a tube)*) just gets bigger.

1.2 Excerpts from the interview with Benni

B1	Int2.:	How do you imagine a spring is formed? I think it would be good if you *(###)* could explain this using your drawing.
B2	Benni:	=Ok, err (#), I drew a spring there. Err, there are different springs, I thought. Um, I've also seen them *((springs))* from glacier water *((makes eye contact with Int2))* yeah, that flows down in a cave ... Or, I've also heard that rain goes in the ground ((*moves right index finger to the downward seeping rain in his drawing))* and then there's a hole, so a cave, ((*moves right index finger to his self-drawn cave; makes eye contact))* where it falls into, then there are stalactites, and yeah *(###)* *((speaks Swiss-German dialect))*.

DOI: pending

B3	Int2.:	And there *((on the drawing))* you have a little *(#)* of both in it *((Int1 and Benni look at the drawing)).*
B4	Benni:	Yes, exactly.
B5	Int2.:	So, here the rain falls on the mountain *((moves finger over the drawing))* and what happens then, can you briefly explain it again?
B6	Benni:	=Um, then it *((the water, the rain)) ((changes his talk from Swiss-German dialect to High-German))* goes here *((points to a point on his drawing)*) through the stone basically *((looks directly at Int2))* into the cave, yes.
B7	Int2.:	How does it go through the stone?
B8	Benni:	Through grooves, um yeah.
B9	Int2.:	=And and this water from the glacier, how does that get in the cave?
B10	Benni:	Um, the water, basically digs holes, yes, and I've been in one *((a hole))*, in one from the Jungfrau glacier *((makes a rotating movement with right hand)*), where the water flows down like that *((shows a steep slope with hand)),* um, and that was very impressive, there the water comes at a huge pace from the top to the bottom, you could really see how the water had drilled its way under *((moves a slightly bent right hand horizontally away from and towards himself, looks at his drawing during the whole explanation.))*, so yeah.
B11	Int2.:	=How could you see that it had drilled there *((makes an impactful movement with left hand))*?
B12	Benni:	Well yeah, there is a huge hole *((moves his right hand in circles over the table-top imitating the process of carving out the hole))*, basically, where the water then flows down and, yeah *((looks at his drawing during the whole explanation.))*
		[...]
B13	Int2.:	How do you know that?
B14	Benni:	Um, yeah, I've been to Lucerne, to the ... Glacier Garden, there it's also like that *(##) ((makes spiral hand movement as in turn B12))*, yes like it digs and just there at the Jungfrau *((area))*, where the glacier … , and yeah. My dad has also talked about it, from museums, yes *((looks directly at Int2 and shrugs slightly; signals uncertainty))*.
B15	Int2.:	And the part about the stalactite cave and so on?

B16	Benni:	I've also been to a stalactite cave and we had a guide there, who explained how it happened, I mean how they were formed, basically *((turns head and looks into the camera))*.
B17	Int2.:	Hmm ok…, how do you imagine a mountain? What is it made from?
B18	Benni:	Um, I think a mountain is made from stone, so yeah, first there is a soil layer and then the stone *((makes horizontal hand movements over the table))* and then a cave *((forms a hollow in the air with his hands))*, if we're talking about springs, err yes.
		[...]
B19	Int2.:	How can we imagine this cave? What's the nature of it?
B20	Benni:	Err, it *((the inside of the cave))* is err, not just round somehow *((makes a quick movement with right hand with outstretched index fingers))*. It suddenly has a corner that faces forward but it's nevertheless rounded out *((means hollowed out or rounded off)) ((copies the hollowing process with a turning movement of his arched right hand))*, so yes, um, it's not completely square there. When there's a curve, the curve is really rounded out so the water comes like that and then it does that *((imitates the development of curves in the underground waterflow and a right-angled change in course with an arched right hand.)).*
B21	Int2.:	Hmm, Ok. And what material are the walls, the ceiling and the floor made from?
B22	Benni:	=From stone, well yes, water and stone, so limestone or whatever it's called, um yeah.
B23	Int2.:	=And why doesn't the water that comes into the cave just sink further down?
B24	Benni:	=Um, because the further down you go, the harder the stone becomes, and yeah.
B25	Int2.:	Ok. Um..., why does the water flow out at all and not just collect inside?
B26	Benni:	Um, I am sure that there are caves where the water just stays there, but *((raises voice and speaks louder))* the water eats further into the stone and at some point it will then just come out,... yes.
B27	Int2.:	Ok, so it makes its own way out?
B28	Benni:	Yes.
B29	Int2.:	*((Nods in agreement))* Ah, how does ... why can the water drill at all?

B30	Benni:	Um, through the, the movement, well the movement again and again *((scratches audibly with his fingernails on the table-top in anticlockwise circular movements ((imitates the grinding of the water))*, so yeah.
B31	Int2.:	=So because it flows, in principle *((makes a flowing movement with right hand)).*
B32	Benni:	=Yes, smacks against the wall.
B33	Int2.:	Yes. And why does it come out in this particular place? *((points with right index finger to a point on the drawing))*
B34	Benni:	I just drew it like that now, um, just as an example... in the example of Jungfrau ((region)) it *((the water))* comes out as a river *((makes river movements with right hand))*. Yes and here is an opening there *((in the mountain flank that the cave is behind; moves right index finger over his drawing of the opening in the mountain and the way into the cave.))*, you can go in there and see. It *((the water))* just comes out there, basically through a hole.
		[...]
B35	Int2.:	How does the underground water come up at all, how should we imagine that?
B36	Benni:	Yes, it's um, it's probably not quiet, the water, but constantly moving, um ((*makes a wave movement with right hand parallel to the table-top*)), in the mountain it goes down and when it reaches the hard stone ((*shows a 90° steep surface gradually increasing the slope until it is horizontal))*, it flows forward, so yeah, against the wall *((moves his right arm with an outstretched hand sideways from his body rhythmically against an imaginary barrier*)), when more and more new water comes *((shows first a vertical surface with right hand, on which he imitates the drain water))*, then, it just hits the wall again and again and drills further. *((Then makes a turning movement with an arched hand, which symbolises the hollowing of the wall))*. Yes, so not very quietly at all *((in the sense that the water is not still))*.
		[...]
B 37	Int2:	Is it true that the Earth's crust, so the underground, is made of several layers?
B38	Benni:	=Yes.
B39	Int2:	Are they all the same layers?

DOI: pending

B40 Benni: No, the further you go in, the harder they are and then it keeps getting warmer and right in the middle, it's basically lava, for sure, like a lava ball, if you like, yes.

[...]

B41 Int1: You didn't say anything about why it is that the ground water collects somewhere underground. So when it seeps through the rock, why does it not seep further into the earth's core?

B42 Benni: Um, because there's harder stone underneath and it just stops the water.

B43 Int1: So what does hard mean to you then?

B44 Benni: Um *(###)*, earth is made of lots of little balls, so yeah for example, and then it can flow through, the water, and um, the further you go under, um there is harder stone there, then it can't flow through any more.

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