A framework for knowledge: Analysing high school students’ understanding of data modelling

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Abstract

The discursive interaction both with teacher and fellow students plays an important role for each student’s construction of knowledge. The teacher’s understanding of the students’ mental models is essential for the outcome of this interaction. This paper discusses epistemological aspects of using students’ verbal explanations as measure of mental models. A framework of different types of knowledge – typical for informatics – is outlined and used to analyse high school students' understanding of data modelling concepts like keys and queries. Learning is seen as an interaction between skills and understanding. The students in this study displayed good practical knowledge about the different concepts. However, there were indications to lack of theoretical understanding. Both the methodological and the epistemological conclusions of this paper may prove useful in future research as well as in teaching practises.

Introduction

A vast body of research has been published on the theoretical aspects of learning and teaching within subjects like Mathematics and Science. With some noteworthy exceptions (Ben-Ari, 1998; Booth, 1992; Ehrlich & Soloway, 1984; Navarro-Prieto & Catmas, 1999; Petre & Blackwell, 1999; Soloway & Spohrer, 1986), many of the corresponding studies accumulated in Computer Science education ‘are largely atheoretical’ (Brooks, 1999). Fortunately there seems to be an increasing interest among computer scientists as well as cognitive psychologists in the – so far almost non-existent – discipline of ‘didactics of informatics’.

This paper presents the results of a pilot study for my PhD-project, aiming to describe general aspects of students’ knowledge and knowledge acquisition in informatics. Construction of knowledge in a classroom situation depends in part on the establishment of a common frame of reference. To achieve this, the teacher needs a means to evaluate students mental models and guidelines in designing good learning environments facilitating further knowledge construction. The paper describes typical aspects of students' mental representations of data modelling concepts. The study also aims at evaluating written versus oral answers to direct questions as material for analysing student's knowledge.

Theoretical basis

Situated construction of knowledge

Since Piaget first launched the theory of individual cognitive schemes being modified through reflections on experiences (Glasersfeld, 1982), constructivism has been a leading epistemological strand in educational research. Radical social contructivism (Bloor, 1976; Driver, Asoko, Leach, Mortimer, & Scott, 1994; Glasersfeld, 1989) has been heavily criticised for not recognising the existence of an ontological truth independent of human thought and speech (Matthews, 1998;

Phillips, 1997; Suchting, 1992). There is also an increasing criticism, which states that the constructivistic theory, in focusing on the individual construction of knowledge, does not take sufficient account for the situation in wich learning takes place.

I advocate a synthesis between these views in stating that all learning must be seen as part of a context in which the learning takes place, and is hence situated. The issue of an ontological reality is in my opinion not nessesarily in conflict with a constructivist epistemology. Following the Vygotskyan tradition as explained below, and supported by the Kantian theory of the "Ding an sich" (Devitt, 1991), one can well accept an ontological realism, and still maintain a constructivistic view of cognition and mental representations (Glasersfeld, 1992). Recent development in cognitive neuroscience tends to support a view of learning as the construction of mental representations to adapt to the environment (Rappaport, 1998). This construction takes place in a continuous interaction with contextual information. The epistemological view to emerge from this synthesis would be that learning is 'the situated construction of knowledge as mental representations of an independent reality'.

Language and common knowledge

Vygotsky (1986) bases his theory of the relationship between thought and language on the realist view that ontological independent objects exist. For these objects, formal expressions are introduced in the form of words that we use to represent them in oral and written language. The connection between the object and the formal expression is, however, not a direct one. Each individual 'assigns' a subjective content to the term, linking it to the object. This subjective content corresponds to the person's cognitive perception of the object being referred to.

Having established learning as a situated practice, it follows that verbal interaction plays an important role (Edwards, 1997; Mercer, 1995; Scott, 1998). A prerequisite for successful communication – and hence for learning – is that the interacting parties find a platform of 'common knowledge' (Edwards, 1990). In discursive interaction with other individuals, there is a need for a common frame of reference to give the sense that we understand each other. Since each person 'assigns' his or her own semantic content to the different terms, the subjective content will vary. Such a common frame of reference is not automatically present. This conceptual incompatibility is often not evident in a conversation – especially not when referring to relatively noncomplex phenomenons like tables or chairs. When moving on to more abstract themes, the incompatibility will be more obvious and we might even feel that we are not talking about the same thing (Glasersfeld, 1989).

Empirical basis

The material for this paper was collected from 3 different high school classes from 2 different schools. The relatively small groups of 7-9 students were attending the last of two consecutive optional courses in System Development. During the first year, the curriculum concerned with system development and databases is limited to making simple data models with up to 5 entities, using the ER (Entity Relationship) modelling notation. The implementation is done in MS Access. The second year is entirely devoted to System Development. The data models are more complex and emphasis is put on project planning and managing, as well as documentation (e.g. various analyses and reports). The tools used are still ER and MS Access as well as MS Project and MS Office. The students usually work in teams with project based problem solving activities.

Database terminology

An large number of introductory books have been published on relational databases and data modelling. Correspondingly, there are numerous sets of terms being used and different ways of defining their semantic content. In this paper I will use translations of the definitions provided in the textbooks used by the students in the study (Kolderup & Bostrøm, 1998).

A data model consists of *relation types* between different *entity types*. Each entity type has a set of *attributes*, of which one, or a subset, is chosen as identifier (*primary key)*. The primary key determines uniquely the value of the remaining attributes in a given record. Two related entity types are 'linked' by introducing the primary key from one as an extra attribute (*foreign key*) in the other. An entity type with a set of records forms a *table*, which in MS Access is displayed as a *scheme*.

For simplicity, the students – and hence this paper – uses *entity* and *relation* for *entity types* and *relation types* respectively.

Methodological basis

Measures of knowledge

International comparative studies in education have traditionally measured knowledge by students' performances on standardised tests, mainly consisting of Multiple Choice items. More resent studies have demonstrated the advantages of open-ended items, providing the possibility for diagnostic coding and analysis (Lie, Taylor, & Harmon, 1996). A problem with both these types of written tests is the students' failing ability to understand the problem when presented in writing. Students also may have problems articulating their knowledge in writing, which provides possibly biased results to the latter type. Schoultz (1999) showed that the average performance of 15-year-olds on a given problem was improved from 19% to 90% by changing the format from a written MC-item to an oral interview setting. The problem of biases and lack of objectivity in conducting interviews has also been documented (Lang & Lang, 1991; Mercer, 1995). Wanting to measure knowledge, one is faced with a number of such methodological challenges.

Short direct questions

Having placed myself in the Vygotskian tradition, focusing on the connection between thought and language, it is natural to utilise students' verbal accounts as basis for analysing their understanding. Considering both the mentioned and other methodological challenges (Peräkylä, 1997), and in order to provoke the students' immediate everyday understanding of the different concepts, I have chosen to use a minimalistic interview form with straight forward ”What is…”-questions[1]. The questions were the following:

1 What is a candidate key?

2 What is an entitisation?

3 What is a primary key?

4 What is a query?

5 What is a foreign key?

The answers to the questions were recorded and then transcribed for later analysis. Five students were interviewed individually by giving them two of the questions orally. After concluding the interviews, the whole class was given a written version consisting of five open-ended items including the two from the interviews. The students were given approximately 7 minutes to complete the ”test”, and were informed that the results would neither be evaluated by their teacher nor influence their grades.

Coding of written answers

For categorisation of the written responses, a special coding system was developed. Separate lists of terms and possible 'means of explanation' were set up for each item. The students' responses were checked against this list by marking for an occurrence of the particular notions. The following

[1] Widdicombe and Wooffitt (1995) have successfully used a similar method of short direct questions.

explanation of a candidate key is for example registered for reference to *primary key* and *alternative*, but not for *attribute(s)*, *identifier*, *uniqueness* or *record* etc.

Q1:[2] ”If an entity consists of 2 primary keys, then one will operate as a candidate key.”

For each notion on the list, the number of students in a class referring explicitly to it, was counted. This method proved to be a useful tool for identifying patterns of explanation-types both within and between groups.

Findings

The findings are divided in three sections. First I will discuss the relationship between the oral and written answers of the five students that were interviewed. This is a methodological discussion, giving an idea of the accurateness and validity of the different methods of data collection. Then the results of the written test is examined searching for ’within group similarity’ to support the theories of ’common knowledge’ (Edwards & Mercer, 1987) as described earlier. These sections both focus on methodological aspects of the study, whereas the last section deals with more theoretical epistemological aspects. A framework for classifying different types of understanding or knowledge is outlined and used to describe the types of knowledge displayed by the students in this study. This framework may function as basis for future research in the ‘didactics of informatics’.

(1) Oral vs written answers

The general impression is that the level of correctness is approximately the same in the two formats. The written responses are generally shorter and more precise than in the interviews. The latter, though, can be more elaborate. To put in writing an articulated answer containing relevant arguments is difficult (Schoultz, 1999). High school students in general also have little experience in formulating such precise explanations. This makes their accounts seem arbitrary in regards to which aspects of a phenomenon is included or excluded in their explanations. In the oral answers this problem is sometimes ‘solved’ by making multiple elaborations or referring to examples as part of the explanation. We shall examine the responses from one of the students.

ORAL INTERVIEW	WRITTEN TEST
I: What is a foreign key? S: Foreign key, it is e:h what y’use i:: (0.2) n’a data modell (.) to con:nect (.) e:ntities, (0.2) or (.) to eh to: (0.1) >get the connection between the entities of the relation< (.) deside it.	Q: What is a foreign key? S: A foreign key is nessesary to get the relations between the entities correct, such that there is a connection between the entities that are connected.
I: And then one more question, What is a query? S: A query is a scheme >or not a scheme< a:: e:h thing you make in Access to:: (0.2) make schemes out of it. (0.1) or (0.4) >my God ho’do’I explain that?< (0.3) You: e: og and choose e: cert- s:ome certain inf’mation from (0.3) ↑scemes (0.2) a:nd tables (.) for then to: (0.1) make a: (.) new scheme out of what you:	Q: What is a query? S: In a query one can define the different instances one wants to have in a scheme. One takes the instances from tables or schemes and set the conditions you want there to be.

2 ’Q1’ indicates that the answer is given to question number 1 (see list of questions above).

ask for in the query= I: Uhm S: =You: (.) define what you want to have in the scheme in the query.	

Table 1: Transcription and translation[3] *of one student's oral and written answers respectively to the same two questions.*

The two explanations of *foreign key* are quite similar. The oral account being a grammatically less structured statement. This should indicate that the format of the test is of little significance for the outcome in this case. But through a careful transcription of the oral answer, we see that the text carries quite a bit of additional information. One example is the hesitation initiated by the 'or' in the fifth line of the response, indicating an uncertainty and a wish to clarify the explanation further. This is followed up by repeating the initial explanation in the following two lines. Hence – what, in the written response, seems to be a firm mental representation of a foreign key, may not be as certain after all.

In the two accounts of what a *query* is, we find a similar pattern. The main content of the two responses is based on more or less the same references and the same means of explanations. An important difference lies in the reference to setting conditions, which is only made in the written answer. Apart from that, the difference mainly lies in the manner in which the account is delivered and the additional information available from the transcript of the oral answer. We notice that the student initially makes a wrong statement and then corrects himself immediately. Such spontaneous mechanisms would hardly appear in a written reply. Then again there is a line starting with 'or' followed by a more explicit statement of uncertainty. The second explanation (lines 7-12) is an elaboration and clarification of the initial attempt at answering. Then finally in the last two lines a third version is provided. This one is shorter and the key words are all emphasised. It may seem like this last part is initiated by the interviewers 'Uhm', but notice the immediateness of the transfer from the word 'query' to 'You:'. It is therefore more likely that the clarification is motivated in the student's need to sum up.

This brief comparison between the oral and written responses from one of the students indicates that there is little difference in achievements on these kinds of direct questions. The additional information available in the oral answers can be valuable, whereas the written version enables collection of a larger body of empirical data. It may therefore be fruitful to use both kinds of data collection simultaneously also in the future.

(2) Similarity within groups

The material includes clear examples of similarity in the means of explanation within the groups. This is evident in terms of which properties or words are included in the explanations as well as which are excluded by the students in a particular group. Differences between the groups support this finding further. Even the two groups having the same teacher display significant differences.

In the explanation of candidate key most of the students in classes B and C mentioned the *primary key*, while only the students in class C explicitly stated that this possibly came in addition to the selected primary key for the entity. It is tempting to think that the students in this class had a generally higher level of knowledge. The distribution of answers to question 2, about entitisation, however, illustrates that this is not necessarily so, since 4 students (3 of the same) from this class has not understood what an entitisation is.

[3] The interviews were transcribed in Norwegian using the conventions developed by Jefferson as described in Potter (1996). The analysis of the material was mainly completed prior to the translation to English.

Q	Notion	A	B	C
1	Candidate key being possible *primary key*	2	6	5
1	Possibility of *multiple* candidate keys	1	0	5
2	Entitisation when *many-to-many*	4	7	3
2	Entitisation is *data modelling*	1	1	4
3	Primary key as *identifier*	7	2	5
4	Query used to make *schemes or reports*	6	6	6
5	Foreign key *connecting/binding*	5	2	2
5	Foreign key linked with *primary key*	0	7	7
5	Foreign key transferred by *relation*	3	7	3

Table 2: Number of students in each class that made reference to the respective notions in their explanations. Only a few of the 60+ notions on the list are included here. The total numbers of students were 7, 9 and 8 respectively. Groups B and C are from the same school and have the same teacher.

These 'within group similarities' are probably a result of classroom culture and discursive activity (Edwards & Mercer, 1987; Roth, 1995) and not of cognitive level. The shared meaning (Scott, 1998) within the classroom is even more evident when all the students in class A refer to the primary key being the *identifier*, while none of them mentions that the foreign key comes from a related *primary key* in question 5.

(3) The students' understanding

Operational and structural knowledge

The first encounter with a new concept or phenomenon will normally be in terms of operations on known entities. Through practising the skills by applying operations to different objects, an understanding of the concept as such is developed. The operation or process is then experienced as an object of its own. The *operational knowledge* is *reificated* (made into an object for further treatment on a higher level) (Sfard, 1991). What is known as operations on one cognitive level, return as objects on a higher level.

Cognitive development can be described as an interaction between the operational (dynamic) knowledge and structural (static) knowledge. In other words: Knowledge is created through an interaction between skills and understanding. A student needs knowledge of the process as well as the concept on which the process operates (Gray & Tall, 1994). Mare understanding has no value without the skills to implement it, and the skills alone, though useful in many situations, can not be seen as knowledge unless accompanied by a mental understanding of the concepts at hand.

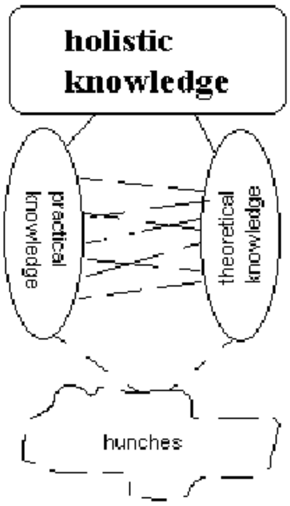
Framework for knowledge in informatics

In a former study (Holmboe, 1999), a framework for knowledge in informatics was outlined. The four types of knowledge introduced are illustrated in the figure below. This framework encompasses the duality described above and introduces two further types of knowledge, i.e. *hunches* and *holistic knowledge*.

Hunches: On the first encounter with an unfamiliar concept, one usually does not manage to grasp the fundamental idea. Little is understood, but in the intuitive search for meaning, some cognitive scheme is constructed. These vague ideas may take many different forms.

> **Q3:** “It always has to be a key in an entity and it is called primary key.”

> **Q4:** “A query is used to make it easier to make larger schemes and reports.”



The latter student shows no understanding neither of the practical or theoretical concept of a *query*. The only knowledge displayed is a vague idea that it is something used when producing reports. Another typical aspect could be that – in order to simplify – only one or a few arbitrary properties are used to describe the phenomenon at hand. Either way, a description based on an *initial hunch* is rarely very accurate.

Practical knowledge: In the 1999 study it was shown that *practical knowledge* seemed to be the typical type of knowledge for lower grade university students. The concept of Object Orientation was perceived in terms of the processes and operations performed by the programmer.

> **Q2:** “It is that you put an entity on a many-to-many relation.”

This explanation refers explicitly to the procedure performed when making an *entitisation* in the data modelling application on the computer – dropping a new entity on top of a many-to-many relation. The common factor for *practical knowledge* is that the explanations are based on skills with little reference to understanding of underlying concepts. The typical explanation tells us how something works and not why it works or what it really is.

Theoretical knowledge: To develop knowledge based on theoretical definitions, will mean trying to understand the formal aspects without a practical frame of reference.

> **Q3:** “The attribute that identifies each single record. The primary key is unique for that record.”

This description is fairly close to a formal definition. People who have *theoretical knowledge* may display a lack of ability to relate the definition provided to the “real” concept being defined. The apparently accurate understanding may just be a recalled definition from a textbook or from the teachers presentation. It may therefore be difficult to distinguish theoretical from holistic knowledge without further information about the student.

Holistic knowledge: Finally – when able to grasp the relationship between the theoretical definition and the practical implications – one reaches *holistic knowledge* as a result of interaction between practical and theoretical knowledge.

> **Q2:** “If there is a many-to-many relation between two entities, this relation has to be entitisised. The new entity will contain the foreign keys.”

> **Q5:** “A foreign key is an attribute that is a primary key in a different entity, but that you have transferred from that entity via a relation.”

Analytical comments

Referential explanations

Some answers provide direct reference to a different question. Such an answer does not by itself provide sufficient basis for a categorisation. The advantage of including several questions is the possibility to analyse such answers in connection with the related question. This especially occurred in the question about candidate keys where reference was made to a primary key.

> **Q1:** "Can be primary key."
>
> **Q3:** "The primary key is the identifier among the attributes, the attribute that is unique and only can appear once."

In this example the answer to primary key indicates that the student has a quite well developed theoretical knowledge of the *candidate key* concept. Other cases was not so accurate and could therefore indicate that the knowledge was only an *initial hunch*.

Problematic classification

Often it may be difficult to draw the line between a hunch and practical knowledge or to distinguish between practical and theoretical knowledge. The latter is particularly relevant for the three different *keys*. Many of the explanations describe what the key *is* (i.e exactly what the question asks them to do). The only process or action the students experience in relation to a primary key is choosing it and underlining the attributes in the model. It is therefore natural to expect their explanations of such phenomena to be of e more theoretical or definition-like character.

A query, on the other hand, is an operation in itself and will therefore more easily be described in terms of the practice of performing one. As many as 18 of the 24 students explained a query as a kind of tool used to make a scheme or report, which is a clear indication of practical knowledge.

> **Q4:** "A function in Access where we can collect attributes from several entities, to make schemes or reports."

It is important to notice that the framework does not present distinct alternative knowledge types. Rather, it is a continuous model in (at least) two dimensions where a student's knowledge can be more or less practical/theoretical and more or less developed towards holistic knowledge.

Conclusions

Text as representation

It is a much debated field whether oral or written accounts can be interpreted as representations of a persons mental models of the world. I have advocated such a view in this paper. This however presupposes that the students are able to articulate fairly precise what they want to say. Consider for example the following explanation of a *foreign key*:

> **Q5:** "A primary key is an attribute in an other entity than where it is a foreign key, because of a one-to-many relationship."

This student has obviously understood a lot more than he is able to articulate in writing. Strictly interpreted, the sentence is semantically nonsense, but it contains most of the properties of a foreign key. I would classify this as *theoretical knowledge* – not because I think that this student lacks personal hands-on experience, but because the way the explanation is made, is without reference to what the foreign key does.

This brings me to an important point. In classifying single answers like this, it is important to distinguish between the student's understanding and the knowledge type displayed in this single statement. In this paper I have shown examples of classification of isolated and relative short answers to single questions. To be able to analyse a student's cognitive representations, we need to collect several similar statements – both oral and written answers as well as recordings of discursive interaction in the classroom. Such material is being collected continuously from all the groups in this study and the results will be presented in a paper at a later point in time.

Implications for teaching

We have established knowledge to be based on interaction between operational and structural knowledge (Sfard, 1991). Following this, the education should aim for parallel development of practical skills and theoretical understanding. The construction of knowledge should be situated in a context with continuous interaction between practical experiences and formal representations. Language is an important component for knowledge construction. The students should participate in discursive interaction both with fellow students and with the teacher.

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