

Essential Ingredients of Literacy in Informatics

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Abstract: In 2003, a discussion about literacy in informatics was initiated in Germany. Its aim was to coin the literacy concept in the sense of OECD-PISA for the domain of informatics or computer science. To illustrate the intended concept, a few sample test items were published along with an explanation of which competencies they ask for. This proved to be a very fruitful approach towards stimulating the discussion in teacher training seminars.

With the experience of these discussions and further test items in mind, this article endeavours to strengthen the underlying theory of literacy in informatics. We claim that education which yields literacy in informatics must enable young persons to explain and understand what we call the phenomena of informatics, i. e. the appearances and consequences of informatics in every day life which need not necessarily be labelled as such at first glance. It may even be that the phenomena are a good starting point for informatics education similarly to what was proposed by Wagenschein for physics education and by Freudenthal for mathematics education. Looking at the phenomena leads to a process of modelling, another central issue in informatics education. Here, a careful distinction between modelling as a process and various modelling techniques in computer science has to be made. While the former is a creative process of thought, the latter may be useful tools for this process and play a role similar to various calculi in mathematical modelling.

Of course, in addressing central ideas like phenomena and modelling, informatics in school will have to deal with the more formal aspects of informatics such as algorithms as well, and a certain degree of instruction in computer and software usage will also be needed. Returning to the initial approach of formulating test items, these sub-categories will have a place in their own right, since items addressing them are useful in analyzing various degrees of informatical literacy.

1 Informatics and PISA

In 2003, and inspired by OECD-PISA 2000 [OE01, DBKN⁺01], a discussion about literacy in informatics was initiated in Germany. OECD-PISA defines the concept of literacy in the domains of reading, mathematics and the natural sciences. A large number of test items answered by thousands of 15-year old pupils in the participating countries served as the basis for a comparison of the achievement of different educational systems.

An interesting aspect of this approach is that PISA dismissed the principle of former international studies, such as TIMSS, to restrict test items to topics from the common denominator of the national curricula of the participants. In other words, test items from PISA may happen to be unfamiliar to parts of the test population as long as the required competencies can sensibly be asked for from 15 year olds.

In [Pu03] it was argued that radically neglecting national or — in the case of Germany — regional curricula will be the only way of achieving an assessment that measures young persons' abilities in informatics. A curriculum-oriented approach has to be ruled out because the curricula are too different from each other. Therefore, the PISA-approach was transferred to the domain of informatics, the concept of literacy in informatics was defined, and sample test items were presented.

These test items proved to be particularly stimulating for discussions in teacher training seminars as well as in university seminars on didactics of informatics. As a result, new test items were designed in these seminars. The discussion focused on the question which aspect of literacy in informatics is covered by an item. It turned out that items which started with a real-life situation were very popular. As they are most likely to test young people's capacity to use knowledge in informatics in order to meet real-life challenges, those items are very much in the spirit of PISA.

The aim of this paper is to strengthen the theoretical foundation of literacy in informatics beyond the ideas from [Pu03]. There, three classes of competencies were defined, referring to different kinds of informatics-related occupation: "application" which focuses on the qualifications needed to use soft- and hardware, "construction" which covers the skills needed to create new informatics systems¹, and "decision" for the qualifications needed to decide and reason about the use of informatics systems and its consequences. In this article, the aspect of understanding occurrences of informatics in the world — so-called phenomena — is considered instead. The goal of measuring literacy in informatics is underlying the discussion, hence sample test questions come along with the theory.

The paper is organized as follows: We start with an example of a phenomenon, formulated as a test item, followed by a general discussion of phenomena and their role in literacy in informatics. Thereafter we turn to the process of modelling which is closely related to understanding phenomena. Finally, it is argued that questions addressing more isolated knowledge and skills should also be part of a test instrument, and the construction of tests for different purposes is briefly considered.

2 Understanding phenomena: the heart of literacy

If the aim of education is to enable young persons to take part in society in an active and responsible way, which is a main aspect of literacy in the definition of PISA, then the touchstone or the heart of literacy with respect to informatics is whether someone understands the occurrences of informatics in everyday life and society. It will be insufficient to merely have some internal knowledge of informatics that cannot be linked to the world.

We call the occurrences of informatics *phenomena of informatics*. This section gives examples, three categories of phenomena and a discussion of their relevance in teaching and assessment.

¹See the Appendix for a definition of the term "informatics system".

An example

Let us start with a real-life example², a situation taken from the checkout of a supermarket. A photograph shows a bottle of lemonade which is being pulled over a sheet of glass, i. e. the scanner of the checkout. Figure 1 shows part of the text that comes with the photograph.

Another question gives an informal algorithm (i. e. in natural language) for the process of checking out and asks for a suitable extension to include a “buy two, get one free”-offer. Finally, there is a question on how the storekeeping and the checkouts can be combined. Here, the required data structure is to be modelled.

Joanna is buying a bottle of lemonade in a large supermarket with many checkouts. The cashier pulls the bottle over a sheet of glass. There is a “beep”, and the price of the bottle is displayed.

Question 1:

Where can you find the price of the bottle? Mark *all* correct answers.

- The price is included in the barcode on the label of the bottle.
- For each barcode, the price is stored in each of the checkouts.
- The price for each barcode is stored in a central computer system.
- The cashier enters the price using a keyboard.

Question 2:

The supermarket wants to sell the lemonade as a special offer at reduced prices.

The former price of EURO 0.98 is reduced to EURO 0.78.

What has to be done? Mark *all* correct answers.

- The bottles need new labels, stating the new price.
- A large number of bottles of this lemonade has to be stocked up.
- The price must be updated in every single checkout.
- The new price must be entered into the central computer system.
- The cashiers need to learn the new price by heart.

Figure 1: Test-Items “Supermarket checkout”

The example of the supermarket shows that there is a lot of informatics in everyday life. The seemingly simple question of where the price is quoted may lead to the discussion of the lookup in a database with barcode-price-pairs. As the questions indicate, a connection to networked computing, algorithms and data modelling is also feasible.

²This example was developed by Andreas Schwill and the authors.

Three categories of phenomena

The fact that teachers like and invent test items of this kind shows that teachers understand and appreciate the notion of literacy as defined in PISA, i. e. the ability to complete tasks relating to real-life, depending on a broad understanding of key concepts, rather than the possession of specific knowledge [DBKN⁺01, p19]. Teachers realize that these real-life settings are well known to their pupils. They believe that pupils should be able to cope with these tasks, even if their actual lessons do not yet foster the real-life approach. We will return to the impact this may have on informatics education below.

A closer look at various test items featuring real-life situations suggests that informatics is incorporated in three different flavours. We therefore distinguish the following *phenomena of informatics*:

1. Phenomena that are directly related to informatics systems. They occur when a person consciously uses an informatics system, such as a word processor. A part of the display on the screen, a feature of the software or a certain behaviour of the system may often be happily ignored without losing the basic functionality of the system. A deeper understanding of the fact (based on knowledge in informatics), i. e. the ability of reasoning about and explaining the phenomenon, however, makes using the system easier, more efficient and maybe even more pleasant.
2. Phenomena that are indirectly linked with informatics systems. They occur in everyday situations whenever informatics systems are involved without being apparent at first glance. Some of these phenomena can even be quoted without reference to an informatics system (remember the example above: “Where can you find the price?”). The connection is then made by analyzing the phenomenon.
3. Phenomena that are not connected to informatics systems but have an inherent informatical structure or suggest informatical reasoning. Examples in the area of sorting and searching, which happen to be major tasks not only in informatics, abound. A person without informatics education may well be able to cope with these phenomena, she may even develop pieces of theory of informatics from a phenomenon, albeit in a less formal way.

Although sample phenomena were briefly indicated in this list, we will now discuss each kind of phenomenon on the basis of a more explicit example.

1. A phenomenon known to young persons is that it cannot be guaranteed that a short message (SMS), sent with a mobile phone, arrives at the mobile it is sent to. Although the loss of an SMS may not happen very frequently, any particular instance of this phenomenon can be extremely annoying, and it is only natural to ask why this can happen.

This phenomenon is directly related to the informatics system “mobile phone”. It matches our intention in various ways: First, it is relevant to pupils of secondary school as they often make extensive use of the short message service. Second, addressing this issue opens an important part of informatics, namely the question of

networking and protocols. Finally, and closely linked with the importance of the networking issue, the informatics addressed is not only important for informatics as a scientific discipline, but it allows to make connections to other occurrences of informatics in the pupils' lives, such as linking computers locally in "network parties" or the various uses of the internet.

2. As indicated, the supermarket scenario from above is a phenomenon of the second type. Although it is clear that computers are involved in modern checkouts, the shopper does not need to be aware of this. He may have a naïve understanding of the checkout being a large electronic calculator, and there is no immediate need for questioning this. But what if the price quoted at the shelf is different from that on the receipt? Will it be wrong at all checkouts? Is it all right if the complaining customer is reimbursed and no further action is taken?

All of this leads to an analysis of the background, and, depending on the depth of analysis, one has to deal with database systems, networked computers or algorithmic representation of processes. Again, these are important parts of informatics, the phenomenon is relevant in everyday life, and the issues addressed are not isolated but open for links to other occurrences of informatics. Furthermore, it must be stressed that the combination of background knowledge from informatics and the skill of applying this knowledge to the checkout-example is the kind of qualification that is essential for full participation in society.

3. For the third kind of phenomenon we pick up the idea of sorting and searching, which is important in many situations. Imagine someone playing a card-game such as bridge. Once the cards are dealt out, every player has to sort the cards in her hands. Players have different strategies for this, which amounts to defining different orderings on the set of cards. In the case of (younger) children with small hands, one can also observe different "algorithms" for sorting the cards, e.g. by using stacks for every colour, sorting within each stack and then merging the four stacks by concatenation.

Analyzing situations like this appears to be valuable in the learning process because pupils can (re-)invent parts of informatics. They may achieve results which are in fact "state of the art" in informatics, namely in those cases where the common sense solution is what is being used. Or they may find a good starting point for further discussion.

An example for this, and another phenomenon of the third kind, is the travelling salesman problem, the relevance of which is easily understood by pupils. Often a first "common sense" solution is the "next neighbour"-strategy. This is easily revealed to lead to different results depending on the starting point. Thus, a discussion on other strategies, correctness issues (does the strategy lead to an optimum?) and complexity may follow.

The importance of phenomena in the education process is not a new idea. Wagenschein [Wa76] pointed out that studying phenomena drives the process of learning in physics, and

Freudenthal [Fr83] claimed that the learning and teaching of mathematics has to start with the phenomenology of mathematical structures.

In a similar way we propose to take phenomena as starting and focal points in informatics education in school. As the examples demonstrate, phenomena allow a wide range of issues in informatics to be addressed, and they foster mental links between different areas. Of course the phenomena have to be carefully chosen in order to establish concepts of informatics, and after an initial analysis one has to free oneself from the particular setting of the phenomenon in order to address the informatical contents in a broader way. This may lead to doing informatics seemingly for the sake of itself for a while. It would however be splendid to see (possibly another) phenomenon thereafter that can be explained with the newly acquired knowledge.

There are, admittedly, also critics of the phenomena-driven approach (e.g. [Mu01]). One of their major points is that there are deep results e.g. in physics which are not accessible by phenomena but by strict adherence to theoretical, maybe abstract reasoning. This may also be the case in informatics. Were this only restricted to informatics for the specialist, we might ignore it. But e.g. results from theoretical informatics about complexity and computability are enlightening for everyone since they may correct wrong beliefs about the possibilities of computing. In so far, we admit the need of parts of a curriculum that can hardly be accessed by phenomena. However, even in these cases one might find phenomena that work as openers for the field. (Consider the next-neighbour strategy for the travelling salesman problem which by no means addresses the P vs. NP issue.)

We argued that phenomena are desirable as an element of informatics instruction. Independently, and in the context of this article, more importantly, we claim that—as indicated above—understanding phenomena is a core element of literacy. What is really wanted as an outcome of the educational system (and what PISA defines as literacy) is that young people are able to use their knowledge and skills in everyday situations and that they can make wellfounded judgements in questions where information technology is involved, be it for their personal use or in the context of society. For this, formal knowledge or the ability to reason within the scientific framework of informatics will not suffice. It is essential to make the connection to the occurrences of informatics, i. e. phenomena, if these goals of education are to be achieved. Therefore, any instrument that tests competencies of pupils in informatics should have a large portion of phenomenon-based test items.

3 Modelling skills

Modelling as a process

A person with a high degree of literacy in informatics will understand phenomena on the basis of a comprehensive knowledge in informatics and high skills in connecting this knowledge and the real-life occurrences of informatics. In many cases this will not only involve finding the connection but there is some work to do on both sides, the side of informatics and the side of real life. Together, these pieces form a *modelling process*.

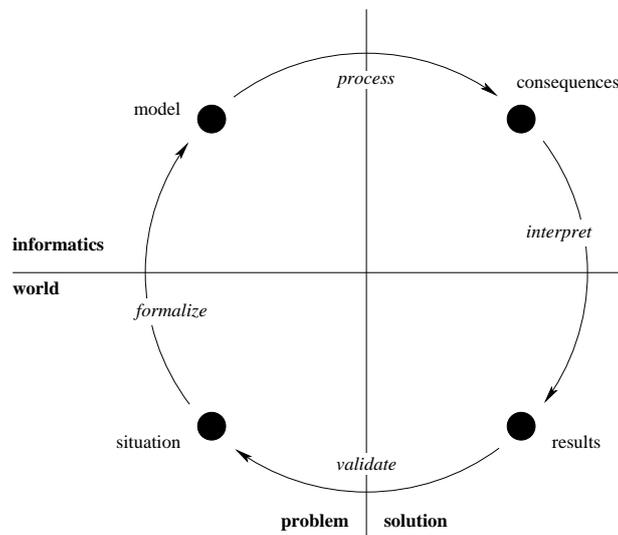


Figure 2: The process of modelling in informatics

The process of modelling is well described in [DBKN⁺01, p143] for mathematical modelling, and it is very much the same for modelling in informatics (cf. Figure 2, adapted to informatics from [DBKN⁺01, p144]): Starting on the side of the “world”, one has to formalize the situation, i. e. translate a real-life situation into the language and thinking of informatics which yields an informatical model. Within the side of informatics, the model is processed further, be it by implementing it on a computer and running a program or by some sort of reasoning about the model. In either case, a result in the language of computing is achieved. This must be interpreted within the original setting from the “world”, leading to a solution for or answer to the real-life situation. Finally, this solution must be validated with respect to the initial problem, and possibly one has to do these four steps once again in order to improve the solution.

Ideally, the cycle of modelling includes the choice of the instrument or technique for the step of formalization. After all, phenomena have no label attached saying e.g. “use an entity-relationship-diagram to understand me”. In order to choose an appropriate modelling technique, a person must have a large repertoire to choose from. This is where the necessity of learning and teaching different techniques of formalization arises.

As a matter of fact, many of them happen to have the word “model” in their name, and the word itself is widely used in informatics (cf. [Th02] for a survey). Often it is connected with special techniques of mapping “the world” to a formal system. Both, the formal system and the specific representation of “the world” within the formal system, are called a model (e. g. the entity-relationship-model as a system using boxes and diamonds with their respective semantics and a concrete ER-diagram for, say, the situation of a public library). Unless one wants to create a new modelling technique, the knowledge of techniques like this is needed to model aspects of the world, but bear in mind that the word “model” does

not need to occur in the technique's name. Sometimes simple things, such as the rule of three in mathematics will do the job without having an impressive name. So, within an informatics lesson, the achievement will not depend on the formalization technique being called a "modelling technique". What is important is that the modelling techniques are used to highlight the modelling process. So a foundation for general modelling skills can be laid, and a piece is added to the repertoire of techniques the learner will later depend on.

Addressing specific modelling techniques — an example

Even with a boost in informatics education, it will be unrealistic that everyone knows about every single technique of formalization and can do the rest of the modelling process in every case. But with the separation of activities from Figure 2 we can pick out parts of the modelling process. We can construct test items that ask if someone can do the processing of a model that is given. Or we can ask for a suitable formalization of a situation in the world without going on to the processing etc.

Another way of restricting the complexity of a question is by explicitly giving the intended formalization technique (though it excludes those who do not know this particular method but could have chosen a different one).

Phone call to a friend

You want to make a phone call to your friend. There are several actions needed to do so, such as picking up the receiver, dialling the phone number, stating your name etc. The actions take place at either of the two locations "your home" and "home of your friend".

.....

your home	home of your friend
<p>pick up receiver</p> <p style="text-align: center;">↓</p> <p>dial number</p>	<p>Question:</p> <p>Think about the actions needed from picking up the receiver to finishing the call. Complete the sequence diagram by filling in the actions and connecting them through arrows.</p>

Figure 3: A modelling task

In the example it is assumed that persons being tested know about sequence diagrams. Then the task is to find appropriate actions at the two locations and the sequence in which the actions take place. There is not “the” right solution because the granularity of actions may differ. A coding scheme for the evaluation should reflect this and group possible answers accordingly. Of course, one can think of variations of this test item, making the item harder or easier. It will probably be easier if the actions are explicitly given and only the correct sequence must be constructed. A more demanding version might ask for a graphical representation of the actions needed to complete a phone call without referring to sequence diagrams or giving the initial diagram.

We do not declare ourselves in favour of one of these variants. The choice will depend on the role of the item within a test. In order to test the knowledge about the particular modelling technique of sequence diagrams, one may give more details. A variant with less details given focuses on the ability of modelling a situation regardless of the technique used.

4 Knowledge and skills in formal techniques

Full understanding of a phenomenon will often be paired with a good command of modelling as a process. A restriction by explicitly stating the intended modelling technique shifts the focus from the problem to testing whether this particular technique is known and mastered. In order to get a diagnostic instrument for the outcome of an educational system with respect to informatics, one might consider further restrictions: one can ask mere knowledge questions and test the skills in formal techniques that are needed as a small sub-part of some modelling process.

Examples of knowledge questions

Knowledge questions may ask if someone is familiar with the terminology of informatics or if he is able to choose an appropriate application to complete a task:

Knowledge: What is a login and why/and for whom is it useful?

1. Which data is transferred when you log in a computer system?
2. Give an example of a “good” and a “bad” password. Explain your choice.

Choice of application: You want to share the solution to your maths homework with a friend who lives too far to simply drop in on. How can a computer help you?

Testing skills in formal techniques

Skills in formal techniques are needed at various steps of the modelling process. They also build the foundations for continuing education, in particular for those who aim for a profession in the field of informatics. Examples for questions addressing these skills are:

Programming skills: Encode the algorithm shown in the Nassi-Shneiderman-diagram in a programming language of your choice. (The question would have to show a diagram.)

Computer usage skills: You typed a text with 4375 characters. How can you find out, how large it will be when saved to a disc?

5 Consequences for test-construction

Literacy is not something a person has or has not. Instead, there are various degrees of literacy, and one aim of a test instrument may be to determine the degree of literacy in informatics a person or a whole test population has. It may even be that literacy in informatics is a multi-dimensional concept. E.g. there might be the two dimensions “ability to link formal knowledge to real-life situations” and “comprehensive knowledge within informatics”. While the former seems to be the kind of literacy needed to navigate through life, the latter is certainly needed for those who want to continue their informatics education and possibly earn their living in the field of informatics. However, it may also turn out that the two aspects are closely linked in that whoever excels in one aspect does so in the other. The decision on the dimensionality needs empirical data and cannot be made at this point.

A second aim of a test instrument may be to get information about the educational system. In the case of informatics, it would be highly interesting to compare the curricula (if informatics is part of the curriculum) with the abilities of the test population. Will there be isolated pieces of knowledge or is the knowledge interrelated? Do pupils have competencies as intended by the curricula or do their competencies exceed the curricula in some cases? And of course: what is the *de facto*-status of informatics education within a system, does it build a good foundation for further development?

Depending on the primary intention of a test, the aspects of phenomena, modelling, and knowledge and skills in formal techniques will play a different role. This should be reflected in the test. As a rule of thumb, the share of “knowledge and skills”-questions may be larger in tests for a single class and a short period of time, where the test aims at examining if the class has learned a specific part of the curriculum. If the test covers a longer period of time, any informatics curriculum should be expected to contain some modelling and, hopefully, phenomena. So the focus of the test should shift to these aspects in this case as well as in the case of a larger test population where a common curriculum cannot be guaranteed.

For large scale tests such as OECD-PISA, further aspects have to be considered: in order to measure different degrees and possibly different dimensions of literacy in informatics, the test items must cover a wide range of difficulties. They must be well distributed between different classes of competencies (such as “application”, “construction”, “decision”, cf. [Pu03]) and different aspects of literacy.

In the light of the discussions we had in teacher training seminars, one of the most no-

ble tasks will be the construction of phenomena-oriented items which require low reading competency and address some central aspect from informatics. The authors welcome any contribution to this and will be happy to discuss further ideas towards setting up an evaluation scheme for the achievement of informatics in school.

Appendix

Informatics and informatics systems

In this article, the term “informatics” is used in the sense of “Informatik” in German or “Informatique” in French, although it is not yet widely used in the English language, where the words “computing” or “computer science” are more common. Furthermore, we use the term “informatics system” as defined in [CS01, p301] (translation by the authors):

An *informatics system* is the specific combination of hardware, software and networking facilities needed to solve some application problem. The term includes those non-technical issues and their solutions that arise from embedding the system into the application area, in particular questions of system design, user training, security and consequences of using the system.

Informatics in this setting is the scientific discipline addressing the construction and design of informatics systems.

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