Särinmer

A computer model for diabetes education

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Abstract

In diabetes mellitus pancreas fails to produce insulin enough to maintain tissue utilisation of blood glucose. To maintain a normalised metabolism many diabetic patients have to provide insulin from injections or an infusion pump. The disease affects some percent of western population.

The insulin provided by the patient has to be adjusted to food and physical exercise. This may be achieved by following rules from diabetes professionals, but also by self learning how food, insulin and physical exercise interact and influence the blood glucose. It seems that the patients who have this intuitive knowledge of the interactions are the ones who manages their diabetes treatment best and have the highest quality of life. The learning have, however, been performed by trial and error — to the price of severe inconvenience and bad metabolic control.

A combination of computer science and diabetes physiology has resulted in the computer program Särimner. It is created to give the user a possibility to experiment with diabetes treatment. Food, insulin and physical exercise may be varied and the blood glucose is calculated. Särimner provides a short-cut to obtaining knowledge since it allows experiments, stimulates discussions and let the user by himself formulate and test hypotheses regarding experienced problems. Since Särimner may be adjusted to look more alike an individual, the experiments are driven by the user's own curiosity. He may experiment with situations of importance to himself and finally make himself the expert of his own treatment situation.

The way Särimner is designed, allows interested users to get "under the skin" of the model and study details in the physiological processes. This transparency makes it possible to search for explanations to treatment phenomena. One drawback with the model is that it is quite complex and requires some knowledge from a user with the ambition to understand all the processes.

To measure the impact of Särimner training, 11 diabetic teenagers were evaluated with respect to metabolic control, emotional adjustment, locus of control, self-esteem and ability to discuss treatment phenomena. No control group was possible to recruit.

The results indicated that the education had been useful for some individuals. They increased their knowledge and ability to discuss treatment situations, their sense of control over the diabetes treatment, their self esteem and furthermore Särimner education may have caused a reduction of diabetes related stress. However, an increased level of diabetes related guilt did occur in some individuals, possibly due to either increased knowledge or a more internalised locus of control.

The models ability to look alike reality is depending on for which purpose it is used. Even though it would be theoretically possible to fit the model to an individual, such an experiment would not be performable in reality since Särimner requires input data from the physiology which is impossible to measure. The properties of the model are, however, adequate for illustrating several treatment situations on a phenomenological level.
The thesis is based on the following papers:


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Disposition

Chapter 1, Introduction, contains some basics about the potential of pedagogics in health care, treatment of diabetes, feedback control, process of learning and purpose of process learning.

Chapter 2, Methods, shortly describes the idea of the diabetes simulator and the structure of Särirmer.

Chapter 3, Analysis, presents some physiology experiments with Särirmer to describe situations possible to illustrate to a user. Experiments with IDDM- and NIDDM physiologies are presented, as well as experiments with a non diabetes physiology.

Chapter 4, Discussions, covers some questions which often appear when Särirmer is presented to users or health professionals.

—"Why is it necessary to use a computer?" Those who wonder why may have benefit from reading chapter 4.1, More about learning, which discusses learning in abstract situations, e.g. in understanding of- and manipulating a process.

—"Does Särirmer behave like reality?" is another key question. The discussion concerns the ability to correspond to a real human physiology. The question is not really answered in chapter 4.2, Knowledge and models, but the discussion may inspire a reader to better specify the question to cover the intended aspects of "behave" and "reality".

—"Does Särirmer work?" is another interesting question. Särirmer is designed to create a better understanding for diabetes treatment, in the sense that a user would obtain an increased freedom of action. The result would be measured in patients by either increased metabolic control or increased quality of life. Chapter 4.3, The First Särirmer Pilot Study, is a summary of a small evaluation of 11 diabetic teenagers which participated in some computer training sessions with Särirmer.

Chapter 4.4, The Health Professional Test Pilots, covers some results of evaluations made by health professionals.

—"Is Särirmer good?" may refer to modelling-, technical-, impact- and a lot of other aspects of qualities. Chapter 4.5, About quality, is written to give some tools for analysis of different perspectives of quality.
1 Introduction

1.1 Cure, care and core

Hippocrates — the "father of medicine", an ancient Greek living on the island Kos around 300 b.c., said it was better to know what kind of person who had a disease than what kind of disease a person had.

Louis Pasteur and Claude Bernard, two of the giants in biology during the 19th century were discussing whether the most important factor for diseases was the "soil" — the person — or the "seed" — the bacteria. On his death-bed Pasteur admitted that Bernard was right, and concluded: "It's the soil".

Discussing health sciences today, one may encounter the model of Lydia Hall [1] (fig 1).

![Fig 1. Cure, care and core.](image)

One interpretation of this symbolic figure in a context of diabetes treatment may be that "CURE" represents medical "tools", i.e. medical technologies such as diagnose measures and pharmaceutics for treatment. "CARE" is what's provided by medical staff — bodily care, routines, prescriptions and actions including use of the "tools". "CORE", at last, is the inner properties of the patient — the desire to be healthy [2].

The three conceptions are overlapping — some elements corresponds to two of the categories or to all three of them. Occasionally CURE activities are characterised as technological, corrective, focusing the disease, while CORE activities are pedagogical, preventive and focusing the healthy and sound.

In future, scarce and shrinking resources in public health care may detain people from CURE resources when they have need for it. This would enhance the interest for CORE activities, which can be performed in less rigid and time critical forms than CURE.

This work suggests computer simulator training as one way to increase understanding of insulin treatment of diabetes mellitus, a disease affecting some 2-4 % of western population. The late complications of insufficiently treated diabetes cause severe inconvenience and too early death for the patients, in the end paid for by society. On the contrary diabetes mellitus is a disease with considerable CORE possibilities, since the treatment mainly is performed by the diabetic patient himself.
1.2 Managing blood glucose control

1.2.1 Diabetes mellitus

In diabetes mellitus the pancreas fails to produce insulin enough to maintain tissue utilisation of blood glucose. Therefore a diabetic patient have to provide insulin from an external source, by insulin injections or by means of an insulin infusion pump. The target is to achieve and maintain a normalised metabolic control, which is reflected by the concentration of glucose in blood.

The insulin dosage is adjusted to the meals as well as to the basal needs. Physical activities, food composition, stress, infections and avoidance of insulin deficiency has also to be considered. In a non diabetic individual, all these delicate adjustments are made automatically by the pancreas. To achieve a decent substitute, four daily injections or more are usually required.

To the best of our knowledge today it seems that the optimal treatment goal is a normalised metabolic control. If this condition is obtained, the diabetic patient may choose to regard himself as healthy, with the difference that he has to use external insulin and other supportive measures, and that he has to perform the "control thinking" by himself.

1.2.2 Control theory

Someone has said that "Control theory is the art of achieving a required output with a reasonable control input, despite influences of disturbances and despite incomplete knowledge about the system characteristics".

Applied to diabetes treatment the sentence would read "Diabetes treatment is the art of maintaining a good metabolic control with means of external insulin injections and diet, despite influences of physical activities, stress, infections etc and despite an incomplete knowledge about insulin release and other characteristics of the metabolism". To all this, quality of life aspects has to be considered.

1.2.3 Use of feed back

In controlling a "fuzzy" process or a process subject to disturbances a technique called "feed back" can be used. Feed back means that the actual state continuously is compared to the preferred state, influencing the control action if the result is not to full satisfaction (fig 2).

![Feedback Diagram](image)

**Fig 2. Feed back.**

A feedback application, which also will be discussed later in this text, is the art of riding a bicycle. This requires the balance to be kept in the first place. Let's pretend this is done only by using the handle-bars.
If the equilibrium (actual state) is not fully maintained (preferred state), this is recognised (feedback) by the balance sensing mechanisms in the brain (controller) and the arms are told to turn the handle-bars (control signal). If this is done the right way, the equilibrium is maintained throughout the bicycle ride. This control mechanism actually works even if the road is bumpy or if the favourite bicycle is replaced with a different one.

1.2.4 Feed back for controlling the metabolic balance

The bicycle riding may be compared to the blood glucose control. The concentration is measured with a blood glucose meter, and can be influenced by food intake and insulin injections.

The digestion produces glucose and releases it into the blood, making blood glucose concentration rise. If insulin concentration is high enough, glucose is absorbed by muscles and other tissues, making the blood glucose lower. An extremely simplified feedback control strategy would be: Check the blood glucose level. If it is high, add more insulin. If it is low, add more food.

Evidently it is not quite as simple as that. The blood glucose concentration is a balance between glucose released into- and absorbed from the blood. The insulin level as well is a balance between released insulin from an injected depot and insulin utilised by the tissues. Consider the metaphor model below (fig 3).

Without insulin

With insulin

Fig 3. Metaphor model of insulin influence of blood glucose level.

Food digested to glucose is released into the blood as a soft flow that may last for several hours. Injected insulin is, after a short delay, released from the injected depot in a similar way, causing a similar flow that lasts for several hours. The higher the insulin level, the greater the absorption of glucose out of the blood. Therefore the control action can be regarded as controlling one flow with another flow.
1.2.5 Feed back — and then?

Actually, the process is even more complicated. Insulin has two different actions, one to facilitate utilisation of glucose, one to prevent spending short time glucose storages. Lack of insulin makes the cells unable to utilise glucose. The body misinterprets this as lack of glucose, causing the liver to release its glycogen storages and then to produce glucose from triglycerides and proteins.

Furthermore food composition, physical activities, stress, infections influences the insulin action. A set of rules or a formula composed for obtaining metabolic control has to be extremely complex to handle all this.

So, what is actually needed to be a skilled diabetes treater? More knowledge about physiology? A more complicated block diagram or a metaphor model? Mathematical equations describing the dynamics? More rules of thumb?

To summarise — chapter 1.2 may have demonstrated that it is not enough with theoretical knowledge when controlling a complicated process in real time. There is a need for knowing what to do and when to do it — experience.

1.3 Process learning

1.3.1 Feed back for controlling the controlling — learning

How is experience obtained? One famous method is "trial and error", experience obtained by experimenting. Often enough the most important factor — the feedback — is not mentioned. It is the reflection over the feedback that makes the "error" influence the next "trial".

In bicycle riding, "trial and error" is what it's all about. Is is hardly possible to read about riding a bicycle and succeed in learning. No one can talk, threaten or reward someone in to it. The success comes from trying it — and learn to from the mistakes.

Could this be done in some other way? Bicycle training — hardly. Training in other process operations — yes, e.g. aircraft pilots or nuclear plant operators. It would be possible to teach aircraft pilots different manipulations and make them fly only according to a check list. Similarly nuclear plant operators may run a whole plant only from rules in a handbook.

However, unusual or unexpected situations may occur making the state of the process hard to interpret. In such situations it is crucial that process operators have the right understanding of the process. Operators may use check lists to avoid forgetting important actions — but relying only on an ability to follow instructions has proved to be dangerous [3].

It is no coincidence that aircraft pilots and nuclear plant operators are trained in simulators, in which they can learn from mistakes without risk for real accidents. Someone has said "The source of human knowledge is reflecting over ones actions".

1.3.2 Interaction between theory and practice

Hitherto it may have seemed that theoretical knowledge is of none or peripheral value. An abstract metaphor model with a verbal description has been compared to bicycle riding skills, maybe implicating that diabetes treatment is possible to learn in a couple of hours. It is not so. Theory and practice are both needed to build useful knowledge. The best effect are obtained if both are combined in an interactive way.
If one has a theoretical background and make experiments, observations are more easily understood and put in a context. This makes the theoretical knowledge more intuitive and "topographic" — it is reformulated from written text to something like a map or a picture. This reformulation is done during the "reflection" activities.

If one has experience and encounter theory or facts, theory is more easily interpreted and assimilated into the topographic form. Also in this case reformulation is done during the "reflection" activities.

The interaction between theory and practice is fundamental and makes knowledge "lift itself in the boot straps".

1.4 Teaching turns to learning

1.4.1 Diabetes education

Traditional diabetes treatment was built on the authority of the doctor. This was natural, because the doctor had knowledge and some experience. The doctor prescribed regular meals as well as time and dose for each insulin injection. To provide feedback the patient was supposed to make urine- and blood glucose samples and write them down into a note book.

One problem was that the patient sometimes wanted to eat the same type of food as his friends or his family ate. This could result in periods of disturbed metabolic balance, which made the doctor disappointed. The patient soon learned that samples were "good" or "bad" and incidentally "forgot" to take samples or to write them down in the notebook when they were "bad".

It became evident that some diabetic patients learned how their insulin physiology worked and by themselves accounted for their own insulin treatment. Often enough, it was these street-wise patients that managed their diabetes best and had the highest quality of life. The learning was built on "trial and error" and included in most cases caused long periods with bad metabolic control.

This suggested that diabetic patients with some years experience could put themselves in charge of their insulin treatment. Health care professionals would then have a support function rather than decide about the insulin dosage [4]. One new challenge for diabetes health professionals was hence 'diabetes education'.

1.4.2 Objectives for education

Teaching in its classical form means a teacher supplying facts and verbally formulated knowledge to a more or less interested audience. This leads to well educated diabetic patients but not necessarily patients having better metabolic control.

Knowledge can be coarsely categorised into three levels.

First level: A skill in denominating objects and phenomena
Second level: A skill in understanding the nature of phenomena
Third level: A skill in acting upon the nature of phenomena

In our society, knowledge in general terms is synonymous with the first level. Testing knowledge is easy — school tests and quiz competitions can serve as examples. The tests make it easy to agree upon whether an expert really is an expert.

Knowledge in terms of the second level can be more difficult to judge or criticise, and testing is hence a subtle task. Experts addressing us e.g. in TV express opinions about economics, environmental pollution or wealth. We see that neither economics, environmental pollution nor
wealth always develops the way experts predict, but the experts always have explanations why it
doesn’t. Some of us regard them as experts, others don’t.

A skill in acting upon the nature of phenomena is generally estimated through considering the result
of the acting. Examples from everyday life is, enjoying a piano concert, being impressed by good
professional work or envying a sport athlete. If the result is mediocre, this can be caused by a
number of factors from understanding of the process to sleight of hand — not to forget lack of
motivation.

In consequence with this diabetes education would give a diabetic patient the power to act
successfully upon his diabetes. He may not have to know theoretical facts, but rather to know how
to obtain a normalised metabolic control while living the life he wants to live.
2 Methods

2.1 The use of a diabetes simulator

The subtle processual characteristics of diabetes treatment combined with the possibilities of trial-and-error training lead to the idea of a diabetes simulator. The diabetes simulator may be used for learning how food, insulin and exercise interact and influence the blood glucose.

There are several advantages with a diabetes simulator compared to training in real life.
• Fast. A simulation of 24 hours takes only seconds.
• Safe. Mistakes is simulated and analysed without inconvenience or danger.
• Repeatable. A situation can be saved and later recalled.
• Controllable. Conditions and characteristics can be widely changed.
• Clear and distinct. Diagrams and pictures instead of text.
• "Magic" first. Traditional media like written text have to serve framework and descriptions of the functional mechanisms before the "magic" — the significance for the reader — appears. A simulator works the opposite way. The "magic" appears immediately and an interested user can then study functional mechanisms and framework (see discussion about empirical and theoretical knowledge above).

The value of controllability and clearness in the model may be discussed since reality does not offer the same transparency, i.e. some conditions can not be influenced or measured in real life. These advantages are however useful for theoretical purposes or for "what if..." experiments.

2.2 Särinmer

2.2.1 Block diagram

The development of a computer model of the diabetes metabolism was started in 1987. The aim was to create a "flight simulator" for diabetes treatment training — a computerised learning situation good enough to illustrate most common phenomena in diabetes treatment. The entire physiology from meals and digestion, transport, storages to the utilisation of glucose and fat in the body's basal metabolism and work from exercise was included. Blood glucose control mechanisms, i.e. a pancreas for a non diabetic, insulin injections or an insulin pump for a diabetic, was also included.

The main structure is shown in the block diagram below (fig 4).

A more accurate description of the model is found in [5].
2.2.2 Technical details

Since the model structure was rather excessive, it was necessary to make each component as simple as possible without losing essential characteristics. The model consists of some 100 parameters and some 30 differential equations, non-linear as well as linear.

To keep down computation time the equation solver is very simple with a first order Euler-forward strategy. To avoid unnecessary computations the equations are checked before simulation so that only non-trivial equations are calculated (e.g. when simulating a diabetic physiology, the pancreas equations are not solved). Since different parts of the model have different time constants, different time steps are used. The computation time is some 4 seconds in an ordinary IBM PC (8086) with a math coprocessor (8087).

We chose a type of computer that was widely spread, had a capacity for calculations and wasn’t too expensive. Särinner is made in Turbo Pascal for IBM PC computers or compatibles with an EGA or VGA graphics adapter. A numeric coprocessor is desirable but not necessary. The user interface is built on pull down menus, which are controlled by the arrow keys. This design makes a mouse or other pointing device unnecessary.

Fig 4. Block diagram of main structure of Särinner.
3 Analysis

3.1 Illustration of phenomena

To present the contents of the model, some experiments will be described. With the model a user experiments with situations of interest to himself. To get closer to reality, model parameters like age, height, weight and type of diabetes may be changed, as well as more intricate properties like insulin reactions, dawn phenomenon, Somogyi effect and dynamics in insulin release.

3.1.1 Non diabetes physiology experiments

Experiments with a non diabetes physiology may be validated from own experience, since several food and exercise phenomena influence daily living.

• A default simulation illustrates the fluctuation of blood glucose concentration between 4 and 6 mmol/l. When the blood glucose rises, insulin is released from pancreas. When insulin concentration rises blood glucose lowers. Details in the function of the pancreas can be studied in separate diagrams.

• If the food contains fast carbohydrates (i.e. sugar, sweets, cookies, juice), the blood glucose peaks are higher and more insulin is needed from pancreas. The insulin causes a reactive hypoglycemia with fatigue and lack of ability to concentrate. If food instead contains slow carbohydrates (i.e. vegetables, pasta, rice) the blood glucose concentration is quite constant and energy in food lasts for several hours. This may be useful to show when discussing school lunch with teenagers.

Irrespective of food composition, there is a dip in blood glucose concentration a couple of hours after a meal. In Sweden it is a habit to drink coffee then. The dip can also be used to increase appetite before a meal — five o’clock tea with a sweet cookie or a small alcoholic drink releases insulin, lowers blood glucose and increases the appetite.

• Separate diagrams showing digestion, pancreas, liver, muscles, and energy consumption can also be studied.

• During an exercise pass the blood glucose concentration is quite constant despite the exercise. Separate diagrams illustrates how the energy consumption rises and energy is taken from glycogen storages the first ten minutes. Then fat utilisation begins, and consumption rate of glycogen lowers. During the exercise the insulin sensitivity increases, which makes lower concentrations of insulin have the same influence as normal concentrations did before the exercise.

Short intense exercise consumes mainly glycogen, which releases a lot of water. The resulting weight loss will be recovered again when glycogen storages are refilled. Exercise performed with the purpose to burn fat should be durable rather than intense, since fat consumption does not start immediately. On the other hand the fat consumption from the basal metabolism is increased several hours after a long exercise pass.

3.1.2 IDDM physiology experiments

IDDM means Insulin Dependent Diabetes Mellitus or Type 1 diabetes. In the model this state is achieved by inhibition of the insulin production and release from pancreas. The model also has a slightly reduced insulin sensitivity, that is, more insulin is required compared to the non diabetic model to get the same action.
• Finding an accurate insulin dosage for a normal meal schedule is an activity during which a "feeling" for the insulin action begins to occur already after a few experiments. An accurate regimen may consist of medium slow insulin in the evening and rapid acting insulin half an hour before each meal.

• The importance of timing can be studied. If insulin is injected too early before a meal an insulin reaction may occur. If too late, glucose from food makes its way to the blood before the insulin does, creating a sharp peak with a high blood glucose concentration.

• Composition of food can be varied. A considerable proportion of slow carbohydrates makes the blood glucose more easily controlled, resulting in an almost constant concentration. A change in proportions to fast carbohydrates results in a fluctuating blood glucose. To compensate a rise in blood glucose it is tempting to add short acting insulin. This will however cause an increased risk for insulin reactions some hours later when the fast carbohydrates are digested.

• The model is designed with a difference in insulin release depending on injection site. The release from an injection in the abdomen is faster than from one in the leg.

• Physical activity makes insulin sensitivity increase, which makes insulin influence increase. This makes blood glucose lower, with an increased risk of insulin reactions. The insulin sensitivity is increased several hours after an exercise pass, which requires a lowered insulin dose or more food during that time.

• If an insulin reaction occurs, stress hormones are released in the blood causing insulin sensitivity to lower. This results in a higher blood glucose concentration than before the reaction, due to increased release of glucose from internal sources as well as decreased influence from insulin. This can be studied in separate diagrams.

After six hours the blood glucose may still be too high, and it is tempting to add an extra dose short acting insulin. If done, this may coincide with the normalization of the insulin sensitivity and the extra insulin may cause a new reaction which may start this mechanism all over again.

3.1.3 NIDDM physiology experiments

NIDDM means Non Insulin Dependent Diabetes Mellitus, or Type 2 diabetes. In NIDDM diabetes pancreas still produces some insulin, but due to decreased insulin sensitivity in peripheral tissues the insulin production is insufficient. Hence injected insulin is used primarily for supporting the internal insulin production, not completely replacing it.

• In NIDDM mode, the insulin response is sluggish with the first sharp peak lost. This leads to a characteristic soft rise in blood glucose concentration some hour after a meal, whereas the pancreas releases all insulin it is capable of. This may be enough to make the peaks disappear, but not until several hours after the meals.

• If carbohydrates in the food are mainly of slow type, blood glucose concentration is more constant.

• Supporting insulin injections releases capacity for the pancreas to work with its subtle control task rather than running on maximum capacity to prevent a metabolic catastrophe.

• An exercise pass like going for a walk will increase the insulin sensitivity significantly. The blood glucose is far better balanced several hours after the physical activity.
4 Discussion

Since the discovery of insulin, the goal for insulin treatment is a normalised metabolic control. Several useful devices have been developed to facilitate this goal. Syringes and injection needles have become smaller and more easy to use. Insulin injections can also be performed with insulin pens and through devices in the skin which makes injections hurt less. Insulin infusion pumps can also be used, which makes it possible to tailor-suit the basal insulin profile and give extra insulin doses at snack meals without the trouble with injection tools.

Technology has also developed devices for keeping track of the metabolic control. Measurements of glucose concentration in blood are easily made by the diabetic patient himself. Some of the devices even record the samples together with time and date and transfer them on request to a computer. Computer software processes the samples and presents diagrams and statistics for the benefit of the patient as well as the doctor. Also ketones and urine glucose are easily monitored to complete the picture of the metabolic control.

But in this world of technical devices there is, unfortunately, still a lot to be done to get patients to understand how all resources would be used for obtaining a normalised metabolic control living the life he wants to live.

Again it is tempting to compare with other fields of complex learning, e.g. with the situation of learning car driving in the city. This situation as well includes a "soft" real time process (the city traffic) together with a complex technical environment (the car). To master the task of navigating smoothly towards the desired target calls for knowledge, skills and experience. No one can today imagine a driving education consisting only of book reading and consulting a driving teacher at his office along with driving lessons performed by the learner alone. Instead driving lesson together with a teacher will make the learner solve tricky situations by himself with the teacher as a security backup. Instant feedback and comments from the teacher is available for the learner with the tricky situation in fresh mind.

This learning cannot be directly transferred to diabetes treatment, since diabetes treatment is a 24 hour a day business, which also includes risk for inconvenience or danger. The concept with diabetes simulator training may be one faster way to create a learning situation in which the patient can together with someone more experienced experiment with different treatment alternatives without risk.

4.1 More about learning

This chapter discusses learning and problem solving in abstract situations. Though the first parts are picked up from education theory and the last part from theory of work organisation [6], a lot of this is applicable to learning situations in diabetes treatment. In this chapter, however, the discussion is kept general, i.e. not especially for diabetes treatment.
4.1.1 Five golden rules for better learning

Education theory states five golden rules to obtain better results, which naturally corresponds to Särinmer.

• User activity. The user is lead by his own curiosity to experiment with situations of importance to himself. Actions, results and interpretations are hence better remembered.

• Fast feedback. Results from a 24 hour simulation in a few seconds.

• User’s own formulations. Särinmer is non verbal. Understanding is promoted by the work with formulations and descriptions.

• Concrete. Components of every day diabetes treatment are used. Meals, insulin, physical activity, blood glucose, insulin reactions...

• Right level of motivation. The optimal level of motivation is not always the highest, because the motivation may cause stress which impairs performance. A user can increase a low motivation by thinking that the model looks like himself, and decrease a too high motivation by thinking that the model is, despite all, only a model.

4.1.2 An image used for communication

If Särinmer is used by more than one person it is usually generating discussions. Questions arising from the diagrams are interesting because they often bring the users common knowledge to a head. Even if the model is not an exact mirror of the reality, discussions about the discrepancies are often fruitful for cultivating and working over knowledge and experiences. Doing so, users learn to put words to phenomena and learn to create a language to communicate what’s important.

4.1.3 Different levels of problem solving

What does really happen when someone operates a process? One way to describe different actions can be seen in the following scheme (fig 5).

![Diagram](https://via.placeholder.com/150)

Fig 5. Skill based, Rule based and Knowledge based activities.

Skill-based behaviour can be exemplified from riding a bicycle or playing an instrument. Key features are extracted from the “surroundings” and the process is controlled in a way that does not require attention.
Rule-based behaviour takes the form of either prescribed instructions or as remembered procedures from earlier successful applications. This type of behaviour is used when a previously foreseen or predetermined situation occurs. Rule based behaviour is typical in complex or lengthy activities which are somewhat familiar. Driving in city traffic or flying an airplane using the check list can serve as examples.

Knowledge-based behaviour becomes actual when skills and rules are neither available nor adequate and the situation calls for problem solving and improvisation. Observing, identifying, deciding and planning activities are performed on this level, involving causal and functional reasoning based on knowledge of the functional properties of the process. One example is to buy stamps in a post office and spirits in a liquor store in Sweden the day before Christmas eve. The time is 4.30 p.m. and the traffic is jammed.

It is worth mentioning that problem solving on the knowledge-based level basically contains two different strategies: Symptomatic reasoning ("what makes me regard this as a deviation from the normal?") and topographic reasoning ("is this component of the process strange in some way?"). A typical diagnostic sequence would involve many shifts back and forth between the two strategies.

4.1.4 Mistake categories of the different levels

Failures in skill-based activities could be of different types. Examples from the sensory side can be low alertness in which the key features does not activate, or absent-mindedness in which the key features does not discriminate. Failure causes from the action side can be manual variability — a less successful way of manipulating or fumblingness.

An example of a mistake in the rule-based level is the man from a neighbour country who visited a doctor with burn injuries on both his ears. He had been ironing when the telephone rang.
—"But, both ears...?" said the doctor.
—"Yes", said the man, "I had to call an ambulance"!
Mistakes in the rule-based level are omission of isolated functional acts, familiar associations or mistakes among alternatives.

In the knowledge-based level the problem analysis can be distorted because assumptions and expectations has been used instead of observations. The rule synthesis can be unsuccessful if causal or latent conditions as well as side effects are not considered.

To summarise — operating a process (treating diabetes) leads to a kind of learning based more on observations than traditional education. This requires an additional step in which the observations has to be explained or at least verbalised. It also seems as if different sorts of thinking around a process can be distinguished: A normal, intuitive, "social" relation to the process is the usual state (skill based). It is replaced by a learnt reaction if an unusual but known state would occur (rule based), and is replaced by a more creating analysis, which may require knowledge, if the process behaves in a totally new way (knowledge based).

4.2 Knowledge and models

One aspect of modelling is how to decide whether the model agrees with reality or not. In discussions about Särinmer, this always requires some attention. Since Särinmer consists of a number of subsystems put together, this question is brought to a head.

Chapter 4.2 discusses validity and ends up with that the crucial point is how the model is going to be used.
4.2.1 About knowledge

The only time you can be completely sure about empirical knowledge is when you can show that a hypothesis is wrong. To illustrate this there is a classical example about whether or not all swans are white. Imagine yourself formulating a hypothesis that all swans in the world are white. You go out in the world and see a lot of white swans. Can you then be sure your hypothesis is true? Not necessarily. Actually, the only time you can be completely sure is if you find one black swan — then you can be completely sure your hypothesis is wrong. This is called falsificationism.

But, if you are out there in the world seeing ten white swans and no black one, wouldn't you be better off than if you didn't see any swans at all? And wouldn't you be even better off if you saw hundred white swans and no black one? Maybe you would. This is called positivism. Notice here that you actually would have to see one swan to be able say anything at all.

How can you increase the "trueness" of your hypothesis? Checking swans in the whole world will be rather time consuming, while unchecked swans to move into checked places. Maybe, after all, you were mainly interested of whether all swans were white in your part of your town? The trick to increase quality seems to be to reduce the system. This neither affords a too complicated methodology nor requires too heavy resources. If scientists do like this, science ends up with the pieces in the puzzle of the world. With knowledge about each tiny detail it is fully possible to explain everything in the world. This is called reductionism.

But is everything really possible to explain in terms of its parts? Does an anthill only consist of ants and needles, behaving exactly the same way if taken to pieces and put together again? Does the brain only consist of neurons? Is life only a matter of biochemistry? Maybe there is something more to the whole besides from its parts — something immeasurable and unquantifiable which disappears when the entirety is divided into pieces and analysed. This is called holism.

4.2.2 Mapping reality

When a mathematical model is made, two fundamentally different approaches are available — black box modelling and grey box modelling [7].

With a black box approach a time sequence of inputs and outputs are used to find the parameters in a difference equation. The parameters are automatically obtained so that the output from the equation is close to the real system's. This method ends up in a formula not necessarily revealing anything about the nature of the modelled system. The method is, however, is easy to use with systematic methods both for selecting the structure of the difference equation and for identifying the parameters.

The grey box method requires knowledge of the physical nature of the system. A set of differential equations are formed from energy- or mass balances or from other known laws of nature. The parameters are chosen so that the behaviour of the model is close to the real system's. The advantage with grey boxes is that the parameters often have physical interpretations and that the model is transparent enough to be open for maintenance and adjustments. One drawback is that it is not objective since it is built on its creator's opinion about the system.

These two modelling approaches of making images of "behaviours" can be compared to making pictures of "forms". If you want to show someone what something looks like, you can either take a photo of it or draw a picture of it. The photo corresponds to the black box modelling and the drawing to the grey box modelling.

A snapshot is an objective method, where you use a camera to make a hardcopy of what meets your eyes. The choice of film type (sensitivity, grain, grey scales etc) can be compared to the choice of differential equation. The choice of distance to the motive and lens (telephoto lens or wide angle lens) can be compared to the choice of sampling frequency and measure time. The photo is an objective image of the motive since neither the photo nor the camera "knows" what it represents.
Making a drawing is an art, where you draw the forms you consider the motive have. The picture can be detailed in parts you find important and sketchy and outlined elsewhere. You can give a subjective explanation of what different details of the picture are supposed to represent, i.e. a landscape, a forest or a lot of trees depending on the level of abstraction used. Not two artists would draw a picture the same way, but somehow we may find that different pictures represent the same motive.

There are some more comments to be made. Taking a photo requires some conditions: Everything that would appear on the photo has to be visible or observable. It is not possible to take a photo of a single atom with its nuclear parts and electrons or a cross section of the inside of the earth. Things has to be in "scale" to fit the photographic methods. It is hence not possible to photograph our solar system — the planets would be too small to be visible if all of them was to be caught on the same picture.

These comments also corresponds to black box modelling. The inputs and outputs of which the model is formed must be subject to measurements. The choice of time and sampling frequency must be appropriate for the system.

### 4.2.3 Modelling of Särinmer

Most existing models of insulin/glucose dynamics are models of highly reduced systems. They typically consist of some five to ten parameters which hence are possible to identify automatically from sampled data by means of e.g. least-squares fitting. Since the model is based on measurements on patients it has to be "true" in some sense. But since the model is made from a strongly reduced system it may lose its applicability.

Särinmer, however, is made from a number of different subsystems, where each subsystem is identified as its own model. One part is the digestion, one is the pancreas, one is the injected insulin release etc. Each part is modelled as simple as possible with the aim that all subsystems put together would illustrate important phenomena in diabetes metabolism. The model is made from physical relations, that is, all equations emanate from energy or mass balances and known laws of nature. State variables as well as parameters has physical interpretations. This complexity and transparency would make Särinmer quite useful.

Altogether Särinmer consists of about 30 differential equations, some of them non linear, with about 100 parameters. With this extreme flexibility it would probably be possible to simulate almost any individual. But parameter identification from measured data would require hundreds of guinea-pigs due to the large amount of parameters. Most of the state variables and parameters (glycogen storages, insulin sensitivity or carbohydrate digestion characteristics) are also extremely hard to measure in a living individual. Besides this, parameters changes from time to time in the individual, which makes the identification of limited value.

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State, state variable — Mathematical term used to describe a level, concentration or amount of something in the model. The concentration of glucose in blood is one state, the amount of glycogen in the liver is another state.

Parameter — A numerical constant which is not changed during a simulation. It may be changed between simulations, then causing a different result. Height, weight and age are parameters.

### 4.2.4 Särinmer and reality

A common question is whether Särinmer behaves like an average human being or not. The subsystems are built on "scientific methods" with each subsystem strongly reduced in the reductionistic sense. Subsystems are then put together in the holistic sense to make Särinmer able to illustrate diabetes physiology on a phenomenological level.
The model, regarded as one single system, is thus quite extensive. This has caused validation problems since scientific validation gets more and more vague the greater the system is.

Another common question is whether Sarimner looks like an individual or not. The question is of importance when discussing insulin regimens with a diabetic patient. One attitude is that since the model is built on averages and mathematical formulas it can never be used in treatment discussions for individuals. On the other hand, since the model is extremely flexible due to the large amount of parameters it would be possible to fit it to almost any individual if only adequate physiological parameters were provided from the individual. The focus of the problem then moves from the model to the "reality".

The question remains — how does one decide if Sarimner behaves like reality?

4.2.5 Creating ways to look upon

Let's shortly discuss the conception reality. The traditional science builds on the presumption that there exists a "Truth", a reality that is ultimate and independent of potential observers. The mission of science is to make mappings and images that reflects the Truth. To decide to what extent encountered phenomena really has its origin in the Truth is beyond reach for science.

Criticism to the traditional "mapping" science has slowly been raising. The theory of system analysis appeared as a protest to the traditional scientific tendency to reduce objects so strongly that the interactions with their environments were lost or not properly considered. System analysis does not, however, advice any solutions to the problem, it just puts it at a head.

Traditional scientific methods works when the studied object is "simple", in the meaning that it is deterministic and not too manifolded, e.g. a machine (fig 6). They also works if the object is so randomised or complicated that it is possible to use statistical methods, e.g. a gas. It seems that problem arises when the studied object is only somewhat complicated and randomised [8].

![Diagram of properties of machines, living systems and aggregates.](image)

Recent decades modern cybernetics has proposed the idea that reality is an interaction or co-construction between observers which leads to new ways to look upon or handle reality [9]. One immediate reflection to be made is that knowledge should be put in a social context in a higher degree than before. To the old question "how does it work" should another question be added: "Why do we want this knowledge, anyway?". The discussion following this question is important — not necessarily the result of the discussion, though.
4.2.6 Purpose and co-creation

The question "Does Särinmer behave like reality?" should preferably correspond to the question "In what way is Särinmer going to be used?".

The use of a model can be in different levels.

- Technological level. The model is used to solve the problem. The user may give the model information about conditions and properties expect a result or an advice. The apparent danger is that the model has to be very accurate if the results are critical. The problem corresponding to Särinmer is evident — either the model is general and may be to coarse to solve the problem adequately, or the model is detailed and requires a lot of unmeasurable entities from the physiology of the user.

- Pedagogical level. The model has the same qualitative characteristics as the real system. By using the model a user get familiar with the system. When dealing with the real system, the user is better skilled to control it.

- Co-creative level. In the two levels above the user consider the model as "true" in the aspect of the model he considers — quantitative in the technological case and qualitative in the pedagogical case. In the co-creative level experienced users can get a test-bench in which he can try different ideas about how parts of the physiology works given certain physiological properties. The discussion may reveal new aspects of- or ways to look upon the system.

4.2.7 So, is this science, anyway?

Discussion so far has suggested that Särinmer may be looked upon from different perspectives. This leaves the question whether or not Särinmer agrees with reality without a clear answer. Nevertheless there would actually exist an answer, which clearness cannot be measured in a simple, objective way and therefore cannot be evaluated. If a traditional scientific methodology is followed, this indistinct answer has to be regarded as no answer at all.

If perspective is changed and the purpose of Särinmer is taken into consideration, one can distinguish different fields of application, each with increasing level of abstraction. The degree of agreement with reality which Särinmer possibly has, can then in some sense be graded in to which extent Särinmer serves its purpose. Thus this measure would be a question of practical- rather than theoretical validity.

If one after all claims that the type of modelling which Särinmer is an example of is science, one has to regard science as having a further mission than just mapping reality. To the traditional analyses of reality, the work of creating new ways to look upon also has to be added.

4.3 The First Särinmer Pilot Study

A study was designed to evaluate the impact of training with Särinmer [10]. It has been earlier shown that education programmes not necessarily improve metabolic control, but instead may lead to a richer life for the diabetic patient. An evaluation would hence also consider quality of life aspects.

In autumn 1991 we invited teenagers connected to the Department of Pediatrics at the University Hospital in Linköping to participate in the study, which consisted of 4 guided education sessions. Finally we got 11 participants in the ages of 13 to 19 years. From the invitation answers we learned that no one wanted to take part in a control group with traditional education. Our initial ambition of a "scientific" study was then changed, to a smaller, descriptive, pilot study.
Each lesson was guided and had a specific theme — food, insulin, physical activity and treatment problems, respectively. The teenagers, who worked two by two at each computer, were encouraged to experiment wildly and discuss findings and problems with the partner.

The evaluation included areas as self-esteem [11], locus of control [12] and emotional adjustment [13], areas which were included in an instrument of Likert scale type. Furthermore the ability to discuss treatment problems was probed with a number of text questions. Finally also metabolic control was measured (HbA1c). The evaluations were made before the first lesson, after the last lesson and after 6 months.

No significant results were found for the group. Changes in performance for individuals, however, occurred. After 6 months, improvements on the 99.9% (*** ) significance level was present regarding locus of control (three participants), knowledge questions (three participants) and self esteem (two participants). Furthermore the level of stress was decreased (two participants), but the level of guilt was increased in (three participants), as was also the attitude of disaffection from medical practitioners. It should be noted that since no control group was used, it is not possible to decide whether the changes are due to the computer training.

Most of the results would be regarded as successful changes. However, the increased level of guilt is a not wanted side-effect, which appeared in connection to more internal locus of control (two participants) and increased knowledge (one participant). If the participants, after the education program, did not succeed with improving metabolic control according to his/her ambition this may cause guilt ("should-do"-guilt). New insights may also cause guilt over unsuccessful self care over several years ("should-have-done"-guilt).

Disaffection from medical practitioners may indicate a process, where communication mainly performed to maintain a good relationship is replaced by a communication with a focus on the treatment [14]. This may not necessarily be regarded only as a negative side-effect.

Some open ended questions about computer education, put after the last lesson, indicated that most participants were positive to the education and considered the Särimner program useful to more categories than diabetic patients. The answers indicated preferences for a guided group training or that two persons of which one is experienced should work together. This suggests that the program is used as an illustration tool, while explaining and interpretation occurs in the communication between the two users. The participants regarded, in accordance with our hope, the program as a source of inspiration rather than a technical device for optimising their insulin treatment.

4.4 The Health Professional Test Pilots

During the development of Särimner, several diabetes professionals tried the model. To get non biased feedback they were provided with very few instructions and little information. The professionals were chosen to represent a wide spectrum concerning experience of computers, diabetes education experience and theoretical knowledge.

The first prototype version of Särimner were tested 1990 by five diabetes physicians. In conclusion the first prototype was found quite complicated to manipulate, but interesting and possible to develop.

The second prototype version of Särimner were tested early in 1992 by ten professionals — diabetes physicians at medical and pediatric clinics and two diabetes nurses. The feedback we got this time was more extensive. To summarise some of the criticism.
• Design imperfections:

— Särimner doesn't seem to work well at insulin deficiency, e.g. if Actrapid is injected at 5 pm and Monotard 11 pm and nothing in between. The blood glucose would increase and the insulin sensitivity decrease, which makes the high blood glucose hard to lower with normal doses of insulin. This effect will last for several hours after the insulin deficiency. This is not the case with Särimner.

— Särimner is too slow on a 286 computer without a math coprocessor.

— It's hard to measure some key properties from the patients — insulin sensitivity, dawn phenomenon etc.

— It's hard to show onset of diabetes.

— Takes time to master. If Särimner is used together with a patient, a lot of time has to be allocated.

• User interface comments:

— The user interface would be improved with buttons and switches instead of numbers typed from keyboard.

— Old energy units would be an option (kcal as well as kJ).

• Who have used Särimner?

— Doctors and nurses (several answers).

— Diabetes professionals and 6-8 young type I diabetic patients (2 answers).

— "Ulvsundakursen" — the 4 pediatric clinics of Stockholm (15-18 years) + doctors, nurses, psychologists and dietitians. Mostly 3 teenagers worked together around the computer, and took it in turns with entering the data, and discussed insulin regimens, physical exercise, food, and blood glucose profile.

• Worries:

— Särimner should be used in education to illustrate something, this reduces the worry.

— I have no worry for Särimner to be used in a wrong way, even if this, however, would be possible.

— Overall hesitance of computers is beginning to vanish, the use of computer is not more exclusive.

— Some hesitance for computers and Särimner, however no worry for Särimner to be used the wrong way.

• Knowledge and positive side effects:

— Facts and information OK. Knowledge useful for both professionals and patents.

— I have checked how small variations in doses, composition of food, times etc may give big changes in blood glucose. Possible to show that certain time courses are slow — professionals and patents sometimes changes regimen without waiting long enough since the previous change.

— Reborn interest!

— Patients got aha experiences! May show what is happening at physical exercise and how to compensate for this.

— Särimner together with a food composition analysis program gave the teenagers a holistic view of diabetes and the treatment.
• Judgments:

— Good means of assistance.
— Believe this will be a good product in the long run.
— Enjoying and stimulating to use Särinmer, which is extremely well thought out. Got totally carried away... and were sitting several hours without a break.
— Very ambitious program which gives good possibilities to individualise the conditions, it takes, however, that you are skilled in most fields.
— Särinmer is a brilliant idea. Very good for health care professionals and also for selected patients.
— I'm positive to the program, and got positive reactions from professionals and patents.
— Särinmer was appreciated by both teenagers and medical staff (…) and every minute between lectures, group discussions etc, were dedicated to playing with the computer. — Teenagers from other clinics were actually a bit jealous of our computer exercise.

• Future:

— The program may after completion be useful both for professionals and patents, but only in a larger pedagogic context and not as replacement of other activities. I may use Särinmer in group discussions and use an video display screen. It would be interesting to have the program evaluated systematically and scientifically.
— Education of health care professionals who are going to work with diabetes. Someone who is skilled in Särinmer and diabetes work together with one or two who are going to be educated. The program can be used by computerised and “engineer oriented” persons.
— Health care professionals working with diabetes may enjoy it. Blood glucose and insulin may be visualised to patients. A certain selection would, however, have to be made.
— Computer demonstrations in exhibitions, nurse meetings, regional meetings.
— I think Särinmer has a place in education, especially with patients. For me I can imagine using Särinmer with type I diabetics in group education.
— I see a possibility to use the program in research, if conditions and results can be exported to other programs of be combined with blood glucose samples from the patient.
— My hope and belief is that Särinmer will be in the agenda of the diabetes course next year.

4.5 About quality

In the common debate today the conception ‘quality’ is discussed over and over again. It is said that the 80's were the decade when productivity was focused and that general efforts in western societies aimed to improve methods for ‘doing the things right’. In the 90's we are instead interested in ‘doing the right things’. The productivity is no longer focused, since it is of no meaning increasing effectivity of something that was not right to it's nature in the first place.

Talking about education — also including diabetes education — the aspect of time is often regarded. It seems as time often is the critical factor, and as human activities which requires time is worth less. Activities may thus be connected to results that are simple to measure, and start the circle with a hunt for something with a distinct result to be done in shorter and shorter time. There may, however, be more to it than just time.

4.5.1 Eight aspects of 'good'

If every context is studied where the word “good” is used, can be categorised into eight different cases [15]. They are built by two dimensions:

One dimension concerns form vs nature. When ‘good’ refers to something that has pure form value it's called "smart". When 'good' refers to something that is pure functional it's called "essential" or "right to its nature".
In the other dimension 'good' is put in relation to human beings. In the extremes 'good' can refer to value in experience or value in action. A 'good' experience may be called "enjoyable" and a good action "purposeful".

Putting these two dimensions together gives four remaining cases in the cardinal combinations of the dimensions (fig 7).

When an action is essential it is said to have ethical value and is called "right". Something that is done in a smart way has instrumental value and can be called "effective".

If an experience feels essential it has a value in authenticity and gives an impression of "truth". Sometimes can be experienced as "beautiful", and is then said to have values of pleasure.

4.5.2 Doing the thing right or doing the right thing?

Särinmer is created to increase understanding for diabetes treatment. If the user is a diabetic patient, this may lead to a greater freedom of action, which he may use for improving the metabolic control or improving quality of life. Särinmer does not give any knowledge about facts and medical language of diabetes, nor gives Särinmer automatic solutions to problems or rules of thumb for insulin regimens. Our hypothesis is that an increased freedom of action and understanding of treatment conceptions may be obtained by experimenting with Särinmer.

Having considered this, one can then form an opinion of the quality of Särinmer. We have tried to give it a value of nature by building it of the same major components as the modelled physiology and most intermediate results may be seen in diagrams. This may make Särinmer to be experienced as "true". For manipulating the model we have used food, insulin and exercise as inputs, and the result is the blood glucose diagram. This would make it possible to do the "right" thing. The drawback of a model design that is right to its nature is that it may appear complicated and require some time to make familiar with. Also diabetes treatment in itself may appear complicated sometimes and require some time to make familiar with.

Form values are achieved by some simplifications. One example of making the model "effective" may be the limited number of nutritive substances — fast and slow carbohydrates, fat and protein. Another may be that arterial and venous blood have the same blood glucose concentration and yet another may be that all glycogen storages outside the liver are regarded to be in the muscles.

Choices of technical design may also contribute to effectiveness, such as a simple difference equation solver and an algorithm which make unnecessary parts of the model not calculated. One "experienced form value" may be clear and functional diagrams and symbols — no one has, so far, actually mentioned the word "beautiful"...
With similar tools for quality analysis it is possible to discuss and put in question also the whole concept of Särinmner. Is it a severe limitation to use a computer? Is really the main problem of achieving a normalised metabolic control understanding of the physiologic properties of diabetes treatment? The answer is probably not unambiguous — for some individuals it is a limitation to use a computer, for some individuals it may be emotional or motivational obstacles to obtaining desired results. The self-referring conclusion has to be that Särinmner would be useful for the right purposes, as would other kinds of diabetes education too.

The question of when 'doing the things right' or 'doing the right things' is still left to common sense. And, referring to chapter 4.2.1, no one can say when something is right — not until you see something better you know what you did was not right.
5 Conclusions

It is possible to use the technology of mathematical modelling in combination with diabetes physiology to produce a mathematical model which simulates quite well a real diabetic life situation.

A computer model may be useful in diabetes education. In some patients it may increase knowledge, competence and quality of life.
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7 References


