System dynamics of learning processes – comparing apples with pears

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Abstract Despite fundamental changes in how people work, live, and entertain themselves, education systems at the beginning of the new millennium would be familiar to anyone who attended school 50-60 years ago. While most of the business world has changed with the introduction of information technology, the academic educational curriculum is remarkably unchanged. This paper presents a model of how learning is influenced by the major internal factors such as motivation, metacognitive skills, prior knowledge and external factors such as study time, support, teaching and infrastructure, including information technology. The outcome of the learning model is subordinate the path towards the results. These major internal and external influencing factors are affecting each other in several ways, and the modelling process is forcing and enhancing viewpoints on how they are influencing each other – thus the comparison of apples and pears. The model also suggests how improvements in teaching, support and infrastructure may improve the learning process, including how changes in the infrastructure i.e. with the introduction of information technology are affecting the learning process and the achievements.

Keywords: Learning, knowledge, education, metacognitive skills, motivation, learning technology, soft variables, loop analysis

Introduction

Life is about continuous learning. Most of us learn new things every day. We call it "a stimulating environment". We are getting more and more competent each day. For years it has been attempted within educational science to establish the process of learning. A lot is known about instruction but as to learning and acquiring knowledge and insight we still know relatively little about. Much research is carried out into methods of instruction but very little into learning with learning tools. How can a learning process be turned into a model and how can learning be modelled? A model can help educators to better understand the strengths and relationships between each of the components. It provides a basis for understanding and utilising compensatory relationships among the components, as well. It will also enable a more systemic view on learning systems, and the orchestration of resources for learning. The aim is to investigate how we best can support learning. It also gives possibilities to distinguish the separate external components from internal components, and assumes a few basic principles that can be distinguished in the learning process. The model should also establish a background about how learning takes place with learning tools and how learning can be enhanced by learning technology.

The field of systems analysis has produced few learning models so far. Some attempts have been made (Eftekhar & Strong, 1995; Min et al., 2000). There might be several reasons for this. First, one obvious reason is that learning is still a not a fully understood process. This seldom stops system dynamics modellers. The role of modelling is also emphasized as a way of generating testable hypotheses (Roberts et al., 1983)). Second, learning is influenced by both external factors; teaching system, subject matter, organizational structure, etc, as well as internal factors such as motivation, cognitive processes, memory, behaviour, skills etc.

It is generally agreed that students construct their own knowledge. One "ism" that addresses knowledge construction is constructivism. Teaching strategies based upon constructivism tend to be inquiry oriented. Learners are encouraged to discover rules without a great deal of specific teacher input. Inquiry strategies often include tasks explicitly aimed at uncovering misconceptions. Metacognitive skills play a central role in constructivist learning models. Thus much emphasis is put on teach learners to learn. We have all been taught through lecturing or in classroom environments. This is not likely to be the only and/major learning environment as we learn continuously, also outside "learning environments". Instead concepts as e-Learning, a k a web-based learning and Blended learning, a combination of conventional teaching/training and web-based learning will be more common in the future (Rosenberg, 2001). More time will also be devoted to own learning, individualised and self-paced, and thus self-efficacy will be emphasised (Zimmerman et al., 1994). It also means that more access to learning material and increased opportunities to learn by self-studies, practices, simulations has to be given. It has to be emphasized that learning environments are not necessarily the same as a teaching/instruction environment.

Learning can be briefly conceptualized as: a) increasing one's knowledge, b) memorizing and reproducing, c) applying, d) understanding, e) seeing something in a different way and f) changing as a person (Marton *et al* 1993). The first three categories describe learning as a reproduction of information, whereas the last three depict learning as knowledge transforming. This study does not distinguish these, but of course the latter three categories is what learning efforts should aim for.

Some of the problems that this modelling approach is trying to direct:

- How can motivation be supported?
- What are the effects of increased infrastructure, e.g. introduction of a learning management system?
- What is the relationship between study time and learning achievements?
- What is the relationship between learning achievements and prior knowledge?
- How is prior knowledge affecting learning?
- Can decreased teaching be substituted by an increase in infrastructure?
- What is the relationship between metacognition and learning achievements?

Modelling soft variables - comparing "apples with pears"

Modelling of processes involved in learning require involvement with variables that are internal to the human being. Variables like motivation and knowledge or quality of instruction are not things that can be computed. They do not get numeric or precise value. This simplified learning model is an attempt to compare such variables, and contains both internal "soft" variables as well as external, "hard" and "soft" variables. Can these by compared and combined in a model? And why attempt to do it? If we follow the dimension-based taxonomy of systems suggested by Jordan (1968; in Checkland 1993), three principles lead to three pairs of properties: Rate of change – Structural (static) and Functional (dynamic), purpose – Purposive and Non-purposive, connectivity – Mechanistic and Organismic. All systems can be categorized with these parameters, according to Jordan. These bipolar dimensions describe the information needed to specify any given example of a system. If we look at the model presented in this paper and the two major types of parameters included in the model. How do they differ? Soft variables, e g variables that are not possible to define on a generally agreed scale, are usually functional in terms or rate of change, purposive and organismic in its connectivity. Hard variables, on the other hand, are often easier to at least define what type of scale to use, and can be structural as well as functional, purposive, but often mechanistic in its connectivity. When including or utilising soft variables in a model, the focus is merely on behaviour than on structure (Checkland, 1993). The suitability of the chosen soft variables can often be questioned. However, they are often more interesting, and even defining the scales of soft variables can initiate a good discussion. Soft variables are just as valid to graph as hard variables, but are more challenging. Forrester and Senge (1980) mention three classes of system dynamic model tests—system structure, system behaviour and policy improvement tests. System dynamic model validation is not an ‘‘accept’’ or ‘‘reject’’ statistical significance exercise, but rather a confidence building process resulting from model development and use. Any system dynamic model is a more or less informative parsimonious representation whose results are implicit in the structure chosen.

Model structure and parameter assumptions

A learning model is defined as a theoretical statement outlining the conditions by which students learn and develop with respect to a particular educational goal. A learning model is analogous to a blueprint of the curriculum; it provides a conceptual foundation to guide the selection and arrangement of experiences intended to promote goal achievement. Explicitly acknowledged in a learning model are statements about the structure, process, and content of the curriculum that will lead to achievement of the goal. Each academic programme goal has an associated learning model, although it is seldom expressed. The definition of system structure and parameter estimation remedies this. Below is a causal loop diagram of the model. Learning and learning outcomes (as “Achievements”) are the central parts of the model. Below these two parameters are the external factors; Study time, Support, Teaching, and Infrastructure. Above the two central parameters the three major internal parameters are found; Motivation, Metacognitive skills, and Prior knowledge. The three major external factors, outside the system boundaries of this model, are depicted with dotted lines; Goal/purpose, Personal capability, and Resources.

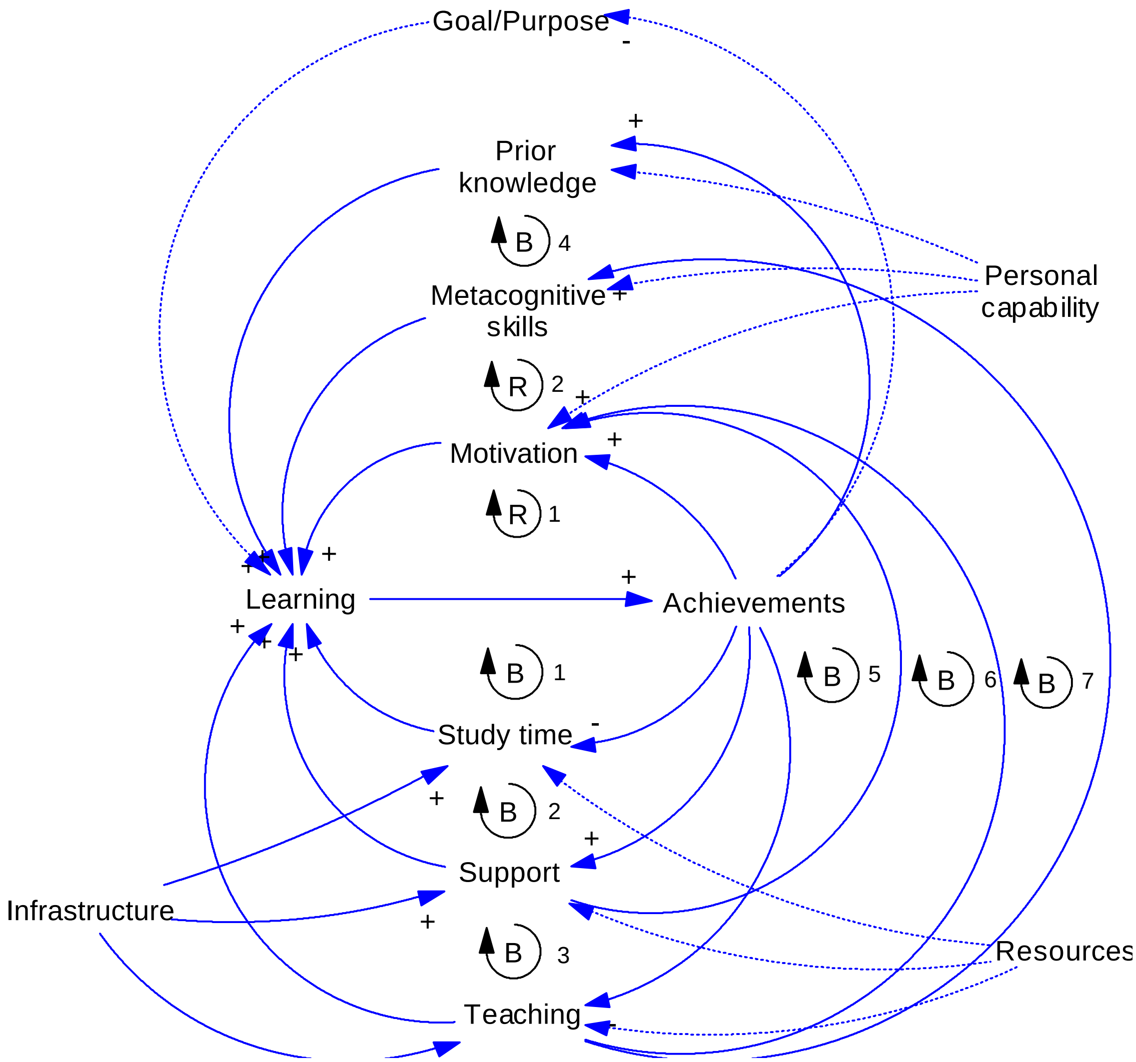


Figure 1. *Causal loop diagram showing the model and the relationships between the learning model's parameters. Loops where the external factors; Study time, Support and Teaching are included, are all balancing loops, i.e. e limiting, while the loops where the internal factors Motivation and Metacognitive skills are Reinforcing. The parameters Goal/Purpose, Personal capability and Resources are external factors not included in the model.*

Learning

Learners use a variety of integrated skills and attitudes to regulate their learning. Learning encompasses cognitive abilities, e g one's capacity to learn. Included in Learning, for simplicity reasons, are cognitive ability, knowledge and strategies. Cognitive ability affects learning directly and indirectly through knowledge and regulation of strategy development. Strategies refer to the mental tactics used to make a cognitive task easier to understand or perform. Even a modest repertoire of strategies can improve learning and performance significantly. In addition, strategy instruction increases positive motivational beliefs and may compensate for lack of intellectual ability or knowledge. There are not any empirical evidences for any clear relationship between cognitive ability and metacognition (Pressley & Ghatala, 1990).

The following parameters are considered as the most important internal factors:

Motivation

Motivation is a primary factor in any theory or model of learning. Motivation refers to beliefs about one's ability to successfully perform a task, as well as one's goals for performing a task. Motivation as used here refers to a number of beliefs and attitudes that affect learning. It is now clear that students do not use existing knowledge and strategies effectively if they do not believe they will improve learning. The sources of motivation dimension ranges from extrinsic (i.e. outside the learning environment) to intrinsic (i.e. integral to the learning environment) (Pintrich & Schunk, 1996).

Metacognition

Metacognition refers to knowledge and regulatory skills people have about their own learning; awareness of objectives, ability to plan and evaluate learning strategies and capacity to adjust learning behaviours to accommodate needs (Alexander *et al.*, 1995). Metacognition, a term coined in the early 1970s, has been viewed as an essential component of skilled learning because it allows students to control a host of other cognitive skills. According to Brown (1987), metacognition includes two related dimensions: knowledge of cognition, and regulation of cognition. Regarding the relationship between knowledge and metacognition, a number of studies report a strong, positive relationship (Garner, 1987). Scaffolding strategies typically improves metacognitive awareness (Schraw & Mossman, 1995). Metacognitive skills increase during studies. The increase is largest in the beginning of the studies.

Prior knowledge

Every task we undertake depends on knowledge: It is therefore also impossible to understand and perform a task without some degree of knowledge. An important thing to keep in mind is that prior knowledge is the best predictor of new learning. This means any instructional methods offer contextual practice at the same level as that intended for testing usually give excellent results. Prior knowledge will shorten the study time, but will also indicate higher metacognitive skills. However, without Motivation, Prior knowledge's importance is less prevalent.

The following parameters were considered as the most important external factors; Study time, Support, Teaching and Infrastructure.

Study time

When we invest in learning, we pay this investment in time and efforts. Usually study time is limiting in how much that can be achieved, but there is certainly no linear relationship between these. In this model it is the only parameter that has any units connected to it.

Support

Support factors include peer students, family and of course tutors/teachers, whereof the most underrated is the peer support importance. The support directly affects the learning through helping and advising about suitable learning strategies and ways, and through strengthening the metacognitive abilities. This is probably one of the most important issues in any learning situation, as it is, besides the direct teaching, the most evident feedback system. Support, through teachers, peer students, friends and parents is strengthening the motivation but also adds to the overall learning efficiency (Dryden & Vos, 1993).

Teaching

Teaching can be designed differently according to the role of the teacher, e.g. the traditional didactic role or the facilitative role. The didactic role is more connected to the subject than the latter, which is focusing more on the learning process *per se*, and less on the particular subject. Effective learning includes a number of autonomous components that compensate for each other. Teaching may exert effects on cognitive ability, choosing appropriate learning activities in accordance with individual learning styles and preferences, as well as improving learning strategies and deeper understanding. For simplicity, these factors are included in the Teaching factor. Teaching works in two major ways; first by explaining the subject, thus enhancing the gained achievements per time, but may also improve Motivation as well as Metacognitive skills.

Infrastructure

Included in the Infrastructure parameter is learning facilities such as classrooms, learning equipment, but also network and learning management systems. Infrastructure is a typical enhancer parameter, thus amplifying or extending other parameter, but does not provide any value in it or alone. It is nevertheless an important parameter where much improvement has been made throughout the history of education, and more will be done. Infrastructure improves the effectiveness of both Teaching and Support, but is also boosting the study time, by providing more access to learning material as well as improves the flexibility.

Parameterisation

Detailed knowledge of a process is the prerequisite for parameterisation. All system dynamic models need numbers to run, but where do they come from? This is a very special topic when modelling soft variables (Graham, 1980). In the model presented in this paper, it is merely a matter of setting the relationship between parameters by providing parameter values that will achieve the appropriate model behaviour. What is then the “appropriate model behaviour”? This is given by the mental model of the behaviour. This model is for policy analysis, which is also indicating the value in the parameter estimation. According to Richardson & Pugh (1981) parameter are value set either by knowledge about the processes involved, and from data on individual relationships in the model, and from data on overall system behaviour. In this model the only parameter that is possible to compare and validate from real data, is study time. This parameter in turn is giving the size of the others. The starting values of parameters are also set according to the ranking of factors, and thus also the amplitude of influence on the outcome. No units were used for the intrinsic parameters such as; prior knowledge, metacognition and motivation, and neither for support and teaching.

Judgemental parameters estimates are likely to be more uncertain (Sterman, 2000), which indicates that model results are also uncertain. Sometimes assumptions for soft variables can only be made to find the right relative magnitude, relative other parameters in the model. This is the case for the internal factor this model encompasses, where it is assumed that the increase of Motivation is a faster process than the increase in Metacognition and Prior knowledge. For initial values of the parameters, see the Equations section below.

Extrinsic factors

There are also extrinsic parameters that are excluded in the model but are shown in the causal loop diagram below (Figure 1.).

Goal/Purpose is an ultimate factor that is mainly influencing the internal factors through the learning parameter. It signifies why students study; career move, inner wishes, visions etc.

Personal capabilities include factors such as intelligence, other cognitive abilities, learning styles etc.

Resources, which is influencing the external factors Study time, Support and Teaching, include limiting factors such as economic resources, budget, and of course time.

Feedback loops

The model contains several loops, whereof all except two are balancing, thus limit the outcome of the learning process.

Loop B1 – Learning ->Achievements -> Study time->Learning: Learning has outcomes, here called Achievements, which could be fulfilment of objectives, or personal goals, or a combination of these. These are usually set towards Study time. So when the Achievements increase the remaining Study time decreases. With less Study time less Learning can take place, thus a balancing loop.

Loop B2 – Learning ->Achievements -> Support->Learning: When the results of the learning is growing, usually both the demand after support as well as the planned given support is decreasing, thus a balancing loop.

Loop B3 – Learning ->Achievements -> Teaching->Learning: Teaching efforts are most useful in the beginning of any learning process, and thus the importance decreases over time when the learning is successful and results are achieved.

Loop R1 – Learning ->Achievements ->Motivation->Learning: When the learning process leads to increasing Achievements, the Motivation increases as a result, this in turn has a positive effect on Learning, thus reinforcing.

Loop R2 – Learning ->Achievements ->Metacognitive skills->Learning: To learn is a positive reinforcing process, which strengthen the metacognitive abilities if learning is achieved, thus a reinforcing loop.

Loop B4 – Learning ->Achievements ->Prior knowledge->Learning: Depending on the overall goal and purpose of the studies, Prior knowledge has a positive effect on the learning process first, but will ultimately limit the learning process, when the goals and the objectives of the studies are fulfilled.

Loop B5 – Learning ->Achievements ->Support->Motivation->Learning: With achieved learning results the support is decreasing, thus also affecting the motivation, and the loop is therefore balancing.

Loop B6 – Learning ->Achievements ->Teaching->Motivation->Learning: As for the loop above, the achieved learning results will lead to a decrease in teaching resources which will lead to a decreased enhancement in Motivation.

Loop B7 – Learning ->Achievements ->Teaching->Metacognitive skills->Learning: The decreases in teaching efforts with the increase in learning achievements are also affecting the increase in Metacognitive skills.

To summarize the feedback loop structure of the model and the consequences – the model includes several balancing loops and any policy change for improved learning must try to change the limitations of these, while keeping the two dominating reinforcing loops.
As this is a model with mostly soft variables, the actual numeric output is of less interest, and the elaboration of the parameter relationships more of interest. The results are therefore focusing on this. In general there are three major types of parameter relationships (Figure 3.).

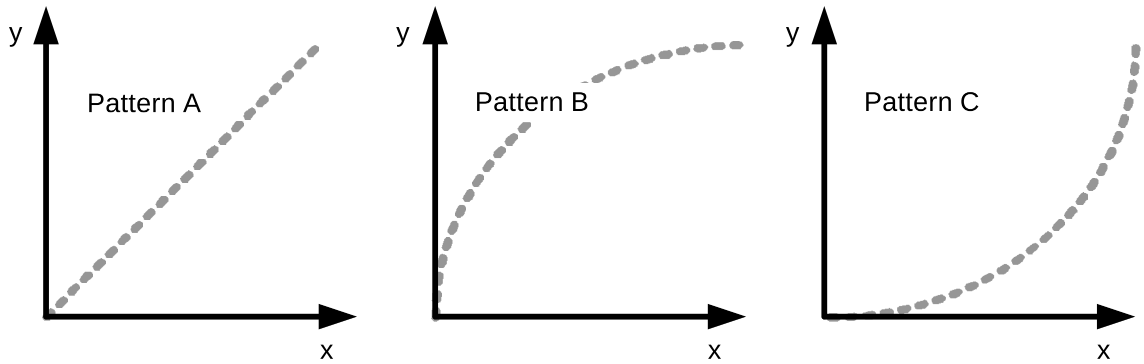


Figure 2. *Major parameter relationship types. Pattern A is a linear relationship, with different multiplicatory effects, e g an increase in parameter x is giving a proportionally similar increase response in parameter y, in the form of* $y = kx+m$. *This is a reinforcing pattern. Pattern B is a saturation relationship, where an increase in parameter x is giving a proportionally larger response in parameter y when x is small, but less when parameter x is increasing, in the form of* $y = a(1-e^{-bx})$. *This is a balancing pattern. Pattern C is an exponential relationship of the form* $y=ae^{bx}$, *where the value of parameter y is getting proportionally larger with a larger value of parameter x. This is a reinforcing pattern. There are of course other relationships but these are the three major and common ones.*

First, the parameter relationships can be categorized into three major positive relationship types (Figure 2):

- Positive linear relationship (pattern A); Study time and Achievements have this type of association. The relationship between Achievements and Prior knowledge is here assumed to be positive and linear, but will likely also be a saturation relationship (Figure 3; pattern B) during longer studies.
- Saturation relationship (pattern B); Support and Achievements have this association type, as the Support is most helpful in the beginning of any studies, and then levels off at a certain intensity. Teaching and Achievements is following the same pattern. The relationship between Achievements and Motivation is also a positive association, but there is a certain level of maximum motivation that is approached. Achievements and Metacognitive skills are also similar in the pattern over time, as the previous one.
- Exponential relationship (pattern C); none of the relationships show this type of association.

Second, what combined effects on learning have these parameters? Are the effects multiplicative or merely additive? And do they differ among different individuals?

Moreover, how is infrastructure influencing the learning outcome? Where should it have an impact for best effect on learning? It is assumed here that it is mainly via Study time, Support and Teaching that Infrastructure has an effect on the learning process and thus the Achievements. Infrastructure is influencing the Study time by improving accessibility and flexibility, thus increasing the Study time.

Equations

With the causal loop diagram of the system (Figure 1) as a blueprint, a numerical model was built, utilising the STELLA® software. The only parameter which has a "real" value is the Study time, given the value of 400 hours corresponding to a semester's course at university level. The following parameter equations were used in the model: Achievements, with an initial value of zero, was assumed to be the resultant of the Learning process. The learning process was assumed to be the product of available Study time per day times Motivation level, Metacognitive skills, Support level and Teaching level and decreased by the inverse value of the Prior knowledge level, assuming a base level of 0.001, with the unit Learning hours/day.

*Learning = Study_time_per_day * Motivation_level * Support_level * Teaching_level * Metacognitive_level * (0.001/Prior_knowledge_level)*

The Motivation level and the Metacognitive level were assumed to be linearly related to the sum of Achievements and Teaching level. If no Learning occurs, no increase of Motivational or Metacognitive levels will occur. Both levels decrease linearly with time.

*Metacognitive_level(t) = Metacognitive_level(t - dt) +(Metacognitive_increase - Metacognitive_decrease) * dt*

The Motivation and Metacognitive increase is set by Achievements and Teaching levels, modified by a strength factor plus a base factor of 0.001. There is no increase in Motivation If no learning is taking place.

Metacogn_increase = IF(Learning>0) THEN 0.01(Achievements+Teaching_level) + 0.001 ELSE 0*

The Prior knowledge increase was assumed to be linearly related to Achievements with a transfer delay of 10 time units. If no learning takes place no change of the Prior knowledge level will occur, as the increase is then the same as the decrease of Prior knowledge.

*Prior_knowledge_level(t) = Prior_knowledge_level(t - dt) + (Prior_knowledge_increase - Prior_knowledge_decrease) * dt*

Total study time was assumed to be limited to 400 hours, and decreased with 8 hours per day, as Study time per day (h/d), plus additional time made available through Infrastructural effects.

*Study_time(t) = Study_time(t - dt) + (- Study_time_per_day) * dt*
*OUTFLOWS: Study_time_per_day = 8+(8*Infrastructure_effect)*

Support level has an initial value of 1 and is increased per time unit by Infrastructural effects and decreased by Achievements. The infrastructural effects on Support level is moderated by an Infrastructure effect factor, set to 0.1. The Support level decrease is assumed to be linear against Achievements, and also has the condition to not change if Study time is zero.

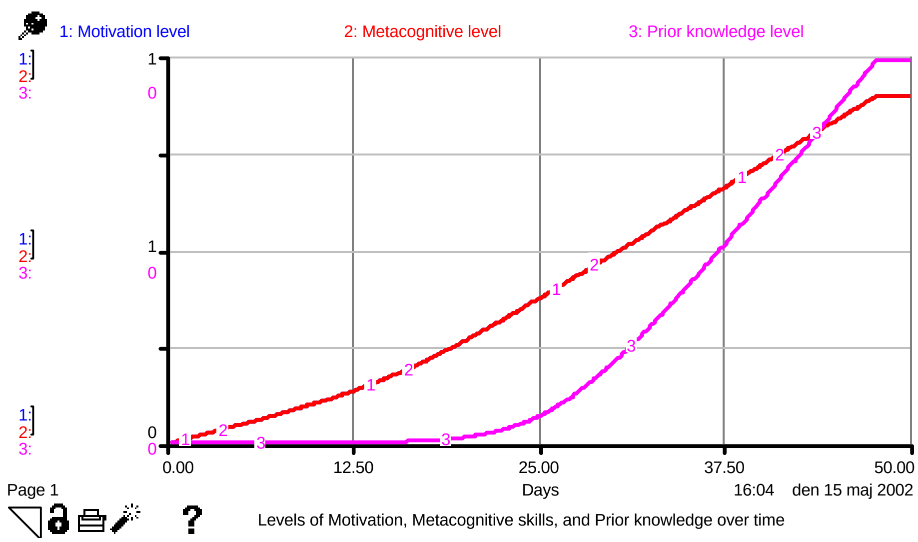
*Support_level(t) = Support_level(t - dt) + (Support_change) * dt*
INIT Support_level = 1
INFLOWS: Support_change = IF (Study_time>0) THEN (Support_increase-Support_decrease) ELSE 0

The Teaching level has similar equations and relationships, except that Teaching level is influencing Motivational and Metacognition levels.

Results

The basic run show as expected an accumulation in Achievements with the Learning, which in turn is increasing the Motivation, Metacognitive and Prior knowledge levels (Figure 3). These three parameters are increasing as long as learning takes place, which is as postulated. They are all levelling off when the Study time is running out.

The infrastructure has a positive effect on the Learning through extending the Study time per day, as well as increasing the Support and Teaching levels.



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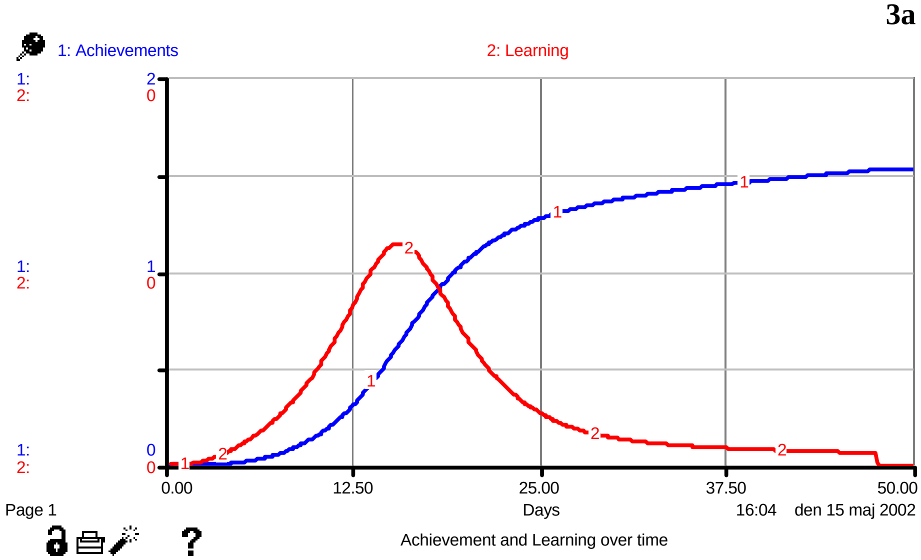

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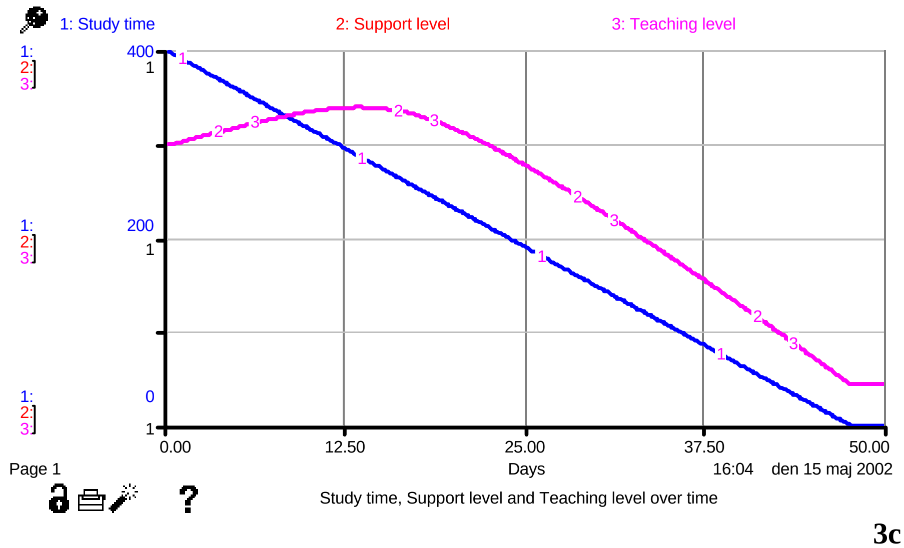


Figure 3. *The diagrams show the base run of the model. Motivation and Metacognitive skills increase with time, until the Study time has reached a value of zero. The Prior knowledge also increases with time, but with a delay (Figure 3a). Learning (line 2 in Figure 3b) is increasing to a peak value at time 15, and then levels off, which is setting the Achievements on a certain level (line 1 in Figure 3b). The variables Support, Teaching, and Study time are all decreasing with Teaching and Support as the limiting factors (Figure 3c). The limiting factor is Study time.*

The base run model show expected behaviour. The initial values and relationships are simple and are assuming a total Study time of 400 hours is available for the Learning.
Study time and Achievements show a decreasing curvilinear relationship, indicating that the Learning is decreasing in the end of the available study time. Learning shows its highest value at day 15 and is then decreasing. The Support and Teaching levels are first increasing and then decreasing as the Study time is used. The Metacognitive skills are first increasing rapidly and then level off, with increasing Achievements, which is also the pattern for Motivational level. The relationship between Achievements and Prior knowledge is also showing the same pattern, but with defined delay.

Infrastructure effects

Infrastructure effects, which in the model are directly affecting the Support and Teaching level, as well as the Study hours per day, are leading to more Learning per time unit and thus higher levels of Achievements. A tenfold increase in Infrastructure effects, from 0.01 to 0.1 lead to 80% higher levels in Achievements, indicating the nonlinearity in the base model.

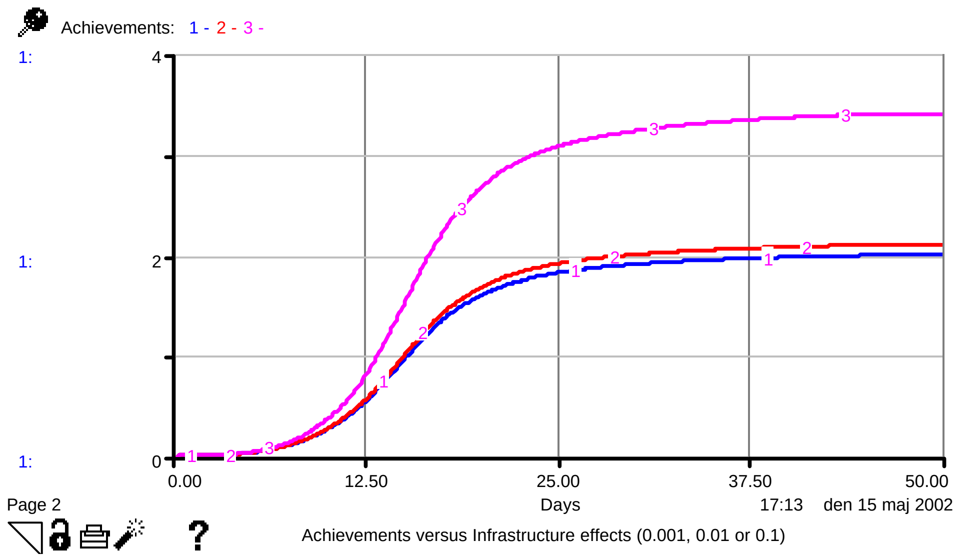


Figure 4. *A sensitivity analysis where, the Infrastructure effect was varied with the values of 0.01, 0.1 and 1.0, which can be interpreted as no infrastructure effect (0.001, or 0.1%), a slight effect (0.01, or 1%, and a 10% effect (0.1), increases the Achievements over time.*

Teaching level effects

Teaching level has an additative effect on the Motivation and Metacognitive levels in this model. An increase in Teaching level will thus not show any major increases in the Motivation and Metacognition levels. If the Teaching level instead would have been multiplicatory in its effect together with the level of Achievements, the result is rather unexpected, shown in Figure 5. The Motivation and Metacognition levels will then never increase and no Learning will take place. This could be suspected to be an artefact due to that the level of Achievement starts at a value of zero, but even if the starting value of Achievement is set to a higher value, the same result will prevail.

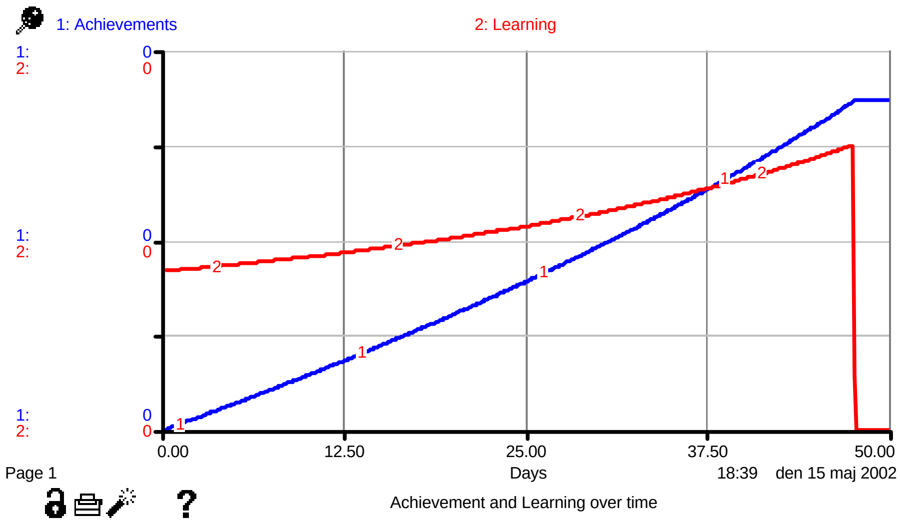


Figure 5. *The effect of Teaching level as a multiplicatory factor affecting Motivation and Metacognition, together with Achievement level.*

Achievement effects

With an increase in Achievements the model will give a linear decrease in Support and Teaching levels. If the relationship is assumed to be nonlinear, pattern B or C in Figure 2, the overall result will be the same, but the timing will be different with a faster learning but also that the dedicated Study time will be finished sooner.

Prior knowledge level is a limiting Learning factor in this model, and by decreasing the effect of Prior knowledge with a factor of 10, will improve the level of Achievements 10-fold, not unexpected.

The delay in the transformation of Achievements to Prior knowledge, set to 10 time steps in the base model, merely influences the constraining effect of Prior knowledge. If the delay is even larger, the constraining effect of Prior knowledge on Learning will accordingly will be later in time. However that will lead to that Support and Teaching levels will be limiting the Learning instead, and will stop further learning before the allocated Study time is running out.

Discussion and Conclusions

Effective learning includes a number of more or less autonomous components that compensate for each other. The purpose of this paper was to describe a model that includes both external factors of both quantitative as well as of qualitative characteristics, with internal qualitative factors, and propose one way of investigate how these factors are enhancing or inhibiting each other. The learning process is of course more complicated than depicted in this model, involving memory types, cognitive abilities, information processing, etc, but is was not in the scope of this model. The scope was merely to propose a way of combining factors that everyone knows are related but do not know how – a perfect but difficult research topic.

Internal factors affecting learning

This model uses four major internal factors; Learning, Motivation, Metacognition and Prior knowledge. These four parameters do of course not cover all internal factors, but I suggest that these are the most important ones. No single factor can do all the work, and it is the orchestration of all that makes learning possible. It is also possible to compensate for weaknesses in one factor using strengths in other. This aspect has not been covered by this model. It is also different combinations that are used for different learning purposes. This is another omitted aspect.

Motivation is often defined as the processes that initiate and sustain certain behaviour (Pintrich & Schunk, 1996). Motivation to learn is about engagement and willingness to learn, to master concepts and skills, and to keep being curious. How can motivation be supported? It is obvious from other investigations as well as from this model that teaching activities that promote motivation is highly awarding in terms of improved learning. What this model is omitting is the clear cross connection between metacognition and motivation that can enhance each other.

How metacognitive abilities are best supported? Again the obvious answer lies in the combinatory effects, and how teaching is defined (Kluwe et al., 1987; Schraw & Mossman, 1995). Maybe teaching shall focus more on teaching on how to learn than the teaching the subject in itself (Brown,1987; Dryden & Vos, 1993; Hattie et al. 1996).

This model establishes a negative relationship between learning and prior knowledge. This is not always true, but is a sacrifice to achieve simplicity. Prior knowledge will often have a positive effect, especially in situations where already known techniques and methods can be applied to a new field or knowledge arena, and thus enhance the learning process.

External factors affecting learning

This model suggest four major external factors; Study time, Support level, Teaching level and Infrastructure, whereof the first and the last are factors that do not encompass any direct feedback mechanism. There is of course a direct relationship between amount of available study time and learning. This model assumes a linear relationship. This is of course only true within certain values, and is probably individually variable, and dependent on the study subject (Ackerman, 1988) . It might be possible to derive certain subject-specific patterns.

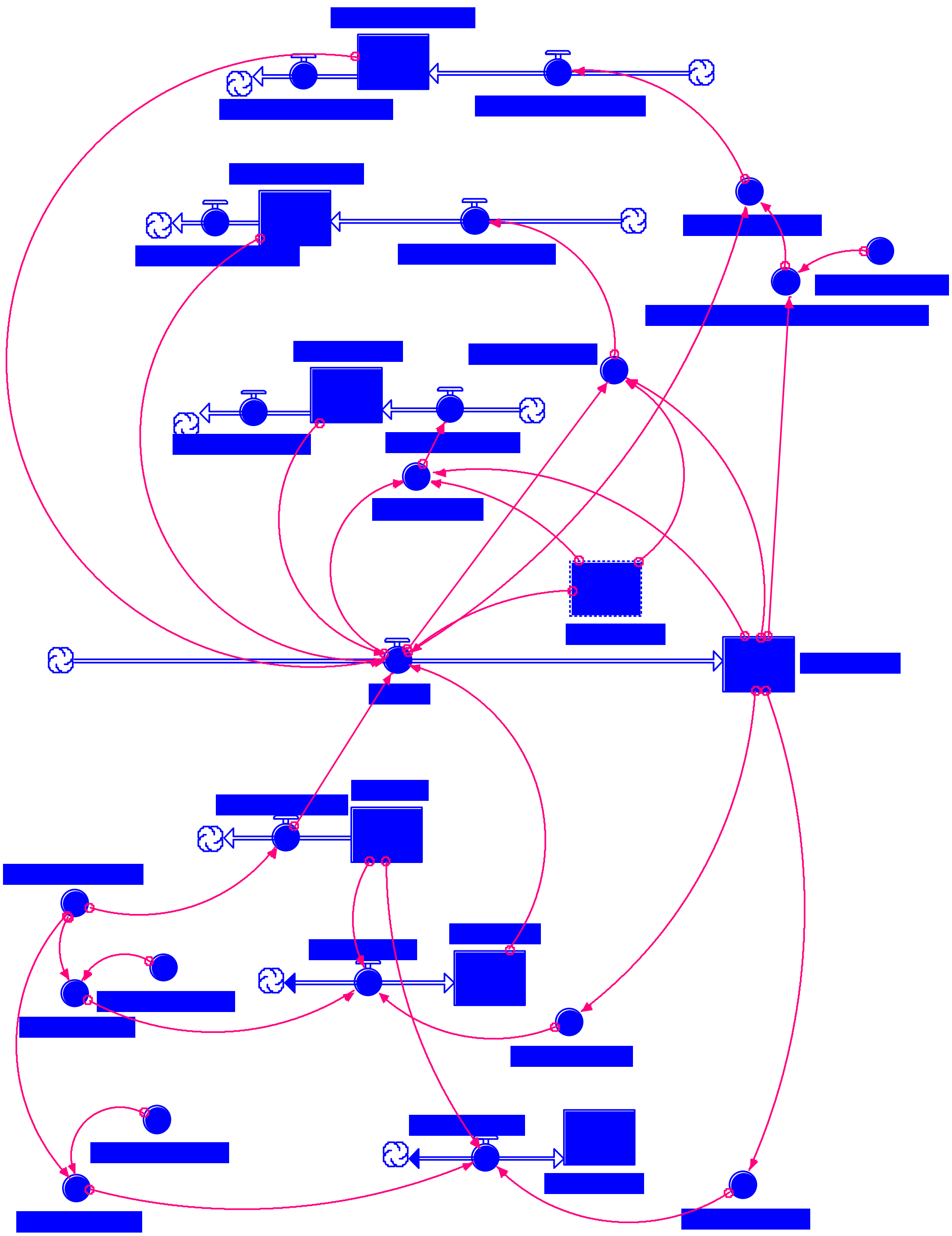
This is probably one of the major factors that restrict the use of this model, as being learning domain-unspecific.

Teaching increases knowledge. But how to make this process as effective as possible, in a limited amount of time and in ways that promote deeper conceptual understanding? This model is not covering such qualitative aspects of teaching, although it could be included. What are the effects of increased infrastructure, e.g. introduction of a learning management system? Can decreased teaching be substituted by an increase in infrastructure? This model actually shows that this is possible, however it is not a one-to-one relationship. By providing better support, increased accessibility to learning resources and further teaching and training in metacognitive skills and motivation amplifying activities, teaching activities can be cut, and this is possible to test with this model. Self-efficacy will likely be a quality that pays off in the future education systems (Zimmerman et al., 1994; Butler & Winne, 1995; Bandura, 1997).

Conclusions - Comparing apples with pears

Is it then possible to compare apples with pears? Yes it is, and sometimes it is inevitable, but often do we not know how. Checkland (1993) addresses this particularly and also compares “hard” and “soft” systems thinking. However, he avoids elegantly the problem of parameterisation of soft variables. It is one thing to define the parameters, and another to define a value for the particular parameter. The model presented here emphasizes this as the values are not important and meaningful, which may be typical for soft variables. I would also argue that the apple versus pear comparison is the quintessence of systems thinking. Many systems are of the transboundary type, not clearly fitting in any systems typology, but nevertheless are resolvable. However, they are challenging and different approaches will always be disputable. Or as Piet Hein been putting it: “Problems worthy of attack, prove their worth by hitting back”.

The model



List of equations

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Achievements(t) = Achievements(t - dt) + (Learning) * dt
INIT Achievements = 0

INFLOWS:
Learning =
study_time_per_day*Motivation_level*Support_level*Teaching_level*Metacognit
ive_level*(0.001/Prior_knowledge_level)


Metacognitive_level(t) = Metacognitive_level(t - dt) +
(Metacognitive_increase - Metacognitive_decrease) * dt
INIT Metacognitive_level = 0.001
INFLOWS:
Metacognitive_increase = Metacogn_increase
OUTFLOWS:
Metacognitive_decrease = 0.001

Motivation_level(t) = Motivation_level(t - dt) + (Motivation_increase -
Motivation_decrease) * dt
INIT Motivation_level = 0.001
INFLOWS:
Motivation_increase = motivn_increase
OUTFLOWS:
Motivation_decrease = 0.001


Prior_knowledge_level(t) = Prior_knowledge_level(t - dt) +
(Prior_knowledge_increase - Prior_knowledge_decrease) * dt
INIT Prior_knowledge_level = 0.001
INFLOWS:
Prior_knowledge_increase = Prior_knowl_increase
OUTFLOWS:
Prior_knowledge_decrease = 0.001

Study_time(t) = Study_time(t - dt) + (- study_time_per_day) * dt
INIT Study_time = 400
OUTFLOWS:
study_time_per_day = 8+(8*Infrastructure_effect) {h/d}

Support_level(t) = Support_level(t - dt) + (Support_change) * dt
INIT Support_level = 1
INFLOWS:
Support_change = IF (Study_time>0) THEN (Support_increase-Support_decrease)
ELSE 0

Teaching_level(t) = Teaching_level(t - dt) + (Teaching_change) * dt
INIT Teaching_level = 1
INFLOWS:
Teaching_change = IF(Study_time>0) THEN Teaching_increase-Teaching_decrease
ELSE 0

Achievement_to_knowledge_transfer_delay_ = DELAY(Achievements,
transfer_delay_term)
infrastructure_effect = 0.05

Metacogn_increase = IF(Learning>0) THEN 0.01*(Achievements+Teaching_level)
+ 0.001 ELSE 0
motivn_increase = IF(Learning>0) THEN
0.01*(Achievements+Teaching_level)+0.001 ELSE 0
```

```
Prior_knowl_increase = IF(Learning>0) THEN
0.01*Achievement_to_knowledge_transfer_delay_+0.001 ELSE 0
Support_increase = infrastructure_effect*S_increase_multiplier
S_increase_multiplier = 0.1

Teaching_increase = infrastructure_effect*T_increase_multiplier
transfer_delay_term = 10
T_increase_multiplier = 0.1

Support_decrease = GRAPH(Achievements)
(0.00, 0.001), (1.00, 0.011), (2.00, 0.021), (3.00, 0.031), (4.00, 0.041),
(5.00, 0.051), (6.00, 0.061), (7.00, 0.071), (8.00, 0.081), (9.00, 0.091),
(10.0, 0.101)

Teaching_decrease = GRAPH(Achievements)
(0.00, 0.001), (1.00, 0.011), (2.00, 0.021), (3.00, 0.031), (4.00, 0.041),
(5.00, 0.051), (6.00, 0.061), (7.00, 0.071), (8.00, 0.081), (9.00, 0.091),
(10.0, 0.101)
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References

Ackerman, P. L. (1988). Determinants of individual differences during skill acquisition: Cognitive abilities and information processing. Journal of Experimental Psychology: General, 117, 288-318.

Alexander, J. M., Carr, M., & Schwanenflugel, P. J. (1995). Development of metacognition in gifted children: Directions for future research. Developmental Review, 15, 1-37.

Bandura, A. (1997). Self-efficacy: The exercise of control. New York: W. H. Freeman..

Brown, A. (1987). Metacognition, executive control, self-regulation, and other more mysterious mechanisms. In F. Weinert & R. Kluwe (Eds.), Metacognition, motivation, and understanding (pp. 65-116). Lawrence Erlbaum, Hillsdale, New Jersey.

Butler, D., & Winne, P. (1995). Feedback and self-regulated learning: A theoretical synthesis. Review of Educational Research, 65, 245-281.

Checkland, P. 1993. Systems thinking, systems practice. Wiley's, London.

Dryden, G. & Vos, J. 1993. The learning revolution. Jalmar Press, Rolling Hills, California.

Eftekhar, N.& Strong, R. (1995) Dynamic modelling of a learning process. Approved for publication in The International Journal of Engineering Education. http://www.ijee.dit.ie/articles/999981/article.htm

Forrester, J.W. & Senge, P. M.1980. Tests for Building Confidence in System Dynamics Models. In A. A. Legasto Jr. (Ed.), *System Dynamics* . Studies in the Management Sciences. (pp. 209-228). North-Holland, New York.

Garner, R. (1987). Metacognition and reading comprehension. Ablex Publishing, Norwood, New Jersey.

Graham, A.K. 1980. Parameter estimation in system dynamic modelling. In Randers, J. (ed.) Elements of the system dynamics method. The MIT Press, Cambridge, Massachussetts.

Hattie, J., Biggs, J., & Purdie, N. (1996). Effects of learning skills interventions on student learning: A meta-analysis. Review of Educational Research, 66, 99-136.

Kluwe, R. H. (1987). Executive decisions and regulation of problem solving. In F. Weinert & R. Kluwe (Eds.), Metacognition, motivation, and understanding (pp. 31-64). Lawrence Erlbaum Press, Hillsdale, New Jersey.

Marton, F. Dall'Albam G. & Beaty, E. 1993. Conceptions of learning. International Journal of Educational Research 19: 277-300.

Min, R., Vos, H., Kommers, P. & van Dijkum, C. 2000. A concpet model for learning. Journal of Interactive Learning Research 11(3-4): 485-506.

Pintrich, P. R., & Schunk, D. H. (1996). Motivation in education: Theory, research, and applications. Prentice Hall, Englewood Cliffs, New Jersey.

Pressley, M., & Ghatala, E. S. (1990). Self-regulated learning: Monitoring learning from text. Educational Psychologist, 25, 19-33.

Richardson, G. P. & Pugh III, A. L. 1981. Introduction to system dynamics modelling. Productivity Press, Portland, Oregon.

Roberts, N., Andersen, D., Deal, R., Garet, M. & Shaffer, W. 1983. Introduction to computer simulation. A system dynamics modeling approach. Productivity Press, Portland, Oregon.

Rosenberg, M. J. 2001. e-Learning. McGraw & Hill, New York.

Schraw, G., & Moshman, D. (1995). Metacognitive theories. Educational Psychology Review, 7, 351-373.

Sterman, J. 2000. Business dynamics. McGraw & Hill, New York.

Zimmerman, B. J., Greenberg, D., & Weinstein, C. E. (1994). Self-regulated academic study time: A strategy approach. In D. Schunk & B. J. Zimmerman (Eds.), Self-regulation of learning and performance: Issues and educational applications (pp. 181-201). Lawrence Erlbaum, Hillsdale, New Jersey.

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