Learning 4.0

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Abstract

Established didactical methods and models of learning are determined by the question where learning content is stored and how it is accessed. The digital transformation of information storage and access therefore necessitates new models of learning and dramatic changes in educational systems. In this article, these new learning paradigms are outlined, classified and weighted for their disruptive impact on societal and industrial processes – ranging from the *everywhere, everytime* of digital mobile devices to human strategies for coping with information overflow.

1. Introduction

Formal models of learning were rare before the 19th century (COMENIUS 1654, KANT 1803), and paradigms such as behaviorism, cognitivism and constructivism blossomed to maturity only in the 20th century. To a large extent they still dominate our view on education in the 21st century. Many teaching persons in all parts of the educational system design their teaching material after one of these paradigms because they believe that these models and their derivatives describe in fact the human mind and therefore are independent of technological and societal changes (ERTMER 1993).

Such an instructional design however ignores the simple fact that up to now the “human mind“ cannot be observed directly. Rather, “human behavior“ is observed – and any conclusion has to go backward, estimating the cause from the effect. In doing so one immediately finds that our learning behavior has undergone dramatical changes in the past 20 years. In searching for a particular public information, adults nowadays rather use a search engine than a large printed encyclopedia. No wonder, one might exclaim, since according to numerous studies internet resources such as Wikipedia are better maintained, faster updated and much larger in volume than printed encyclopedias have ever been.

Today, information is accessed differently also in the professional regime. While two decades ago we were discussing whether internet usage at a work place might not impose a severe drain on the resources of an enterprise, we now find the opposite: Hardly any work place for knowledge workers comes without internet access. Certain branches of our modern industry, like e.g. software development, are indeed completely helpless without internet usage. No platform demonstrates this more profoundly than http://www.stackoverflow.com – the knowledge platform for all kind of technological stuff. On an average workday, an average number of 4,000,000 engineering people from a variety of fields all over the world are exchanging information on this platform at a highly professional level.

A change in learning behavior is also found in top quality scientific research, where preprint services have increased the speed of publication tremendously. Starting 1991 from a small archive for physics papers running on an 486-computer in the Los Alamos National Laboratory, the service http://www.arxiv.org has surpassed the landmark of more than 1 million scientific articles from various fields in January 2015, and currently is getting new submissions of more that 10,000 articles per month. Furthermore, the cost model for scientific publication is toppling over in 2017 following an increasing pressure to publish in Open Access journals, where the author‘s institution pays for publication rather than the reader‘s organization. The DEAL project (see https://www.projektdeal.de/) intends a significant reduction of the estimated 7,600 million € annually paid to publishing houses by German libraries and scientific institutions.

Thus, we have to address the question whether these observed changes in learning behavior are merely customary adaptions that might pass like last year‘s fashion. If this were true, we could maintain our learner models as they have evolved in the 20th century. However, if finding that these changes go deeper and are indeed irreversible changes to society, we should rather develop new paradigms for learning very rapidly. To this end, let us first discuss the established learning paradigms from the viewpoint of the digital age.

2. Behavioristic learning in the digital age

In the behavioristic learner model the human mind is a black box. “Learning” consists of linking a stimulus (the input) to a desired response (the output), without ever needing to discuss the cognitive processes behind this linkage. Two examples demonstrate that this type of learning indeed has its place in the digital age.

1. Consider students in knowledge communities – irrelevant whether they are of more serious type or just (mis-)using Facebook or WhatsApp. In these knowledge communities the frequency of help requests rises tremendously on Sunday afternoon, when next day’s school visit and therefore teacher control of homework assignments are looming. These help requests are going as far as to ask for complete seminar papers or essays, and it may be assumed that these plagiates are then really presented at school.

   The same problem arises in higher education, where plagiates are even more important because academic degrees still are the canonical way to higher social status and income. Consequently, university plagiarism has turned out to be a business case - services like http://www.assignmentking.com are becoming very fashionable. They even claim to provide results that cannot be discovered with plagiate checking software. Apparently plagiarism has become more severe than one would like believe: A systematic survey carried out by australian universities on the originality of “scientific” Master’s Thesis writing reaches the conclusion, that 25% of them are plagiates.

   Digital methods therefore allow to *simulate* learning, they help indeed to establish dysfunctional mappings from input to output in the behavioristic model.

2. Consider players of a massively parallel online role game: In general they do not read manuals or study screencasts of previous game rounds. Rather, they jump into the game and learn by “observation, imitation and modeling”. Even skilled players are seldom able to perform an abstraction of their success, or to derive formal rules from being skillful. All classical elements of the behavioristic paradigms such as punishment (loss of one’s virtual status or life) and reward (as reaching the next level) are identifiable.

   This informal learning is indeed behavioristic, and has been described accurately in Bandura’s model of *Social Learning* (BANDURA 1977). According to this model (not a theory…), people learn from one another, via observation, imitation, and modeling. The Bandura model includes concepts such as attention, memory, and motivation, and therefore is much closer to reality than other behaviorist examples.

   Social informal learning below the cognitive level, in particular through gaming elements, therefore has its representation in the behavioristic model.

3. Cognitivistic learning in the digital age

The cognitivistic paradigm tries to open the behavioristic ‘Black Box’, to see, understand and modify the inner workings of the learner. Since that is the model of programs running on the human computer, cognitivism is the learner model seemingly best suited to the digital age. But what is the proper method to write these programs? Cognitive scientists have tried this for decades, and now well-established “programming” aids such as rehearsal models, the loci method or gesture supported learning (MOÈ 2005, MACEDONIA 2011) as well as infamous pseudo-scientific models exist like e.g. NLP (“neuro-linguistic programming”).

Still, the big unsolved question of cognitivism is: What exactly is the physical difference between a brain that has learned – say a new word in a foreign language – and the same brain before this learning was achieved ?

From 1962 until a few years ago it was thought that this difference is a biochemical ingredient (RNA, to be precise) that might even be transported from one individual to another (MCCONNELL 1962). However, since the work of the latter Nobel Prize awardee Eric Kandel a much more complicated picture has emerged (KANDEL 2007): Thousands of molecules as well as epigenetic switches are – somehow – involved here.

Nevertheless, even today we may clearly state: So far, nobody has understood the programming language of the human computer – and therefore a cognitivistic learner model is useless for *our share* of digital age.

4. Constructivistic learning in the digital age

Our understanding of learning took big step forward when the learner model of constructivism was developed around 1970. According to the constructivistic paradigm, learning is an active process by the learner (ignore the teacher for now). A learner therefore expands his knowledge by *contructing* a mental representation of the outside world (COOPER 1993). From the viewpoint of computer science, this model is very appealing because of its analogy with the World Wide Web, where knowledge is *built* by linking items (JONASSEN 1999).

Closely related to this construction idea is the development of artificial neural networks, going on for a few decades now. These neural networks are, simply spoken, computer programs simulating several layers of coupled artificial neurons. They are trained by exposing them to example patterns, which leads to the *building* of an inner representation. A properly trained neural network is then able to recognize these patterns also in much more complicated input data. One could therefore argue, that with the digital age we have finally discovered how learning really works: By programming neural networks.

In 2017 we are even able to demonstrate this success of neural networks with exciting new technologies. It has only recently become possible to run such neural networks involving many layers of neurons. Together with an immense volume of statistical data for training of such *deep learning* networks, this technological break-through has led to spectacular progress in several fields: Automatic translation of content from one language to another, autonomous driving and speech recognition are milestones of this understanding.

However, this analogy has to be seen rather critical – because a difference exists between *building* and *construction.* Even simple animals are building things, like e.g. spiders do build their beautiful webs. But these are *not rationally planned*, and therefore, in the language of an engineer, *not constructed*. Indeed, even in simple and much more so in deep neural networks we do *not* have an understanding on how the internal representation is mapped to the external world. Therefore we cannot produce artificial neural networks that have a well-defined *a-priori* knowledge. A neural network therefore is a ‘Black Box’ mapping input to output in some unintelligible fashion - and we are suddenly thrown back to the behavioristic model.

The key to understand constructivism in the digital age can be found when looking at a statement advertized by this model even since its early days: *Constructivistic teaching has to pick up a learner where he is now* and has to induce in him new concepts and relations. Constructivistic learning therefore means: One already has a set of terms and relations – an ontology in the language of computer science.

Ontologies are a key ingredient of the Semantic Web, which even now seems to be the future of the World Wide Web (BERNERS-LEE 1999). In the semantic approach, data is accompanied by meta data (=annotations) from different views or knowledge fields (=domains), which allows to deduce the *meaning* of the data. This meaning then allows classification of the terms and relations and is currently considered to be the correct state-of-the-art model to store knowledge (STAAB 2001).

Constructivistic learning therefore consists of the meaningful and planned extension of the learner‘s given ontology. By considering analogies from this given ontology, the constructivistic learner is adding new terms and possible relations among them to his ontology – leading also to new statements and *hypothesis building* about classes of objects. By falsification of such a hypothesis then new classes may be formed, not simply building but instead *constructing* an improved mental model.

5. Connectivism – a new model for the 21st century?

The first genuine 21st century model of learning came up in 2005 when Siemens picked up the term *connectivism* already known earlier to describe the changes in learning behavior due to technological advances. The model has evolved considerably since then (DOWNES 2010), but even now is based on the same eight principles (SIEMENS 2005):

- *Learning and knowledge rests in diversity of opinions.*
- *Learning is a process of connecting specialized nodes or information sources.*
- *Learning may reside in non-human appliances.*
- *Learning is more critical than knowing.*
- *Maintaining and nurturing connections is needed to facilitate continual learning.*
- *Perceiving connections between fields, ideas and concepts is a core skill.*
- *Currency (accurate, up-to-date knowledge) is the intent of learning activities.*
- *Decision-making is itself a learning process. Choosing what to learn and the meaning of incoming information is seen through the lens of a shifting reality. While there is a right answer now, it may be wrong tomorrow due to alterations in the information climate affecting the decision.*

Long papers could be (and have been) written criticizing these “principles” - starting at the topmost principle which emphasizes “opinions” and ending at a semantic analysis of such unprecise non-terms as “information climate” (CHATTI 2010). To summarize the most crucial aspects:

Connectivism is not a complete model of learning, but is focused on a small aspect of constructivism – the linking of top-level knowledge nodes. Neither the internal structure of nodes (and their evolution), nor algorithmic aspects of learning such as reflection, recursion and the cycle of inductive hypothesis building and deductive reasoning are contained. Moreover, the influence of the teacher is treated like some random disturbance, decoupled from the structure of the network as well as from the knowledge domain and not at all influencing the outcome of the learning process.

6. Recent advances in constructivistic learning

Having outlined the most common models of learning, we now take a step backwards and look at the famous question asked by Kant in the early stages of educational theory: "*Wie kultiviere ich die Freiheit bei dem Zwange?* (*How do I cultivate freedom in light of force?*, KANT 1803). As he understood correctly, every educational action employs a certain amount of force acting on the learner. It is then necessary to prove to the learner that this force is used for his own good, i.e. guiding him to the use of his own freedom.

The model of connectivism, to a certain extent, has shown the proper direction: Liberate the learner to make his own choices in building his own personalized knowledge network, but not without guidance and not without meaningful structure. The necessary guidance must encompass

- General pedagogical knowledge accumulated since the age of Comenius, i.e., a pedagogical ontology (SWERTZ et. al. 2014).
- Domain specific knowledge addressing the specific didactical needs for a field of knowledge (=domain), called a Cognitive Map and possibly also written as an ontology.
- Specific knowledge about the available learning material, called a Cognitive Content Map.
- A fourth ontology comprising the knowledge about this particular learner, his abilities, his learning history and learning environment.

T understand the structure of a personalized knowledge network we consider each small and indivisible (=atomic) *Knowledge Object* (KO) as contributing a single bit to a possible very large string describing a *cognitive position* of the learner. If we assume that the field of knowledge (=domain) consists of *N* such KOs, the cognitive position of each learner in this domain corresponds to a corner of an *N*-dimensional hypercube.

In this hypercube model, depicted in Fig. 1 for a simple case of four KO,

- *Learning* is a movement of the cognitive position within the hypercube. This trajectory of the learner's cognitive position is called a *Learning Pathway.* A huge number of possible learning pathways exist (*N*! for *N* KOs) – this is what makes learning so individual.
- *Teaching* consists of leading he learner along one or another predefined learning pathway to achieve the desired goal, i.e. is a *Learning Pathway Recommendation.*

This hypercube model of learning is independent of how the learning material is presented. It may be applied to all modalities of teaching, including classroom teaching, self-paced learning by reading books or viewing videos as well as to technology enhanced learning (TEL) with the help of a computer (MEDER 2006). Indeed, the latter has given birth to this formalized hypercube model of the learning process through the European research project INTUITEL (HENNING 2014a, 2014b, FUCHS 2016, 2017). In this INTUITEL project, learning pathway recommendations are issued to the learner based on the four layers of ontology described above – and some of the leading Learning Management Systems have been equipped with the capability to do so.

In establishing this *counseled freedom of choice,* the hypercube learning model does not consider the learner as a separate entity. Rather, the recommendation system (which may be of human nature, of course) and the learner are a joint system. For the case of a technical recommendation system, a model of such joint entities has been termed a *hybrid actor* (LATOUR 1996), which clearly has more capabilities than either the human learner or technical computer alone. In excerting this freedom of choice in the learning process while still being guided along certain learning pathways, the learner then follows the cognitive process called planned behavior (AJZEN 1991).

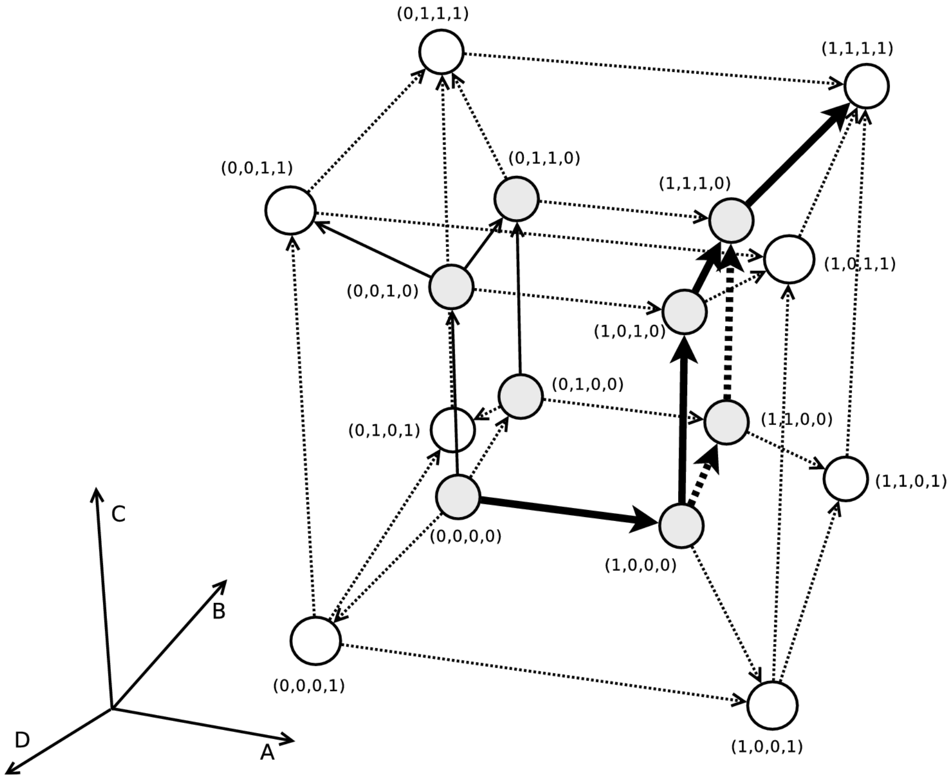

Fig. 1: Four-dimensional cognitive space describing a learning process with only four KO. The model (which is explained in greater detail in FUCHS 2017) here shows two exemplary learning pathways leading form the state (0,0,0,0) = nothing learned to the state (1,1,1,1) = everything learned.

7. Closing the loop of human learning and machine support

One of the key capabilities of a hybrid actor consisting of a human learner and a machine supporting him is the accumulation of precise meta data about the learning process. Only with the support of an advanced learning management system one may register traditional factors like „progress“ and „knowledge level“ together with other data, like e.g.: How much of which KO has been seen? What is the current speed of learning? Can one infer anything about the learner‘s mood from the speed of typing? Can one track the eye movement across a text or image?

Data mining in this (possibly) vast amount of data and concluding anything on the learning process is the focus of *learning analytics* – aiming at an improval of the learning process (FERGUSON 2012). However, first of all one must constitute that in most cases the big word of learning analytics only hides the small reality of measuring classroom performance of employees or students. In particular, most implementations of learning analytics in the commercial sector do not go beyond this. Secondly, it is a completely open question what an *improval of the learning process* could be: Learning faster? Learning more? Improving the learner experience? Or possibly a combination of all these?

- Consider learning speed: If a learner is found to pass through the pages of a course very rapidly – is that a good sign because he knows already and just wants to repeat the content ? Or is it a bad sign because we have lost his attention ?
- Does one really improve learning by adjusting the speed of text presentation such that a constant stress level of the learner is measured (as was done in a recent experiment) ?

It is, very bluntly spoken, not known in general what the proper pedagogical reaction to an arbitratry learning analytics datum could be. Obviously this points towards a weakness of most learner models: They do not allow correction of the learning process by measured data.

While INTUITEL tries to cure this in e-Learning environments by making them adaptive according to ontological data, also other examples exist that hint towards the immense potential of tracking human behavior in learning: The 2010 project "Text 2.0" (see https://text20.net/) introduces a new dimension in the old informational access method of reading by making it *interactive*, *responsive* and *multi-modal*. Clearly, this may be the future of textbooks – but what is really improved here, remains unanswered.

More research therefore is needed, and the learning models that we outlined above need to be extended by proper input channels of real world data.

8. Informational Reality: Mobile first, Upload second

Through numerous studies we know that in the leading industrial nations a vast majority of the adult population owns a mobile digital device – mostly in the form of a smartphone. This geosociological group is defined by having a nearly permanent connection to the internet, and therefore an *everywhere-everytime* access to learning material. Also, this group is expanding rapidly, like e.g.

- in terms of age: Groups of small children will cluster around any of their peers owning such a device already at very young age, and even some seniors of 90 years of age are keen to use such a device.
- in terms of device quality: The educational startup Eneza http://www.enezaeducation.com is providing online courses via old-fashioned non-smart cell phones already to 2 million learners in Africa – targeting at 50 million.

Moreover, information flow is now bi-directional: Actively asking questions in knowledge communities, posting information on social networks, self-organization using instant messages and other uplink methods together with the downlink access possibility has driven learning beyond horizons we imagined even a few years ago and now determines the *informational reality.*

Clearly, this combination of downlink information search and uplink publishing possibilities signals the beginning of process that will be highly disruptive to the eductional systems. For example, already 2014 more than 40% of all school students in Germany admitted to learn for school purpose by using publicly available video sequences – but had to do so outside school (POLS et.al. 2014) since the school system so far is unfit to integrate this learning behavior into its methodology. As a consequence schools and in the long run also institutions of higher education will lose the motivation of their students if they do not take up this informational reality and integrate it into their teaching paradigms. Educational institutions banning mobile digital devices from certain locations or at certain times are fighting a losing battle.

Also the corporate learning and knowledge management area will be affected. A smartphone is not only a communication device (with huge impact on work-life balance and organizational aspects, that are outside the scope of this article), but a device to store, share and transport knowledge. This has a dark spot nevertheless: Huge damage may be the consequence, if such a mobile knowledge device falls into the hands of competing business adversaries – or if knowledge is deliberately transported outside its intended geographical boundaries. Certain car manufacturers therefore do not allow visitors to bring cell phones with camera, much less smartphones along to business visits to their labs.

Clearly, also these companies fight a losing battle: Digital cameras are now so small that they fit into pens, watches, eye glasses – and cannot be recognized by their outer appearance.

Another dark spot arises from the fact that the uplink methods allow to spread and to share information independent of its validity, moreover, they allow to offer guidance towards learning pathways. Some of these learning pathways are harmful or fatal, not only to the learner but also to his environment. While "alternate facts" have been around for centuries, it has only now become possible through digital media to present these to a significantly large audience and to (wrongly) relate them to "true facts" by seemingly logical reasoning. However: hearing, reading or otherwise receiving invalid information (or "alternate facts") does not yet imply *believing* it – other factors must be present.

A major additional factor is disclosed by the model of *Satisficing* as the basis of decision making (SIMON 1956): In a situation with high information flow, humans tend to make decisions on a basis as simple as possible – and rather accept sub-optimal solutions than informational complexity. In other words: The dominant human strategy in a situation with information overflow is the reduction of one's thresholds and expectations.

It is generally easier to (wrongly) generalize from isolated examples, i.e. to follow *inductive* methods, than to understand a possibly complicated rule system and then to *deduce* a prediction for an isolated example. Satisficing therefore also leads to a preference for *inductive* over *deductive* reasoning methods in situations with high information flow. It is, for example, easier to believe that a wall across a continent would secure the future than it is to believe that the education of a skilled workforce would produce this security.

These three factors - *everywhere-everytime* upload ability, inductive reasoning and *satisficing* therefore prove that certain populistic political figures as well as terroristic organizations of the current style are straight consequences of the current informational reality.

9. Learning 4.0

Finally, we are therefore able to collect the pieces of our analysis to describe the most probable *future learning model.*

- Future learning will be *digital to a large extent*. The amount of knowledge that we have assembled is so big, that the last scientifically sound estimate of the world data volume was done in 2003. Today, only big commercial players have the infrastructure to perform such estimates – and one has to trust them about their finding. Management of this data volume can only be achieved through technical support. This will most certainly not mean that learning will occur *only* through digital media, nor will this be the death of the traditional printed book.
- Future learning will be *network-oriented*. Fellow humans that we meet in social networks, digital databases, knowledge archives of all types and a diversity of other sources will be linked together to form our personal knowledge network– much in the sense of the connectivistic paradigm, but clearly not in the form of „opinions" as suggested by connectivism.

- Future learning will be *diverse*: Informal learning environments where social learning takes place (see the section on behaviorism) may be intermixed (spatially as well as in time) with formal learning environments where one follows a well defined learning pathway.
- Future learning will be *constructive* in the sense of controlled and planned ontology buildung. To achieve this construction (as opposed to simple building) also in informal learning environments does however *not* require a stronger or central control of learning processes.

  Rather, it requires a self-confident media critical competency in every learner such that he (or she) is able to exert some control over the own learning process – a well-trained meta cognitive competency must be present in order to achieve organized learning processes. Demands to include computer science into school curricula (exceptionally well done in Great Britain with the National Curriculum Computing at School, see http://www.computingatschool.org.uk) therefore are not targeted at the production of programmers for the industry. Rather, they are to be seen as teaching the *algorithmic competencies* for constructive learning, and are included as one of the most important skills in consideration of 21st century skills (see e.g. http://www.p21.org/our-work/p21-framework)
- Future learning will be based on *semantically enhanced material*. Not only allows the existence of semantically different views on data items their re-use and is the basis for its sharing. But understanding the meaning of data is mandatory to exert the meta-cognitive skills named above. The rapid learning of short pieces of knowledge (or KO) is tremendously easier when it is clear how and where they fit into the existing ontology.
- Future learning will be *individualized* and *adaptive.* As we have shown in the INTUITEL project, the individualization is possible including various layers of knowledge about the learner, the learning material and the learning environment. Each of these factors varies with time and space. While learning in general will be possible independent of space and time, one may achieve a learning process that is strongly coupled to the spatial and temporal location. The future knowledge worker may be able to prepare himself for his daily work equally well in front of his desktop computer or using his smartphone in the commuter train – but the process will be different in both locations.

Reconsidering the historical development, we then clearly see how this future learning fits in. The first stage of learning was strictly behavioristic and informal: Some skills had to be acquired, or you were punished. The second stage of learning gave rise to formal learning environments (such as our school and higher education systems) – but still without a plan. The third stage of learning then installed pedagogical models of all kind in the formal learning environments – but still these formal learning systems were unable to put the human *individual* in the center of the classroom teaching. The aspects of *future learning* outlined above will change this dramatically, as we have now understood the informational aspects of learning more clearly and will be able to implement constructive learning also in the mixed learning environments of the future. We are therefore stepping into the fourth stage of learning – or „Learning 4.0“.

Obviously, the answer to our initial question therefore is a comlpex one (who would have guessed that …): Our society has changed tremendously, and the change in learning behavior is not just a “digital fashion“ that one may ignore. Rather, it is deeply interwoven with the societal changes, and cannot be reverted as long as we are living in the informational reality outlined above. On the other hand it is exactly this informational reality that has provided us with the proper knowledge about *Learning 4.0*, assigning it a proper place in the hierarchy of established learning models. Also, the informational reality provides us with the tools to cope with the information flow.

The informational reality in turn is man-made, i.e., it is a reflection of the societal changes. In principle one may even argue, that we (as humans) always invent exactly those methods and tools that are necessary for the current situation. One could label this *innovation efficiency*, in analogy the formation of efficient financial markets known from the economical sciences.

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