VISUALIZATION IN EDUCATION
Support for the Cognitive Processes in Understanding and Learning

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Abstract: This paper presents examples illustrating the shortcomings of verbal communication, in particular in new contexts, within heterogeneous groups, and in complex situations. In a rapidly changing, multi cultural, and complex world, the words are interpreted differently by different people and at different times. Our understanding of the words is grounded in our own accumulated experience, our perceptions from all senses from different situations. It is a tradition in many academic disciplines to base the teaching and the courses solely on textbooks and verbal communication. Many project models are based upon delivery of text documents assumed to convey information, or understanding, from one project phase to the other. Today there are good reasons and also good possibilities to use visualization, or perceptualization if not only vision is involved, by means of computer systems to enable better communication and understanding.

1 INTRODUCTION

After being involved in education and research, primarily at the university level, for over 45 years, it is natural to look back to the collected experience and to reconsider some of the basic ideas and methods used. During this period, some novel approaches have appeared, sometimes disappeared for some years and then reappeared again. The contents of the courses, educational programs and research projects, as well as the aims and methods used, have been subject to change. Some of the new waves or trends may have been very local and particular for each country or each sector. Other may have been more general and global.

Some of the development the recent decades needs attention:

- The general globalization and its impact in particular on small countries like Sweden. Almost all activities must be multilingual and multicultural and have a global focus
- The complexity of our social, organizational, and technical systems is at such a level that a team of experts and practitioners from many disciplines, sectors, and cultures, is needed to jointly understand and solve the evolving problems.
- The development speed. In most cases, you have to frequently expand what you have understood and experienced before, to include new and unknown concepts and components

However, the development does not only create difficulties and obstacles. There may also be support and solutions for better understanding and learning.

- The development of Internet where everybody (at least in the younger generation) is always connected and available for multimedia interaction.
- The development of World Wide Web with Wikipedia, Google, YouTube *etc.* as components in a continuously growing and always available global multimedia library.
- By means of visualization, maybe in the shape of 3-D virtual reality, we are able to make our imagination available to be explored interactively by others
- Achievements in cognitive science based on *e.g.* better instruments like *Magnetic Resonance Imaging*, MRI, to study brain processes, and *Artificial Neural Networks*, ANN. to model and simulate them, have enabled an emerging understanding of the biological basis for the learning and thinking processes.

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2 OWN EXPERIENCE FROM TEACHING AND FROM RESEARCH

There are many situations where text and documents are the main means to convey knowledge, understanding and mental models from one group to the other, where teaching means to tell the students, orally or in writing, what is right or wrong, and in detail what to do, step by step. There are also situations where we want to focus more on training critical and innovative thinking, where we challenge students and stimulate all their senses when presenting unsolved problems, questions without known correct answers, *etc*. Both approaches are appropriate depending on the subject and on the particular aims. However, it is my experience that the first, the truth telling one, is used also in many cases where the second, the challenging one, should be considered. This section presents a few such cases.

2.1 The Importance of Shared Visions and Team Learning

At least three of Senge's (1990) five disciplines, *shared visions*, *mental models*, and *team learning*, have immediate relevance for this subsection. A longitudinal case study (Cederling 1992) at the Swedish company Philips Elektronikindustrier, PEAB, (later Celsius Tech Systems) during 1985-2000, followed the development of a new command and control system, SS2000, for a family of naval vessels. The system should be based on an entirely new Ethernet based hardware architecture and implemented in a new programming language, Ada, by means of a new programming environment, Rational RS6000. In the contracts with the customers, it was prescribed that a traditional document based development model, DOD-STD-2167A, should be used. This standard forced PEAB to develop a large volume of specification documents early in the project. Documents intended to prescribe what to do, when and how, in later phases.

What was found (Lennartsson 1997), in short, was that despite the highly qualified team involved in the production of all the documents, when questions arose later in the projects, the answers could in general not be found in the documents, simply because these questions had not been foreseen by the document writing teams. Hence, all the files, prescribed by DOD-STD-2167A, were as such of little value. However, they were very useful indirectly. In PEAB they found that the team involved in the development of the files had the capacity to answer the new questions rather directly. In the previous discussions they had developed a shared understanding and established concepts and mental models at the team level. As the teams were still available within the company, they could be used frequently to jointly answer questions and solve problems whenever needed (Cederling 2000).

Conclusion: The large volume of documents produced was as such of very little value, but the effort spent in the development was not wasted, as the team learning achieved was the very important major result. However, it was not possible to pack this capability and carry it through just as texts and diagrams in the files.

2.2 Managing a Moving Target

Another example of the shortcoming of specification documents is from Ericsson and their development of the AXE-10 system generation. In a case study Lars Taxén (1999) found that in a typical subproject, 8-12 months long, about one third of the requirements defined, after careful screening at start-up, were canceled before delivery. About the same amount, not even considered when the project started, had later been added and included in the delivery. These changes were due to competitor moves and to the very fast technological development in the area, telecommunication networks. The organizational setting had to be adapted to this very dynamic situation. The development teams had been given the responsibility and the power to take the decisions they considered necessary. Time did not allow for slow committee decision processes.

Also in this example a capacity and a readiness of a team is required rather than canned documents with instructions.

2.3 Communication in Heterogeneous Teams

A couple of case studies at Whirlpool (Ekinge 2001) during the 1990s also observed the limits of text and verbal concepts. During the development of a new strategy for a development team, the emerging new vision was gradually manifested by means of diagrams, keywords, slogans, and phrases. However, when a new member of the team was hired, they found that they had to restart the process almost from the beginning to enable this person to become holder of the new vision. The new member didn't share the interpretation of the slogans, diagrams, etc., with the rest of the team. The shared meaning and interpretations of the concepts used had been created and established during the previous discussions and were not transferable to the new member.

2.4 Coordinating Distributed Mega-projects

The development of the architecture and the components of Global System for Mobile communication, GSM, within Ericsson, was a very big and complex effort, organizationally as well as technically. Over 10 000 persons were involved all over the world, and there were a lot of new and yet unknown problems and solutions to handle. Just as in the AXE-10 projects mentioned above, project management had to be rather distributed. The top-level management had to focus on co-ordination and support rather than to prescribe details in systems and processes. It became important to establish means for communication and to enable flexibility and updates in the meaning of concepts, in the process model, and in the system architecture. A notion of functional anatomies was introduced and used successfully. Just as for the cases in the previous subsection, the use of verbal or language concepts were not sufficient for the communication or co-ordination, as there was not any shared interpretation of these concepts in the new context and in the global and heterogeneous community of persons involved. The experience from the coordination of the GSM effort within Ericsson has been presented in a PhD thesis (Taxén 2003) and in a forthcoming book (Taxén 2009).

2.5 Top-down vs. Bottom-up

Yet another example is from the experience of how to organize courses in computer programming (Lennartsson 2006). Computer programming is rather unique compared to other subjects I have been teaching. It is about understanding a lot of new and interrelated concepts. To describe one of them you have to use several of the others. The traditional bottom-up approach is not very appropriate. The situation is more like jumping into the unknown and successively discovering the different patterns, and more and more about how they are related. Understanding comes in a very large number of very small steps, and the student has to take each step her/himself in her/his own pace. The aim is not that the student should learn just to understand and copy programs already written, but to enable the student to solve new problems by means of entirely new computer programs (Lennartsson 2004). There is an obvious similarity with the situation where infant child is observing the environment and finds patterns in the perceptions. As there are no existing and understood concepts to start from, we can't achieve our teaching goal just by communicating solutions. A better approach, in the programming course, is to let the student experience rather carefully designed situations. Each student has to start from and build upon her/his own existing experience and mental models and develop the new understanding and capability. There is one more reason for the individual learning and individual feedback and supervision. It is my experience that about 10-20 % of the students are not comfortable with situations where they have to do things before they know which way to do it is a correct one. This is a serious disadvantage when learning programming. The situation where you really learn is when you have written some code that doesn't work, and you are figuring out why it doesn't. It is debated whether such a learning style is in the inherited part of the personality or not. Some research on twins in relation to the Human Dynamics concept (Seagul & Horne 1997) indicates that there may be a genetic component.

3 INDICATIONS FROM BRAIN RESEARCH AND SUPPORT FROM VR TECHNOLOGY

In recent decades (Sylwester 2007) new tools and methods have become available to observe and model processes and basic mechanisms in the brain. There are different kinds of Magnetic Resonance Imaging, MRI (WIKI_MRI), to identify areas in the human brain in different situations and as a result of different stimuli. There is an increasing understanding of what is going on at the microscopic level; the electrical and chemical processes taking place within and between the cells (Sylwester 1995). There is also a larger and more elaborated modeling of this in Artificial Neural Networks, ANN (WIKI_ANN). However, there is still a very wide gap between the observed behavior and the MRI results at the macroscopic level, and the microscopic phenomena. Despite this, it is possible to make assumptions and define hypotheses how our emerging understanding of the brain processes could influence our view of thinking and learning.

3.1 VR Support for Shared Visions

When aiming at changing something in a team or in an organization, the starting point is normally to create a shared vision of where to go and why (Senge 1990). In the case studies presented in previous section, one common success factor for the teams was the ability to establish such a shared vision early in the project. If the task is to design a building, a bridge, or a machine or device of some kind, a 3D model in a computer is very helpful as a tool to verify that everybody has the same view. In such a model, or in a simulation of some dynamic process, the parameters and the structure can be adjusted during the discussion in the team. In other cases different diagrams can be more useful than virtual reality models. If some parameter values can be easily adjusted *e.g.* by means of a slider (Rosling 2009), dependencies become obvious. Generated audio can make the "perceptualization" even more realistic. If applicable, haptic devices can be used. All this will reduce the amount of misunderstanding in a team, compared to what could be expected in case of using only text and verbal concepts for the communication in the team.

3.2 Thinking and Learning Normally not by Means of Words and Language

Many teachers have experienced the value of "learning by doing", "use of all senses" *etc.*, in the learning situation. In the knowledge model by Aristotle, only *episteme* was directly transferable, *i.e.* could be explained, analyzed and transferred verbally orally or in writing. *Techne* was achieved by following and imitating the actions and behavior of the master, and *phronesis,* or wisdom, required a long life experience and deep and wide understanding.

Most of the processes in our brains, *i.e.* thinking, learning, control of actions etc. are taking place without our explicit control. Most of our behavior, our actions, our feelings and our beliefs are just there. We are normally not reasoning or listing verbal arguments for and against different alternatives. Somehow, the perceptions from all our senses are taken care of and resulting in actions and behavior. Automatic reflexes and some responses may be immediate and "hardwired" and not accessible for our thinking. From neuroscience we have learned that there may be such short-cuts for stimuli from several of our senses (Koch 2004). Pheromones (?) (Bear 2006), blind sight (Leh 2006), knee and eye reflexes, are such examples of subconscious responses.

If we are focusing on education and learning in this context, it seems as our brain registers perceptions and creates patterns and associations, such that a similar combination of stimuli later can be recognized as a similar situation. This enables us to reuse the experience from successful or unsuccessful actions later, *i.e.* it enables learning. This pattern recognition takes place at the level of processed stimuli signals. Recognition of straight lines, shapes, colors, motion, size, and human faces are examples of processing vision stimuli. Even if the processing of the stimuli and our response often is automatic, it is also often available for our consciousness in case we decide to interact.

What can we learn from this? The key question in this paper is about how and what we learn from reading texts and documents. We can remember and rephrase sections we have read. Students may get high grades by remembering and repeating what we have said or what is written in the textbooks. This is something they have really learnt during their course, but what have they understood? How is this ability to remember text related to the basic understanding and the received stimuli in real situation?

I think we all know situations where we ourselves or persons in our environment have acted quite contrary to what we/they know would be the best thing to do. Our internal chemical awarding system has different criteria than our conscious mind. Sometimes our automatic reactions, our gut feelings, are more competitive than our logical reasoning. An immediate action may save our life, even if longer reasoning might have resulted in an even better action, but to late.

So, even if we don't understand the details, there are indications from brain research, that "learning by doing" and "all senses" are good ideas (Sylwester 2000). Real learning means change of behavior, and change of behavior means rebuilding the patterns at lower levels of the cognitive maps. These patterns are normally efficiently sorting out of the irrelevant details in the sensory signals, and find matching recorded patterns. As these recorded maps constitute our beliefs and values, normally more than words and phrases are needed to shake them.

There are some FRMI studies on brain activities triggered by reading words and symbols (Liu 2007). Persons having English as their mother tongue, reading a word like "house" resulted in brain activities in the lexeme recognition area and also in the area for phoneme processing, but nothing more. The situation for persons brought up with the Chinese language, also the areas for the "meaning" of the word was activated.

Hypotheses:

Text reading and interpretation alone may be a week instrument for learning. It may work for confirmation and acknowledgement of existing beliefs, but not for relearning, *i.e.* changing existing beliefs and patterns. In such cases massive sensory input from all senses may be needed. Very little of our behavior, actions, beliefs and values are based on conscious logical or verbal reasoning.

However, within a monolingual rather homogeneous community, standardized symbols, spoken and written language may be sufficient means for communicating abstractions and complex relationships between well understood entities and concepts.

3.3 Coordination of Mega-projects and Understanding Mega-systems

In many situations, the main problem is not that we are lacking information and data, but that we have too much of it to be able to figure out what is relevant and how everything is related. In such situations computers and visualization are invaluable. Hans Rosling and his GapMinder (Rosling 2006) is an excellent example. Mikael Jern and his GeoAnalytics Visualization (Johansson 2006) by means of parallel coordinates is another one.

Rosling's and Jern's tools are for displaying quantitative information. Visualization is also very helpful for illustration of different kinds of qualitative relations between entities in general. One such example is the use of Functional Anatomies (Taxén 2009) to update and communicate the state and the relations between all the entities in the complex GSM system under development and the even more complex and dynamic project organization.

The usefulness of all three examples mentioned is due to their interactivity and that they are designed for dynamic updates. They are not just means for generation of visualizations to be printed or studied as static objects. You can change focus, animate time dependency, separate categories by color, size, shape, texture, *etc*. dynamically and interactively.

4 CONCLUSIONS AND DISCUSSION

This paper contains some scattered pieces of experience and some reflections about situations where text or static documents in general, are not sufficient to communicate the information needed or to reflect the current state of the dynamic shared view in a dynamic organization involved in innovative development of complex systems.

The objective is also to argue for using active learning and use of all senses in educational situations. In particular at the university level, at least in my country, I think that the mental models of teaching are too often limited to reading, discussing, and writing texts.

Neuroscience is still far away from understanding and modeling the learning and thinking processes, but very little indicates that it is a wise strategy to base education, teaching and learning only on verbal concepts.

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