Determining the Role of Abstraction and Executive Control in Process Modeling

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Abstract. In this paper, we describe our study on the relation between formation of abstractions and aspects of executive control in the context of process modeling. We have observed and recorded three business process modeling projects in different companies. We report on the findings resulting from the analysis of the first project. We find evidence that certain traits related to high-quality abstraction formation contribute to more structured modeling performance. Through our analysis we gain more insight in the cognitive mechanisms involved in modeling, which provides us with another step towards design of effective modeling support.

Key words: abstraction, executive control, process modeling support

1 The Need to Understand Modeling

Designing effective process modeling support depends on a thorough understanding of the basic properties of modeling. Many authors have written about the crucial importance of modeling in system design [1], [2], [3], [4], [5]. Yet, despite its ubiquity in the design world, it is a poorly understood and error-prone activity [6]. In this article, we present a way of observing modeling sessions and inferring principles of modeling based on psychological mechanisms involved in facilitating modeling.

We distinguish between two core phenomena: abstraction and executive control. Executive control processes involve metacognitive activities such as planning, organizing, monitoring, inhibition of distractions and initiation of corrective actions. Based on observations in practical modeling situations involving modelers and domain stakeholders, we explore how abstraction and aspects of executive control work together to guide modeling behaviors in group situations. In particular, which aspects of executive control feature most prominently in the formation of abstract representations? What differences are there in executive control between the formation of medium-level and high-level abstractions?

With the increasing role of business analysis and engineering in IS industry, the importance of skills related to learning, planning, organization and monitoring for IS professionals is apparent [7], [8], [9], [10]. As McCubbrey & Scudder [11] put it: "This will require that analysts learn to function at a more abstract level; and then translate those abstracts into concrete systems". Such activities typically happen during interactive, collaborative sessions involving both modeling analysts, and domain stakeholders. Involving stakeholders is very important in a modeling process [12], yet problems appear at the point where stakeholders and modelers have to communicate, due to lack of common understanding [13], [3].

Viewing modeling as a conversation in which individuals' mental models are being made explicit and merged into a shared mental model [14], guided by goals and interests and directed by executive skills allows us to decompose modeling into elementary processes pertaining to conversation structure, abstraction formation and executive processes. From this, we may gain an understanding of where some of the key difficulties may lie, and consequently training programs can be adapted to suit such needs.

We begin with a discussion of the core concepts involved in our research and how we used them to create an analytical framework for the study of modeling sessions. Then, we discuss the behavioral patterns emerging from analysis, and finally we speculate on how these might be used as guidelines to design modeling training programs.

1.1 Abstraction: Continuous Refinement of Representations

Modeling involves a continuous refinement of the participants' mental representations. They gradually take shape as they are continuously being explained to others. Such representations are abstractions of the daily practice, involving the domain structure, constraints on information flows and all kinds of domain properties. The process of forming such abstractions is very much an iterative, cyclic process. Abstraction occurs as early as during the perception phase. There is no clear distinction between concrete, sensory experiences and abstract representations, free from such experiences. A concept in the mind may be just as concrete as the real thing in practice, depending on how the representation has been formed in the mind [15]. Good abstractions should be structured and organized, and describe a whole range of behaviors of the issue under discussion in order to create a better model for the intended goal: more complete, or maybe simpler and more elegant. Only in an organized whole can some features hold key positions whereas others become secondary [15]. In support of this, Vennix [16] notes that people indeed tend to think in parts rather than viewing the whole context when improperly trained.

There are many ways to define abstraction, depending on which perspective is taken. In an early theory of abstraction, George Berkeley (1685 - 1753) argued that abstraction occurred through a "shift in attention"; it is possible to focus on a particular feature of a single object, and let that feature represent a whole group of objects [17]. In philosophy, mathematics and logic, it is common to characterize abstraction in this way as *information neglect*: "eliminating specificity by ignoring certain features" [18]. However, whereas the rigid nature of abstractions in mathematics allows ignoring of information, the highly dynamic and interactive nature of computer science is fundamentally different and therefore requires a different interpretation. Arnheim [15] provides a nuance to this view, adding that an abstraction is not a single distinctive attribute or property, or not even a random collection of properties, for that matter. A mere enumeration of traits does not constitute a coherent integrated concept. Rather, it should represent the innermost essence of a concept. This may be explained by saying that a concept should be generative; a more complete description of the object in question must be constructible from the concept in question. Nevertheless, feature distinction is very much guided by interests or goals, and a similar element will not be considered in the same way in every single percept.

Colburn and Shute [18] further specify this notion by introducing the concept of *information hiding* as opposed to information neglect. The main idea is that irrelevant information is deliberately omitted so that the focus is only on relevant aspects within the current scope. However, this omitted information is not forgotten; it is assumed to be in place and correctly functioning at all times. Therefore, the choice for any abstraction level depends on the purpose, goals and intentions of the modeller wishing to view certain system functionality [19]. This notion is fundamental to Rasmussen's *abstraction hierarchy*: "a systematic way to view different system functions according to the purpose, goals and intentions of the person working with a certain part of the system" [19]. Each level in the hierarchy provides certain details and features of the system based on what the person working with the system needs for his task. A change in abstraction level involves a shift in concepts and representation structure as well as a change in information suitable to characterize the state of the function or operation at the various levels of abstraction. For a process at any level of the hierarchy, information on proper function is obtained from the level above, and information about available resources and their limitations is obtained from the level below [19].

Models must provide proper abstractions of the problem domain, but they often end up containing too many details, not using an adequate modeling granularity, or providing inappropriate abstraction layers [6]. Reasoning with abstractions has been found to be considerably more difficult than reasoning with concrete premises, requiring much more information to be held active in mind [20], [21]. Indeed, the ability to form abstraction representations, the quality of the resulting representations and the ability to make them explicit to others differ per individual, which greatly tends to influence the way a modeling session proceeds [22]. Also, it has been found that humans are not very good at following complex chains of reasoning, such as are typically involved in modeling [16]. However, humans learn progressively to handle more formal things [23], as their mental models develop, and content and way of working gradually become more automated. To understand this, we need to explore the principles of executive control and how they play a role in modeling.

1.2 Executive Control: A Facilitatory Mechanism?

Mental representations are made explicit to others by means of conversation [24], [14]. However, while there is usually some basic structure for a modeling session in advance, the actual properties of the model discussed depend very much on the associations made by the participants at the moment of discussion. This may lead to rather fragmented knowledge elicitation, the results of which afterwards have to be coherently integrated by modelers. Regardless of communication abilities, which we do not explicitly consider here, this presents a high cognitive load to modelers, as correctness of model content, coherence of model structure and group discussion progress with regard to project goals have to be monitored simultaneously. Organization of goal-directed behavior requires strong executive control [25], a lack of which can leave modelers overwhelmed with information and at a loss for structure.

Executive functions are a set of cognitive processes mediating one's actions and thoughts, which are separate from cognitive slave constructs such as long term memory. There are metacognitive and self-regulatory executive functions [25, 26]. Metacognitive functions are higher-level functions like planning, organizing, monitoring and initiation, whereas self-regulatory functions are more basic processes like inhibition, attention shifting and updating working memory content. Staying focused on a task [27], as well as fully-fledged multitasking problems [28], have been related to strong executive control. More specifically, attentional control over intruding thoughts is implicated as contributing to better reading comprehension [29]. The most generic mechanism executive tasks tap is hypothesized to be "the maintenance of goal and context information in working memory" [30]. Also, Engle et al. [31] propose that "any situations that involve controlled processes (such as goal maintenance, conflict resolution, resistance to or suppression of distracting information, error monitoring, and effortful memory search) would require this "controlled attention" capacity, regardless of the specifics of the tasks to be performed."

There is a lot of research emphasizing the need to implement executive processes in order to facilitate effective team functioning [14]. For instance, teams should learn to plan effectively, to communicate effectively, to define each others' roles, to learn about each others' background, to develop techniques for monitoring and feedback, to develop communication rules etc. There is no denying that these skills are indeed vitally important for successful team functioning. A deeper understanding of these skills in relation to modeling, however, would be welcome.

1.3 Learning and Reflection During Modeling

Argyris [32] describes a general learning problem in organizations: people in knowledge-intensive, interdisciplinary functions show precious little ability to engage in metacognitive activities. Mere problem solving is not enough, managers and employees need to reflect critically on their own performance and adjust accordingly if improvement is to persist. However, humans have difficulties reasoning with complex structures and they tend to ignore feedback on their performance [16], [32]. Research from the domain of learning theory finds that students do not spontaneously engage in activities in which they reflect on their own work, asking themselves why they have done something in a particular way or looking for possible alternatives. Rather, they have to be actively prompted to go beyond the level of fact-based learning and memorization [33]. In this same fashion, Jeffery et al. [14] recommend the implementation of communication and monitoring strategies for collaborative modeling teams in order to aid their performance.

Vygotskian learning theory states that social situations with lots of interaction facilitate learning that involves both fact based learning and critical reflection on what has been learned [34], with the latter in particular facilitating improvement [35]. Understanding based on passive recall differs from understanding based on active reasoning and knowledge construction [36, 35]. This is where executive processes come into play. We know that students do not spontaneously engage in this type of interaction, and we see in our observations that modelers who do so spontaneously are the minority. Yet these reflections are necessary for structuring the model, monitoring it for correctness and completeness, and structuring and monitoring the discussion leading to this model.

Therefore, we should structure modeling discourse such that it induces the type of conversation that involves active manipulation of present knowledge. This is achieved by involving activities such as explaining, thinking aloud, prompting, resolving discrepancies and trying to integrate different ideas and perspectives [35].

2 Methods and Observations

Our study was conducted at a Dutch organization. We observed two different projects, which were part of an effort to chart the organization's business processes and to design new ones in order to develop a new automated information system. They made use of collaborative modeling workshops to elicit domain knowledge from stakeholders, and separate collaborative modeling sessions involving the analysts only to integrate the elicited knowledge into coherent models. These were again presented to the stakeholders in the consecutive workshop for review. The following stakeholder roles were involved: project manager, business analyst, business architect, change manager, 2 heads of departments, 2 supervising seniors, internal auditor. The minimum group size in our study was two. The types of models used were process models.

2.1 Data Collection

One researcher has spent three months at the company, being present at relevant sessions, and recording them in audio format initially, but as the stakeholders became more accustomed to the researchers presence, a video camera was installed in the workshop room and video recordings were made in addition to audio. The stakeholders indicated not to be bothered by its presence. Additional time was spent getting to know the stakeholders, but care was taken not to talk about the research objectives to avoid introducing research bias.

The modeling sessions and stakeholder workshops all took place in the same project room, which was equipped with a beamer and two flip chart boards. The models under discussion had been printed and were attached to the walls. During the stakeholder workshops, the modelers presented the models to the stakeholders and these were required to respond to certain issues or things that appeared odd to them. In some cases, bits of model were explicitly shown, in other cases, issues were formulated in natural language. During the analyst-only modeling sessions, heavy use was made of the flip charts, and interaction was not explicitly structured. Models were adapted and contradictory issues discussed.

2.2 Coding and Analysis

We recorded a total of 30 sessions. So far, we have transcribed 4 sessions, and selected 12 interval-based fragments. They were coded for conversation structure, cognitive processes, abstraction and executive control by two coders.

The components of conversation structure were taken and adapted from [37]. We have included here only those conversational constructs which have so far appeared in our modeling sessions. Also, the adjacency pairs, as specified in [37], do not necessarily always occur in direct pairs. Sometimes the expected reply is missing, the pairs are nested or multiple pairs get mixed up. But in general, they give a good overview of the kind of conversational constructs that are used in different phases of the modeling discussion.

Cognitive processes are those operations that people perform either on directly available knowledge, such as inferences or justifications, or more complex situations in which they reason with pro, such as reasoning by analogy or comparing different outcomes. The goal of analyzing cognitive processes is to find out whether people use different types of reasoning as the discussion progresses, or whether there are individual differences in reasoning styles which may correlate with abstraction and executive control skills.

Abstraction is viewed from two perspectives: the different levels of abstraction, ranging from concrete to highly abstract [38], [21], and the process of refinement people go through during a discussion [15], characterized by shifts in abstraction levels, either instantiating to a lower level, or generalizing to a higher level.

The structure of the executive control section is based on [25], and has been adapted to include specific behaviors occurring during modeling sessions.

In order to code, we used a table in which we assigned codes for each coding component to each sentence uttered by a participant. We defined a sentence as a set of words, separated by pauses in speech. This does not mean that a sentence has to be complete, it can be broken off halfway through. Also, there can be multiple sentences within a single speaking turn.

So far, our analysis has not proceeded far enough to do actual counting of code occurrences, so we infer patterns of behavior based on what we have seen in the sessions analyzed. After coding, we discussed our findings. As the codebook is also still developing, no inter-coder reliability could yet be computed.

3 Results: Patterns of Modeling Interaction

The general pattern of interaction observed in both modeling workshops and analyst-only session is that a discussion cycle covering one topic generally starts with extensive refinement of representations. A combination of speculating about possible situations, and paraphrasing them to make sure everyone understands the issue at hand correctly, is used. This is followed by a cycle of inferences, elaborations, instantiations, justifications on the cognitive side, structured in the conversation in terms of questions, contradictions, encouraging and doubt-signaling probes and extensive answer accounts using illustrations and examples. In abstraction terms, this second cycle is characterized by a continuous set of shifts to a lower level: from a medium abstract to a concrete level of representation. Shifts to higher levels are rare during this cycle, and they often tend to fail because of insufficient comprehension. Only after this cycle has been repeated for several minutes do shifts from medium abstract to highly abstract levels start to appear more frequently, and importantly, more successfully.

One of the main differences observed in the formulation of abstract representations is that some participants tend to pick out single properties and use them as a metonymy for an entire issue. Others give generic descriptions of how issues behave in more generic context using multiple properties. They complete their abstraction refinements more often, reasoning them through to the end rather than breaking off halfway through.

Monitoring of the modeling goals, the entire group progress, and group discussion topics, appear much more frequently in participants who make more complete abstractions. They were also more flexible in topic and strategy switching, and they also more easily self-correct and explicitly admit faults. They stay more focused and recover faster from distractions, such as jokes or irrelevant issues. In the other participants, monitoring is more limited to self-monitoring on a smaller scale. On top of that, the behavioral pattern includes much more frequent deviations from focus, difficulty understanding and keeping to the scope of concepts and echoing peers.

Important to notice that these monitoring skills are not limited to modelers, stakeholders engage in monitoring behavior and good abstraction formulation just as much if they are capable.

3.1 Examples

Below is an example of an initiation of a discussion cycle, with a stakeholder trying to formulate an issue, and other participants (stakeholders (S) and modelers (M)) trying to refine what he means by means of examples. This represents a cycle of shifts to a lower level of abstraction.

```
S1: look, the employer also delivers to eh... the tax office,
and if you ... have to deliver your data from the same salary system ...
yes... well then eh... you should eh...
in my opinion... use it, finished...

M1: [...] what we should figure out for this is... what is the
percentage that someone does not deliver... and actually is out of
service... so that you get a kind of code 23 and that appears to be
correct because he has forgotten to send in his AAD... and what is
the percentage that something else is going ... going on... [..]

S2: so you would... you would say that hey, 95 percent is eh...

S3 and S2: out of service!

S2: but has not sent in an AAD... and 5 percent is indeed
something else... that we can conclude eh...
```

An example of an abstraction shift to a higher level being corrected because it had been attempted too early on in the process:

```
M2: okay so currently... it is too much to say okay,
if an employer delivers, we can assume that it is complete...

S1: no, you have to see if the employer will eh...
 deliver, you will get a signal immediately
[...]
so then with eh... what you miss... you already report that,
we don't do that now
[...]
now he gets 5 days [..] hey we have not received an AAD
from you... if that .. report comes back immediately...
then you can initiate action... in whatever form...
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An example of a case of explicit monitoring between two modelers:

```
M2: why don't I go and put it into the tool, like this?
M1: what if..... eh.... Goal of the process is to register the
details about the wages....
[...]
M1: what if we eh.... Monitoring..... huh.... We send a reminder,
hey good friend, eh.... Eh.... You haven't sent us anything yet....
M2: yes...
M1: we get no reply....
M2: yes..
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M1: what happens then?
M2: there is no reply, then we receive nothing...
M1: right, then we receive nothing
M2: and then we don't achieve our goal...
```

4 Discussion and Future Research

There appears to be a clustering of behavioral traits that lead to desirable modeling performance: the ability to formulate generic abstractions capturing the essence of a concept, switch flexibly between abstraction levels to good effect, be able to structure a discussion, stay focused on the topic and scope, monitor both one's own thoughts and contributions and the group's progress towards modeling goals as a whole. On the other hand, participants who make more superficial abstractions, focusing rather on single properties of concepts and using them to represent the entire thing, also show less awareness of what is being discussed, deviate from focus more often, become more easily distracted and tend break off their reasoning processes and sentences halfway through. If we keep in mind Arnheim's [15] definitions for what does and what does not constitute an abstraction, we can say that the first group makes abstractions of a higher quality than does the second group. Given that this appears to depend on the individual rather than the individual's background and training, it seems that individual differences may override background and experience, in any case when explicit training has not been given.

The higher or lower quality which these traits display seems to be a collection of symptoms resulting from a psychological mechanism, which may function more or less efficiently in different individuals. We suspect that working memory (WM) capacity may play an important facilitating role in the formation of abstractions. WM has been implicated in executive control, and since our analysis suggests a strong associative relationship between executive control and abstraction, it will be interesting to test whether WM capacity plays a direct role in abstract reasoning processes during modeling. If this should be so, executive control for our purposes will be no more than a descriptive construct, and it may be necessary to find ways to directly support memory and attentional resources during modeling rather than the higher-level communication and feedback processes described by many authors.

However, a lot more study is required before we gain a sufficient understanding of the role of memory in modeling. On the short term, promising results are being obtained with explicit training of executive and metacognitive skills using strategy training, eg. [39], [40]. This is a form of training used in education to make students aware of their ways of learning and reasoning. People are taught metacognitive strategies to monitor their comprehension and progress.

Teaching modelers strategies which lead to successful modeling results may provide them with footholds based on which they can structure a modeling session. For instance, making goals explicit before starting a session, ensuring that the initial phases of a session contain lots of discussion in which different mental representations are made explicit using examples and illustrations on a concrete level before moving on to higher abstractions, using predefined moments to monitor progress and evaluate where the modeling process is in relation to the previously specified goals, or explicitly testing whether abstractions made really do capture the essence of a concept rather than a single random property.

In summary, it boils down to making people consciously aware of a certain structure to aid their way of working, and implementing explicit markers to remind them to perform the necessary actions. In a way, this is already a form of directly supporting working memory, since its contents are being offloaded to a static form in which they can be viewed and re-evaluated at all times.

5 Conclusion

We find that some of the most prominent aspects of executive control in facilitating the formation of abstract representations are the ability to stay focused, to finish complex chains of reasoning, to monitor individual and group progress at all times, and to view concepts holistically rather than according to single properties. All these executive aspects demand focused attention and reflective awareness of one's actions.

The essential difference in abstraction formation quality does not appear to be so much whether or not a certain level of abstraction can be achieved, but rather *how* the abstractions are formed: people who form abstractions based on single properties can make high-level abstractions and still be corrected by their peers because some aspect of the object's behavior has been overlooked in this way. Those who make generative, holistic abstractions can make high-level abstractions which are good reflections of the essence of a certain concept in a given context. This difference appears to correlate with overall strength of executive functioning in individuals.

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For an overview of the codebook, please contact the first author.

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