Attention management for dynamic and adaptive scaffolding

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Abstract

Many pedagogues have argued that learners should shape their own learning experience whilst tutors should facilitate this process of knowledge construction. Digital environments have been often used in an attempt to scaffold learning in these innovative learning settings. However the results obtained have been mixed both in terms of learning achievements and learners' satisfaction. We argue that this is due to the fact that scaffolds are often implemented in a too static and generic manner, and attention-related, fine-grained aspects of timeliness and fitness are normally disregarded. We propose that dynamic and adaptive scaffolds can be provided by observing and responding-to learners' attentional processes. We present a system that implements such attention-based scaffolding. We indicate how learners' attentional states may be detected and how several categories of interventions with the learners may scaffold learning in a timely and appropriate manner. Finally, we report the results obtained in system tests which show an improvement in performance and motivation for the students working with attention based scaffolding.

Keywords: Attention; Adaptive Scaffolding; Attention Management system; E-learning systems; Attention Aware Systems

1 Introduction

As digital learning environments become more ubiquitous, it is also becoming obvious that a more accurate application of pedagogical theories is needed in order to overcome some of the problems that many learners experience in such environments. Classic learning challenges are accompanied by challenges proper to the usage of digital tools; the former have been increasingly addressed with innovative pedagogical approaches including experiential learning, situated learning, and many others. Digital tools have been widely employed by teachers embracing these pedagogical approaches; those tools however, whilst providing access to a much larger and varied set of information, have generated a new set of difficulties for learners. In Roda & Nabeth (2005) we argue that many of these difficulties are due to the fact that current IT based learning environments are still mostly inspired by classic *lecture style* teaching which mainly emphasise the *presentation of information to learners*. In this framework the teacher selects the information to be presented, and mode of presentation. This selection happens in a static manner when teachers prepare their lectures and "configure" the digital tools for information presentation. innovative pedagogical approaches instead, assume that learners can somehow shape their own learning experience (Papert & Harel, 1991), and therefore information selection cannot happen statically and cannot be solely guided by the teacher. Learners should be free to access information and tools when and if they need them. In order to enable this, many instructors and learning systems simply provide as much access as possible to information and tools so that students can choose those best suited to their needs at any given time. Unfortunately, this frequently results in overwhelming environments where learners have difficulties finding information, selecting the appropriate course of action, and generally focussing their attention.

Ideally, learning support systems should contribute to supporting learners in a non-classical setting by allowing students to better control their own learning processes. It is important that learners are allowed to actively participate in setting their own learning agenda, which would result: (1) in their ability to self regulate learning; (2) in gaining a better knowledge transfer due to a better connection between the prior knowledge and the learning content; and (3) in higher motivation of the students. Therefore, digital tools assisting learning environments must provide learners with the help necessary to direct and sustain attention to the appropriate tools and information; further, this support must evolve with the student's knowledge and skills. In educational psychology this evolving support of students is called *adaptive scaffolding*. In this paper we argue that in order to derive the information needed to support adaptive scaffolding with diagnosis, calibration and fading (i.e. following the classic description originally proposed by (Wood, Bruner, & Ross, 1976)) e-learning systems have to observe, and reason about, the learner's attention-allocation processes. We describe a system, AtgentSchool, in which attention management, and scaffolding constructs are integrated to produce a dynamic and adaptive e-

learning environment for school children.

In section 2, we review several interpretations and implementations of scaffolding, we report on the main findings related to human attention and attention aware systems, and we describe how attention aware systems can provide the input needed to support adaptive scaffolding.

In section 3 we describe a conceptual framework for attention aware scaffolding, and we detail a model in which scaffolding *interventions* are connected to different events tracking the learning environment of the learner. We claim that the model proposed is a generic attention-based model for scaffolding that can be applied to a variety of e-learning applications. In section 4 we describe the implementation of the conceptual framework in the Atgentschool system. In section 5 we report the results of a set of evaluation studies aimed at evaluating the AtgentSchool system and the effects of attention-based dynamic and adaptive scaffolding.

2 Relevant background

The next two sections provide a short introduction to scaffolding and attention aware systems. We restrict ourselves to the aspects most relevant to our work; this means that this section is by no means a full literature study of these two areas.

2.1 Scaffolding learning

Hadwin, Winn, & Nesbit, (2005) provide an overview of the advancements and possibilities of software for the field of educational psychology. The broad theme addressed is the changing nature of instructional interventions, which refers to both the delivery of instruction and the use of computers to guide and tutor learning. The use of computers to guide and tutor learning is identified as an exciting line of investigation, which "could shape research that aims to study and improve instructional processes and scaffold learning" (ibid 2005: p. 2). In recent years it has been often claimed that various digital tools could be used to scaffold learning. This is certainly the case, in the same sense in which a book, a drawing, and many other tools can, if appropriately employed, provide some support to scaffolding. Digital scaffolding however has presented several, difficult to address, problems; below we provide an overview of the interpretations of the term scaffolding an its use in digital environments.

The term *scaffolding* was introduced by Wood, Bruner, & Ross (1976). It is defined as providing assistance to a student on as-needed basis, fading the assistance as the competence increases (Wood, Bruner, & Ross, 1976). The general idea behind scaffolding is that some of the control within the learning environment is temporally transferred from the learner to another more experienced actor in order to support students in the acquisition of the abilities necessary to fully self sustain learning. *Scaffolds* support the execution of learning tasks difficult for the student and they are removed when no longer necessary. Several studies have provided evidence that students, learning about complex topics in computer based learning environments, experience various types of difficulties in absence of scaffolding. These studies show the students' poor ability to regulate their learning and their failure to gain a conceptual understanding of the topics (Azevedo & Hadwin, 2005). In particular, within innovative learning arrangements, where student are provided with more control of both learning content and learning procedures, scaffolds can support students in dealing with this increased responsibility.
Three elements that were essential for scaffolding in Wood's traditional descriptions are *diagnosis*, *calibration* and *fading* (Puntambekar & Hübscher, 2005). In this framework the abilities of the learner must be diagnosed continuously in order to define the appropriate scaffolding. This diagnosis supports the careful calibration of the scaffolds and eventual fading of the support provided. When the learner masters all aspects of the task the control is fully transferred to the learner.
In analyzing the literature and the application of Wood's theory in innovative learning arrangement, it is important to notice that the meaning associated to the term *scaffolding* has evolved over time. In recent literature the use of the term is often different from the traditional meaning. Puntambeker and Hübscher (2005), for example, refer to the modern scaffolding approaches as *blanket support*. The amount and type of support is fixed and not adjusted on the basis of an observation and diagnosis of the learner. Frequently, the support is the same for all students and no adaptive tuning of the support to the changing needs of the individual student is offered. Adaptive scaffolding directed at the dialogue between the learner and the tutor has been reduced to passively setting the scaffolds. The fading of the scaffolding is not in place; the scaffolds are permanent and unchanging.
On the basis of the above analysis two types of scaffolding have been specified: *Fixed scaffolding* is defined once, and it is the same for all students (e.g. one may provide a list of instructions that helps users to perform a learning activity). *Adaptive scaffolding* entails pedagogical agents which diagnose, calibrate, and provide support to learning in an individualised manner, such agents are capable of fading or adapting as the learners'

abilities and confidence increase. Whilst fixed scaffolding appears to produce mixed results, adaptive scaffolding has been shown to benefit several aspects of students learning (Aleven & Koedinger, 2002; Chi, Siler, Jeong, Yamauchi, & Hausmann, 2001). Scaffolding has two main functions: the immediate intent to support knowledge construction, and the long term intent to develop heuristics to support future independent learning (Holton & Clarke, 2006). These two functions connect closely to the benefits of more constructive learning environments as mentioned in the introduction.

Different techniques for scaffolding within computer based environments exist. Among others: prompts and question prompting (Ge, Chen, & Davis, 2005; Kauffman, 2004); expert modeling (Schoenfeld, 1985); guided peer questioning (King, 1991); process models (Lin & llehman, 1999); support lists; representations; and reports. Process models, support list, representations, and reports represent mostly fixed scaffolding techniques. Prompts and question prompts can be provided to the user as adaptive forms of scaffolding. Prompts are statements provided to the user to highlight specific elements in the learning environment. Questions prompts are questions posed to elicit responses from the user. Prompts and question prompts have been found to support students' structuring of problem solving (King, 1991); reasoning and justification process (King, 1992; Lin & llehman, 1999); self monitoring and strategic studying (Kauffman, 2004); problem representation, developing solutions, making justifications, and monitoring and evaluation (Ge & Land.S.M., 2003). These prompts and question prompts are generated based upon the answers students give to questions asked in the learning systems. This is adaptive in form, but we cannot speak of agents that diagnose, calibrate and fade their interventions. Below we propose to use attention and attention aware systems to support adaptive scaffolding.

2.2 Attention and Attention Aware Systems

Systems capable of adapting to, and supporting, human attentional processes have been called Attention Aware Systems (Roda & Thomas, 2006; Roda & Nabeth 2007). In this section we very briefly review the vast literature that has aimed at defining what attention is and how it is controlled, and we highlight the findings that are most relevant to the design of Attention Aware e-learning Systems (for a more thorough review see (Roda & Thomas, 2006)).

Human *attention* is normally understood as the set of processes that enable us to cope with our limited cognitive abilities; these processes guide the selection of incoming perceptual stimuli (Driver, 2001: p.53; Lavie & Tsal, 1994: p.183; Posner, 1982). What we see, hear, and generally perceive around us (in the physical world) exceeds, probably by several orders of magnitude, what we are actually capable of processing. Chun and Wolfe propose that ''First, attention can be used to select behaviorally relevant information and/or to ignore the irrelevant or interfering information. [. . .] Second, attention can modulate or enhance this selected information according to the state and goals of the perceiver. With attention, the perceivers are more than passive receivers of information. They become active seekers and processors of information, able to interact intelligently with their environment'' Chun and Wolfe (Chun & Wolfe, 2001:p.273).

In the cognitive psychology literature, there is a general agreement that attention can either be controlled voluntarily by the subject, or it can be captured by some external event (Arvidson, 2003; Posner, 1980; Yantis, 1998). Voluntary control is referred to as *endogenous*, *top-down*, or *goal-driven* attention. Attention captured by external events is referred to as *exogenous*, *bottom-up*, or *stimulus-driven* attention. For example, if one reads some text applies endogenous attention, however a sudden noise may attract attention through and exogenous process. Chun & Wolfe indicate that these two mechanisms have different characteristics, ''endogenous attention is voluntary, effortful, and has a slow (sustained) time course; [. . .] exogenous attention draws attention automatically and has a rapid, transient time course'' (Chun & Wolfe, 2001: p.279). The two mechanisms (exogenous and endogenous) are strongly related (Yantis, 2000). In fact the endogenous mechanisms in place (e.g. what one is looking for in a visual field, and how this search is performed at the voluntary level) seem to determine whether one will automatically be able to ignore certain stimuli; in other words ''the guidance of attention is determined by interactions between the bottom-up input and top-down perceptual set'' (Chun & Wolfe, 2001:p.280).

In modern learning settings the strategy used to "set off" the learning process provides for the top-down attention allocation processes, i.e. the student is given the motivation necessary to pay attention to certain information and tools. Scaffolding provides for guiding the learner's attention to the most relevant items often using both endogenous (motivational) mechanisms, and exogenous (perception-related) mechanisms.

Several researchers have aimed at clarifying how endogenous and exogenous processes may interact in the environment and which role these processes may play in the pre-attentive and attentive stages. Treisman (1960, 1969) has suggested that non-attended stimuli may be elaborated at the attentive stage if they are particularly significant in someone's current environment or personal experience. This partially explains the different reactions of individual students to the same scaffold.

Hillstrom and Chai (2006) review the main factors intervening in retaining/distracting visual attention in computer interaction. They analyse how the direction of attention may be influenced by the distinctiveness of

stimuli in the visual scene, the observer's intentions, memory of what has been attended in the past, and the perceptual organization of the display. Several theories relate attentional mechanisms to personal experience and current environment in an attempt to explain interference effects (delays in the processing of stimuli due to unwanted stimuli called distractors). Interference effects would be responsible for situations in which we are unable to keep attention on a target stimulus or to avoid distractors. For example, stimuli that have been actively ignored in preceding trials are more difficult to select (negative priming) (Allport, 1989; Tipper, 1985); distractors with features similar to the features currently prioritized generate more interference (Folk, Remington, & Johnston, 1992); and stimuli related to familiar and recent foci may cause greater disruption to the user's current activity (Rafal & Henik, 1994; Rogers & Monsell, 1995). The history of the learner's interaction with the learning environment (including the tutor and the learner's peers) and with previous learning environments impacts on the effect that a new stimulus (possibly a scaffold) will have on that learner.

In terms of e-learning systems design the above findings imply that the impact of interventions on the learner cannot be evaluated statically (at design time), but it varies and depends on the recent activities and goals of the learner. For example, one could expect that if a learner is working at a team project, the notification of an email from a team member is more likely to attract the learner's attention than any message unrelated to recent activities.

This is confirmed by experimental results by research in change blindness (the phenomenon by which significant changes in the visual field may go unnoticed) which demonstrate that attention is highly selective and information is extracted only "just in time" if relevant to the current task (Hayhoe, 2000; Triesch, Ballard, Hayhoe, & Sullivan, 2003). This corroborates the fact that endogenous and exogenous attentional processes interact to define what we perceive. The selective nature of vision has been demonstrated by several other works in inattentional blindness (Mack & Rock, 1998; Rensink, 2000) and inattentional amnesia (Rensink, 2000; Woolfe, 1999), whilst other experiments emphasise involuntary attention-capture related to visual context (Jiang, Chun, & Olson, 2004; Wells & Olson, 2003) rather than to task. Historically, the study of change blindness has significantly contributed to the understanding of attention and its relations to memory and awareness, some reviews (Durlach, 2004; Rensink, 2002) report on the many situations in which observers fail to detect significant changes in their visual field. Simons and Rensink (2005) explain that in all these situations the localization of the motion signals that accompanied the change was impaired, which suggests that "attention is needed for change perception, with change blindness resulting whenever the accompanying motion signals failed to draw attention" and that "these effects are even stronger when the changes are unexpected" (ibid, p. 16). See, for example, the surprising results on unexpected changes reported in (Levin & Simons, 1997; Levin, Simons, Angelone, & Chabris, 2002; Simons & Levin, 1998) which somehow contradict our naïve understanding of what would draw attention. Although all the results above refer to the visual modality, what we can abstract is that, given the selective nature of attention allocation processes, scaffolds have a much better chance to be effective in environments in which the learner is strongly motivated and if they are proposed just-in-time, i.e. when the learner is in need of the knowledge being scaffolded.

Some research has aimed at building overall models of attentional processes within the frame of other cognitive processes. Grossberg (1976a, 1976b, 1999), for example, proposes a model addressing learning and conscious experience, and explains how intentions may guide attention in two ways. First, intentions reflect expectations of events that may (or may not) occur. Second, intentions help monitoring sequences of events that should take place in order to satisfy behavioural goals. In this manner "we can get ready to experience an expected event so that when it finally occurs we can react to it more quickly and vigorously, and until it occurs, we are able to ignore other, less desired, events'' (Grossberg, 1999: p.12). Grossberg's theory hints that since users' attention will be focussed on information that matches their momentary expectations, understanding users' intentions (both in the sense of behavioural goals, and in the sense of events likelihood) is essential in supporting attentional processes. The diagnosis phase proposed by Wood, therefore should include the assessment of the learner's expectations in terms of his/her intentions. Furthermore, one way of directing and maintaining learners' focus is to act at the level of intention.

Several experiments (and common experience) reveal however that intentionality may not always result in attending appropriate events: sometimes, relevant cues are ignored and irrelevant ones are attended. Kruschke (2001, 2003) explains the above phenomena stipulating that in order to achieve rapid error reduction in the selection of the cue to attend, we learn to attend to certain cues (learned attention - highlighting) and to ignore others (learned inattention - conditioned blocking). A similar model, where attention to cues that have been learned to be relevant increases, whilst attention to cues that have been learned to be irrelevant decreases, had been already proposed by (Mackintosh, 1975). We seem to apply these strategies all the time both at the macro level (e.g. we establish *trusted* learning resources), and at the micro level (we disregard information displayed in certain areas of the screen if we have often experienced the area as irrelevant to our current activity). An initial analysis of how these processes may be modelled within an interactivist model of learning is proposed in (Roda,

2007). In terms of automatic scaffolds this entails that the calibration phase should take into consideration the history of the interaction of the learner with previously proposed scaffolds and enough variety should be available to be able to cope with learned attention and learned inattention especially.

Multi-tasking, which regularly occurs in human activity, adds complexity to the understanding of attention allocation. How do we manage to switch our attention from one task to another? Under which conditions can we do this most efficiently? What are the effects on task performance and learning? Based on a computational model addressing these issues, the EPIC architecture, some studies (Kieras, Meyer, Ballas, & Lauber, 2000; Rubinstein, Meyer, & Evans, 2001) have proposed that two distinguishable sets of processes control the execution of consecutive tasks: *executive control processes*, and *task processes*. *Task processes* control performance of the individual tasks and *executive control processes* control task switching. In this model endogenous control prepares, in a top-down manner, for the next task; and exogenous control, triggered by the onset of the next task stimulus, completes the preparation for the task. The authors explain delays occurring in task switching condition by the fact that ''if a switch occurs from one task to another, there is a pause between the end of stimulus identification and the beginning of response selection for the current task [. . .]. This pause is used by an executive control process whose operations enable the subsequent response selection stage to proceed correctly'' (Rubinstein, Meyer, & Evans, 2001: p.770). This model seems to match several experimental results. First it models appropriately the fact that the difference in performance time for task repetition and task alternation increases with the complexity of the tasks (Jersild, 1927). Second, under the assumption that task cueing may facilitate the executive control process selecting the next task, the model explains the fact that task switching times may be significantly reduced if visual cues are provided about the task to be performed next (Spector & Biederman, 1976). Third, under the hypothesis that endogenous processes initiate preparing for the next task only if the Response Stimulus Interval (RSI) is predictable, the model explains why, under certain conditions, increasing the length of RSI decreases switching times costs only if the RSI is constant (Allport, Styles, & Hsieh, 1994; Rogers & Monsell, 1995).

The findings reported in this section have three important implications on the design of Attention Aware e-learning Systems.
First, **there is always a cost associated with switching attention** from one task to another and this cost is **related to the complexity of the tasks involved**. In order to design systems supporting the learning process, it is necessary to identify the parameters that define task complexity and evaluate the cost of focus switching on the basis of these parameters. It seems likely that both general and learner-related parameters will contribute to the evaluation of task complexity (intuitively we can define the level of complexity of a task both ''in a general sense'' and ''for a specific person''). An example of the application of the evaluation of task switching cost is the case in which the system has some project-relevant information and should decide whether to interrupt the student activity in order to provide the information.
Second, results on task cueing in task alternation hint that **systems capable of providing cues about the task to be performed next would reduce cognitive load for the learner**. Further it seems likely that, in the case of task resumption, providing cues about the context of interrupted work would reduce cognitive load. For example, in a word processor, task cues may provide information about which part of a document was last edited, and about the context in which that editing took place (e.g., after opening a certain web page and reading a certain email.).
Third, in relation to interruptions, it appears that increasing the time between attention switches will not per se reduce users' cognitive load. A system aimed at supporting users' attentional processes should instead **allow the user to predict interruption times.**

2.3 Attention awareness for adaptive scaffolding

The system and methodology described in this paper are based on the observation that an essential element required for providing adaptive and dynamic scaffolding is the management of the learners' attentional state.
In their original work, Wood and his colleagues stated, "The actual pattern of effective instruction then, will be both task and tutee dependent, the requirements of the tutorial being generated by the interaction of the tutor's two theories" about the task and how it may be completed, and about the performance characteristics of the tutee. (Wood, Bruner, & Ross, 1976: p.97) Unfortunately, within e-learning research and applications, the "theory of performance characteristics of the tutee" (Wood, Bruner, & Ross, 1976: p.97) has often been interpreted (or implemented) through static models of the tutee performance. Such models are normally static both from a temporal and ontological point of view. *Temporally static* models represent the performance characteristics of the tutee once-for-all and do not take into account the changes that intervene during the learning experience. *Ontologically static* models define the learning-relevant characteristics of the tutees once-for-all and, although the "values" associated to these characteristics may vary over time during the learning process, it is not possible to introduce new ontological categories adapted to the specific learning experience and

tutee. For example, the fact that a tutee is (or is not) a *good programmer* may not be part of the categories originally defined as describing his/her performance. Such category may however become relevant for certain learning projects, or for certain strategies chosen by the tutee in order to work on a learning project. Whilst the dynamic creation of ontological categories is desirable, in this research we concentrate on temporally dynamic and ontologically static, but configurable (for the specific learning application) user/tutee models. We propose that the problem of having static ontological models may be (for the time being) addressed by a continuous tracking of the tutee attention allocation associated to an evaluation of his/her performance on the selected foci. In this manner for example, although being a good/bad programmer may not be part of the tutee profile, one is able to detect whether the attention allocated to a certain activity (programming) actually results in the tutee moving closer to the problem solution or not. Within our framework the **diagnostic phase** is based on the detection of the learner current attentional focus and an evaluation of whether the user performs as expected (based on the task model and the tutee model) on the associated task. **Calibration** corresponds to *intervening* with the learner in a manner that is *adapted* to both his/her current attentional focus and characteristics (e.g. history of interaction, needs, abilities, etc.); intervening with the learner amounts to either supporting the learner's current attentional focus or proposing alternative ones. **Fading** results from the adaptation process of calibration.
Good tutors, not only are able to select the appropriate scaffolds for students but they can also choose, in a very precise manner, the **best time and modality for providing those scaffolds**. This aspect, which has been often neglected in systems aimed at scaffolding learning, emerges naturally from the model we propose of attention-based scaffolding.

3 Conceptual Framework for Attention-Based Scaffolding

Our objective is to model on the basis of system-observable ***events***, the attentional state of a learner and select appropriate ***interventions*** to either support such state or guide the learner towards a different attentional state. Consequently the input to our model will be a set of *events*, and the output of the model will be *interventions*. Because our model aims at being *temporally dynamic* the generation of interventions is based both on current *events* and on the memory of past events. The memory of past events is maintained in a learner description, called ***learner model***, which subsumes the previous activity of the user in the environment. Because interventions on the attentional state of the learner must also be based on some knowledge of the task being performed by the user, the model also includes a ***task model*** describing in some detail the structure that users' activities may have within the learning environment. Below we describe the different components (events models; learner model; task model; intervention model) of our conceptual framework. In section 4 we will describe how such framework can be implemented in a system supporting dynamic and adaptive scaffolding.

3.1 Model Input: events

Below we use a simple grammar to describe only the main elements of our model, the complete grammar is not reported for sake of brevity. The grammar we employ here is similar to a BNF (Backus–Naur form) and supplies derivation rules, written as LHS ::= RHS where LHS is a non-terminal symbol of the grammar that can be substituted with one of the OR separated expressions on the LHS (OR is indicated by the vertical bar |). Terminal symbols are enclosed in triangular brackets (e.g. <this is a terminal>). Optional items are enclosed in square brackets (e.g. [this is an optional item]). Items repeating 0 or more times are suffixed with an asterisk *.

Events reveal either the current attentional focus of the learner (e.g. the learner is working on a certain exercise, or is typing in a certain window) or items that may be relevant foci for the learner in the future (e.g. an email that has arrived for the learner, a lecture on the same subject of the exercise the learner is working on). We have defined three types of events: *Application events*, *User events*, *Tracking events*.

(1) EVENT ::= APPLICATION_EVENT | USER_EVENT | TRACKING_EVENT

The three sections below describe each one of these events in more detail. A complete description of the model's events is out of the scope of this paper and the interested reader should see (Roda, 2006) for the complete events taxonomy.

3.1.1 Application events

Application events reveal the activity of the user within a software application. We assume that e-learning applications are capable of supplying information about the learner's activity to the model. This information may include:

- Explicit actions of the learner (e.g. the user starts reading chapter 1, the user has completed exercise 1); we call these events *user-applications events*.

- Changes in the application environment (e.g. a new chapter is available, the teacher has corrected the exercise); we call these *environment-application events*.

(2) APPLICATION_EVENT::=USER_APPLICATION_EVENT|
ENVIRONMENT_APPLICATION_EVENT

User-application events reveal the current focus of the learner, whilst Environment-application events reveal possible alternative foci for the learner. Table 1 provides some examples, of application events[i].

Table 1. Examples of application events (these are the events that the e-learning application sends to the model)

APPLICATION EVENTS (Events generated by the application)		
Event name	**Description**	**Examples / Comments**
	User-Application Events	
Start event	User starts a new task	student starts *exercise 1*
Continue event	User switches sub-task continuing on a super-task	student accesses a text describing *exercise 1*
Complete event	User has completed a task	student has completed *exercise 1*
Resume event	User resumes a task previously interrupted	student re-starts *exercise 1* after an interruption
Initiating event	User enters the application	
Stop event	User leaves the application	
	Environment-Application Events	
New information available event	The application recognises that the user could focus on newly available information	Arrival of an email message from the teacher

3.1.2 User Events

In most cases learners are the best judges of their own characteristics, preferences, and needs; user events represent the cases in which the user directly supply some input to the model. This can be in the form of:

- Information about their attentional preferences and constraints such as the maximum frequency of interruption, the preferred method of interruption, tasks deadlines, or how long they will be available until the next off-line interruption. We call these *user-information-supply events*
- Requests of services such as: notification of events, context restoration for a task, help in interacting with the model. We call these *service-request events*
- Feedback on the model's interventions by for example explicitly accepting or dismissing them. We call these *feedback events*

(3) USER_EVENT ::= USER_INFORMATION_SUPPLY_EVENT | SERVICE_REQUEST_EVENT | FEEDBACK_EVENT

Table 2 provides some examples, of user events.

Table 2. Examples of user events (these are the events that the user sends to the model)

USER EVENTS (Events generated by the user)		
Event name	**Description**	**Examples / Comments**
	User-Information-Supply Events	
Set time available event	User indicates a time when he will interrupt the activity	User indicates that he has a meeting in 30'
Set task priority event	User indicates the priority that he assigns to a certain task	User indicates that the task *review for exam* has the highest priority
Set task deadline event	User indicates a deadline for the task	User indicates that *exercise 1* should be finished by Tuesday
Set interruption frequency event	User indicates the maximum frequency of interruptions	User indicates that interruptions should only be presented at 10' intervals
	Service-Request Events	
Notify me event	User informs the agents about events for which he wants to receive notification	User asks to be notified about any email received from the teacher
Resume task event	User requests to set the context in order to resume a task that was previously interrupted	User asks that the context of *exercise 1* be restored so that he can restart working at it

Help event	The user requests help on the current task	User asks further explanations for *exercise 1*
	Feedback Events	
Dismiss suggestion event	User indicates that a suggested focus should not be further suggested	Following a suggestion to restore the context for *exercise 1*, the user indicates that it is obsolete
Accept suggestion event	User indicates that a suggestion is accepted	Following a suggestion that the user works at *exercise 1*, the user accepts the suggestion
Mood event	The user indicates his/her level of satisfaction with the system behaviour	The user indicates that he/she is happy/neutral/unhappy about the suggestion generated by the system

3.1.3 Tracking Events

It is assumed that attention-related events may also result from either tracking application-independent user activities or changes in the environment.

- User-tracking events report on the user's states by either directly observing the user through psycho-physiological measures (e.g. gaze, facial expression, body posture, etc.) or by tracking the user activity on the devices. Examples of these events include: *idle input events* generated when the user has not provided input for a time longer than a specified time (normally dependent upon the current user task), or *low input frequency events* generated if the user becomes too slow in his/her activity (also user and task dependant).
- Environment-tracking events report on the environmental states that might affect the user attentional state. This tracking may include the observation of the computing environment (e.g. the user being active in a different application) or the overall environment (e.g. the phone ringing, a person entering the room)

(4) TRACKING_EVENT ::= USER_TRACKING_EVENT | ENVIRONMENT_TRACKING_EVENT

Table 3 provides some examples, of tracking events.

Table 3. Examples of user events (these are the events that the user sends to the model)

TRACKING EVENTS (Events generated by tracking devices)		
Event name	**Description**	**Examples / Comments**
	User-Tracking Events	
Idle-input event	User has not performed any input activity for longer than a given expected reaction time	No keyboard, nor mouse activity
Low input frequency event	User is providing input at a rate slower than expected	Slow keyboard or mouse activity
Foci sequences event	A pattern is recognised in the sequence of user's foci	After accessing an exercise the learner always accesses the related lecture
Low alertness event	The user appears tired	Events generated by psycho-physiological measurements
	Environment tracking	
Idle application event	The application has been idle for a certain amount of time	The user has temporarily left the application
Physical event event	Tracking devices report changes in the physical environment that may indicate a switch in the user's attentional state	The phone rings, someone walks in the room
Copy and past event	Reports copy and paste operations between the window(s) of the current task and other windows	Allows to associate windows from other applications to the context of the current task

3.2 Learner model

The learner model serves as a memory storing information about the characteristics, experience, and progress of the learner over time. The information stored in the learner model forms the basis for the assessment of the learner attentional state, for the evaluation of possible alternative foci, and for the definition of appropriate scaffolding interventions. A complete description of the learner model is out of the scope of this paper; below we briefly describe the information maintained in the learner model that is most crucial for the following discussion of scaffolding:

- The learner's current focus and foci history – these describe the current and past activity of the learner and allow to infer the learner's advancement on the learning activities based on the events information
- The learner's characteristics, e.g. expertise level, learning preferences
- A list of alternative foci – these are activities that the learner is not currently focussing on but that could, in the future, constitute relevant foci. Alternative foci may be foci that have been suspended by the user (e.g. foci related to interrupted task) or that have been evaluated as relevant but have not yet been considered by the learner (e.g. a new important email, a task related to the learner's current activity). Alterative foci represent possible activities and scaffolds for the tutee that can be activated on an as-needed basis
- User preferences – A set of declared preferences including: maximum frequency of interruption no-interruption times, notification modalities, tasks that shouldn't be interrupted, etc.
- Reactions to previous interventions – This information allows the fine-tuning of interventions to the specific users

LEARNER_MODEL ::= LEARNER_MODEL_ELEMENT*
LEARNER_MODEL_ELEMENT ::= CURRENT_FOCUS | PREVIOUS_FOCUS | LEARNER_CHARACTERISTIC | LEARNER_PREFERENCE | LEARNER_FEEDBACK
LEARNER_CHARACTERISTIC ::= EXPERTISE_LEVEL | LEARNING_PREFERENCES
EXPERTISE_LEVEL ::= <new user> | <known user> | <frequent user> | <expert user>

Within the conceptual framework it is possible to express *conditions on the learner state* by indicating what the content of certain fields of the learner model should be at a certain time using the following grammar:

LEARNER_STATE ::= LM_CONDITION*
LM_CONDITION ::= LM[LEARNER_MODEL_ELEMENT = LEARNER_MODEL_ELEMENT_VALUE] where the LEARNER_MODEL_ELEMENT_VALUE is a possible value for the corresponding LEARNER_MODEL_ELEMENT[ii].

For example, within the conceptual framework it is possible to indicate that a certain type of scaffolding action should take place only for new users by using the condition:

LM[EXPERTISE_LEVEL=new user].

3.3 Task model

The ***task model*** (Laukkanen, Roda, & Molenaar, 2007) describes the tasks that the learner may perform within the e-learning application. Tasks are organised in hierarchies, may be defined at different levels of granularity, may be ordered, and may be either mandatory or optional. For example, the task *complete class project 1* may be organised in sub-tasks *read preliminary information* and *build object X* where the subtask *read preliminary information* is optional, and the subtask *build object X* is mandatory.
Task structure however, may not provide sufficient information to reason about the attention allocation processes of a learner who is performing or is about to perform the task. As discussed in section 2, the specific characteristic of the task with respect to the user and his previous activity play an important role in attention allocation and eventually in the choice of the scaffolding necessary to support the learner in performing the task. For this reason, in our framework we associate to each task a set of properties including:

- the *resources needed* for the task – this allows to avoid proposing to a learner to perform a task for which the resources are currently unavailable
- the *time on task* – the total time the learner has spent on the task. This indicator, together with the *expected* duration indicator, allows to evaluate the *progression state* of a task. The progression state of a task is important in the management of focus switches, for example one may want to avoid interrupting a task that is very close to completion, or one may want to suggest completing an interrupted task that is close to completion. Further, knowledge of the progression state may help in deadlines management, and in the evaluation of achievements over time.
- the *deadline for completion* of the task – this allows generating interventions reminding the user to attend those tasks that are close to the deadline. As described in {Roda, 2007 #901}, in situations of frequent interruption and multitasking, deadline management may impose high levels of cognitive load therefore the model aims at providing support that may reduce this load
- some *keywords* describing the task – these allow recognising similarities between tasks
- the *maximum time the learner could be idle* on the task – this allows intervening with learners that remain idle for too long on a task. This indicator is necessary to distinguish tasks that may result in the user being *apparently* idle (e.g. a learner is reading a long text on screen), from tasks that require obvious learner's activity (e.g. answering to a short question)
- the *expected duration* of the task – this indicator is used in combination with the *time on task* indicator in

order to evaluate the *task progression state.*

- the *people* associated with the task - this allow recognising when interventions (e.g. emails) from certain people may be relevant to the task
- the *difficulty level* of the task – as discussed in section 2, this indicator may be necessary for the evaluation of the cost of interrupting the task. This indicator may also allow defining the level of support that one may want to provide for the task.
- The *task activity* – this allows to define task specific parameters. For example, for a task that involves typing some text in a text-field, it allows to indicate how much text has been entered in the text-field. This indicator, together with the *time-on-task* indicator allows one to obtain a good evaluation on the state of advancement of the task.

In our model it is also possible to associate *help tasks* or *help messages* to a task. Help task and help messages basically provide the different types of scaffolding that can be associated to a tasks. Help tasks and messages belong to one of three categories: pre-task support, on-task support, and post task support indicating the time when the scaffold applies: respectively, as the learner is about to perform the task, when the learner is performing the task, and as the learner completes the task

(5) TASK_MODEL ::= TASK _MODEL_ELEMENT*

(6) TASK _MODEL_ELEMENT ::= RESOURCES_NEEDED | TIME_ON_TASK | TASK_DEADLINE | TASK_KEYWORDS | MAXIMUM_TIME_IDLE | EXPECTED_DURATION | TASK_PEOPLE | DIFFICULTY_LEVEL | TASK_ACTIVITY | PRE-TASK_SUPPORT | ON-TASK_SUPPORT | POST-TASK_SUPPORT

Within the conceptual framework it is possible to express *conditions on the state of a task* by indicating what the value of certain task elements should be using:

TASK_STATE ::= TASK_CONDITION*
TASK_CONDITION ::= task(TASK_MODEL_ELEMENT = TASK_MODEL_ELEMENT_VALUE]
where the TASK_MODEL_ELEMENT_VALUE is a possible value for the corresponding TASK_MODEL_ELEMENT.

For example, within the conceptual framework it is possible to indicate that a certain type of scaffolding action should take place only if the task is a difficult one, by using the condition:

task(DIFFICULTY_LEVEL=high)

3.4 Model Output: Interventions

The set of possible interventions provided to the user could be very situation and domain dependent. The objective of our work has been the creation of a general model of interventions applicable to many learning situations and largely independent of the learning domain at hand.
Originally six types of scaffolding support were defined in (Wood, Bruner, & Ross, 1976): recruiting the child's interest, reducing the degrees of freedom by simplifying the task, maintaining direction, highlighting the critical task features, controlling frustration and demonstrating ideal solution paths. Scaffolding can be directed at different instructional targets: learning domain knowledge; learning to regulate one's own learning; learning about using an electronic learning environment; learning how to adapt to particular instructional context (Azevedo & Hadwin, 2005). Interventions can be provided towards the development of declarative, procedural, conceptual, or metacognitive knowledge. We have categorised our interventions following the classic model of support to self regulated learning (Zimmerman & Chrunk, 2001) which distinguishes 4 levels namely cognition, metacognition, motivation, and behaviour. *Cognition* has a focus on thinking, *metacognition* is focussed on monitoring and evaluation, *behaviour* is focussed on doing, and *motivation* is directed towards feelings (Hadwin, Wozney, & Pontin, 2005).

Cognitive interventions support the user(s)'s learning process during the execution of a learning activity, and they are directed at activating cognitive behaviour. Cognitive interventions support actions with respect to content and context of the learning task and they are direct at the level that Nelson (1996) referred to as the object level opposed to the meta level which refers to the metacognitive activities. Cognitive interventions provide the knowledge and skills necessary to perform the task (Garner, 1987). Cognitive interventions support the mental activities of the learner at a specific time.
Meta-cognitive interventions support users in the regulation of the learning process by helping them understand how the learning process is developing. This form of support is directed at activating meta-cognitive behaviour in user(s). (Wolters, Meijer, & Veernman, 2006) define the following metacognitive activities: orientation, planning, execution, monitoring evaluation and reflection. Metacogntive interventions help learners

becoming aware of different learning-related meta cognitive activities. The literature reports that learners with low self regulation skills do not perform meta cognitive activities during their learning process. This results in less efficient learning and a strong dependence of the student on external regulation by the teacher (Zimmerman, 2002).

Motivational interventions support the user(s) motivation to work on the task and they are directed at increasing the drive of the students. Motivation strongly influences learning activities (Boekarts, 1999).

Behavioural interventions support the user(s) in effectively working with the environment. These interventions, which target the learner's actions in the environment, are directed at supporting the user(s) in effectively moving between activities.

In this section we first briefly describe the case-study analysis that has guided the specification of each intervention category in intervention types. We then detail the interventions types derived for each main category and how they may be generated on the basis of the attention-based input events.

3.4.1 Case studies analysis for identifying scaffolding cases

3.4.1.1 Context

The case study was undertaken within the context of the Ontdeknet e-learning system (Molenaar, 2003), an electronic learning environment for students aged 7 to 16. This environment supports students in maintaining a virtual learning relationship with a human *expert* on the subject of an assigned project. Students work in small groups collaborating with the expert in order to learn from his/her expertise. Students control the learning content by asking questions and requesting information about project-related topics. Teachers act as facilitators. Earlier research has shown that students are motivated to work with Ontdeknet and that this environment promotes transformative use of ICT in education (Molenaar, 2003). Ontdeknet is often used to support students' vocational orientation, for example, a student consults a lawyer, a chemist, or a carpenter about their daily activities, schooling, schedules, payment and career paths as well as finding out about technical issues such as instruments and procedures used in the profession. Several hundreds experts, representing many professions, are available for consultancy. In order to support the collaboration between the student and the expert, collaboration scripts (Dillenbourg, 1999) are embedded in the environment. A script is defined as a didactic scenario that structures the collaborative learning activities, specifying the roles, subtasks and deadlines. In Ontdeknet a script is provided to the learner in the form of a project screen which consists of: (1) a main assignment, (2) an overview of the learning activities supporting the main assignment, (3) a description and connection to the expert, (4) an overview of the team, and (5) a planner. The Ontdeknet system has been used for several years in many schools in the Nederland.

3.4.1.2 Procedure

The purpose of the case studies was to asses the basic framework for the interventions by the agent, i.e. we wanted to understand if and how learning within the Ontdeknet system could be scaffolded by an attention aware system. To achieve this we have observed how teachers intervened with students working with Ontdeknet. We have observed and recorded the dialogues of 4 groups of 3 students working with the Ontdeknet system for a period of 6 hours per group. Two groups were formed by eight years old students; and two groups were formed by twelve years old students. Groups were formed by teachers and each group included: three students each with a different recommendation for their high school education; one student with good reading abilities; one student with good computer skills; and a mix of boys and girls. Students were asked to write a paper about a profession with the help of an expert. In order to complete the assignment, the groups worked in a computer lab, 1 hour per week, for a period of six weeks, under the supervision of one of the authors. The groups of three students worked together on one computer. During each one-hour session, children received instruction at the beginning of the session and were then asked to work independently and only ask for support if they really did not know what to do anymore. The project within Ontdeknet was organised in five learning activities (tasks) for the students: (1) *introduction* of the team to the expert, (2) *presentation of the assignment* to the expert, (3) *selection of the expert*, (4) creation of a *mindmap* based on the expert input, (5) writing the *paper* and asking questions to the expert.

3.4.1.3 Results

Within the observation data and the dialogue protocols, we analysed occurrences where the teacher interfered with the children activity and cases where the students were in need of additional help. For each one of these occurrences we defined a "scaffolding case" describing the types of intervention that could support the students in the specific situation. We collected all the interventions made by teachers in order to specify the four intervention categories further into different interventions types. Table 4 reports two examples of the

observations and scaffolding cases.

Table 4. Examples from case study for intervention definitions

Observation of the task introduction
Group 1 (8 years old): Students read the explanation and they understand the *introduction* task immediately and start with it. 1a. After a while they do not know what to add anymore Intervention teacher: the teacher suggests writing their hobbies and age. SCAFFOLDING CASE: model input: low activity. Model output: help with task, e.g. suggest topics to write about 1b. Students asks: "What else can we write?" Teacher responds: "Nothing we are done" SCAFFOLDING CASE: model input: finishing of an activity. Model output: provide feedback on task
Group 3 (11 years old) 3a. Students are making jokes while reading the explanation. Then they do not know what they have to do. Students; What do we have to do? Intervention teacher: what does it say in the explanation? Students: That we have to introduce ourselves Intervention teacher : what do you think our expert wants to know about you? Students: we introduce ourselves to your expert. Now students start to work SCAFFOLDING CASE: model input: students are lost (e.g. idle input, off-task activity; request for help). Model output: provide explanation for task 3b. Finish: Intervention teacher : time is up, please save. SCAFFOLDING CASE: model input: approaching end of time available. Model output: notify students and ask to save

3.4.2 Definition of Interventions on the basis of scaffolding cases

The analysis of the case studies allowed us to identify the interventions needed to support the learning process. Table 5 exemplifies the interventions derived from the sample case studies shown in table 4. The first column of table 5 refers to the case study that prompted the intervention, the second column indicates the conditions under which the model would generate the intervention, the third column indicates the intervention category and type, and the fifth column gives an example of the specific content for the intervention. The conditions indicated in the second column are expressed using the grammar specified in sections 3.1 – 3.3.

Table 5 Sample interventions derived from the case study shown in Wilcoxon Signed Ranks Test showing significant items for first and second questionnaires for the Control group 4 –

Activity	**Input events / State**	**Intervention Category**	**Intervention Content**
Case 1a	IDLE_USER_EVENT LM[current focus = task(name = introduction)] LM[experience = new users] LM[current focus = task(timeActive = 15')] LM[current_focus=task(Amount of text in fields = large)]	Cognitive / C_support	"Did you include the following topics?" Show a checklist
Case 1b	START_TASK_EVENT(task(name=save page_introduction)) LM[current focus = task(name = introduction)] LM[experience = new users] LM[current focus = task(timeActive = 15')] LM[current_focus=task(Amount of text in fields = large)]	Metacognitive / MC_monitoring	"Quite a story you wrote, good to meet you!.
Case 3a.	HELP_EVENT LM[current focus = task(name = introduction)] LM[experience = new users]	Metacognitive / MC_orientation	Please start with introducing yourselves to your expert.

	LM[current focus = task(timeActive = 2')] LM[current_focus=task(Amount of text in fields = empty)]		
Case 3b.	START_TASK_EVENT(task(name=fill form introduction)) LM[current focus = task(name = introduction)] LM[experience = new users] LM[current focus = task(timeActive = 30')] LM[current_focus=task(Amount of text in fields = medium)]	Behavioural /support	Please save, the lesson is almost over.

In a similar manner we continued for all the learning activities included in the assignment. These interventions were classified along the four main interventions categories: metacognitive, cognitive, behavioural and motivational support. The total intervention model after this study consisted of 39 intervention types, 16 of which were implemented in the system described in section 4.

3.4.3 Presentation of interventions to the user: timing and modality

Although in this paper we concentrate on the discussion of how one may appropriately select the *content* of scaffolding interventions (i.e. what one would say to a student to provide such scaffolding), two other aspects are important: *timing* and *mode* of presentation. Some aspects of intervention timing are discussed above (in particular those related to the synchronisation with the appropriate tasks), more fine aspects of such timing are only very briefly touched upon in this paper with respect to *breakpoint* selection (see section 4.1), a more detailed discussion can be found in (Laukkanen, Roda, Molenaar 2007)

The choice of *how* to present interventions may also impact on the learners activity at various levels: it may go completely unnoticed, it may smoothly integrate with their current task, or it may capture their attention and cause a temporary or durable focus switch. We assume that each intervention may be presented as text only, audio only, a combination of the two, or through an *embodied agent*.

Within these main modalities it is possible to identify further sub-modalities related, for example, to the size on screen of the intervention, the possible choices in terms of colours, tone of voice, loudness, text size, and many others. In order to control complexity within the conceptual framework we have chosen to provide as output of the model three parameters: the *modality* (text, sound, or embodied agent), the *mood* (happy, angry, neutral), and the *strength* (*strong, neutral*, and *weak*). We assume that a dedicated component will be responsible for the implementation of the three parameters in appropriate interactions with the user (see section 4.4).

Modality selection is based at least on two parameters: the characteristics of the intervention, and the learner's preferences. The characteristics of the intervention include the complexity of the message that needs to be transmitted to the user, the urgency of the intervention, the level of certainty of the proposed intervention (this is related to "how much better" the agents believe the proposed focus is with respect to the current one). The learner's preferences include: preferences on modalities explicitly declared by the user (through the set preferences event), inferred preferred modalities (either by observation of the user, or as a result of a feedback event). The choice of modality, mood, and strength is guided by rules similar to those presented in table 5.

3.5 Attention based approach to scaffolding

In this section the three essential elements of scaffolding - diagnosing, calibration and fading - are explained in the light of the event and the intervention model.

3.5.1 Diagnosis

Diagnosing is defined as the ongoing measurement of the students' current level of understanding (Wood, Bruner, & Ross, 1976). This entails the evaluation of user's progress during the learning activities. Two main processes are distinguished: the development of knowledge over the learning domain, and the development of the performance characteristics of the student. In our model the progress of the students is diagnosed based on the attention-relevant events occurring in the learning environment, the task model and the learner model. User-application events are particularly important for diagnosing because they provide a real-time description of the learner's activity within the learning domain. Additional information is supplied by *environment-events* tracing the overall behaviour of the learner, and *user events* which allow a direct interaction with the learner. This information enables the attention management system to go beyond the level of involvement in the learning application, by also measuring the activities of the students in the overall environment. This environmental information provides the context necessary to the model for reasoning about a more complete set of the learner's activities rather than just those within the individual e-learning application. With respect to the development of the **performance characteristics** of the students, the learner's experience and progress are always accessible

within the learner's model and can be incorporated in the diagnosis. For example, if a learner is using the concept map tool in the learning application proceeding quickly, filling-in different fields, and continuing with the selection of different fields accordingly; then, this information is stored in the learner's model and it may be subsumed by an indication that the learner is capable of appropriately using the mind-map tools. Our model currently does not provide for a description of the development of the **knowledge over the learning domain,** to this end, either diagnostic tests or semantic reasoning on the content provided by the users would be needed and could be included in the framework in the future.

3.5.2 Calibration

Calibration is directed at selecting the right interventions and providing it to the user at the right time. This entails that both the selected intervention as well as the timing of the interventions can be different for different students, but also for the same student over a period of time (Puntambekar & Hübscher, 2005). Calibration also reflects the adaptive and dynamic aspects of scaffolding. The dynamic aspect implies adjusting the timing and selection of the interventions to the progress and current activity of the learner (e.g. when a student starts a task for the first time the system provides an explanation of the task). The adaptive aspect implies the selection of the right intervention for the advancement of a particular student taking into account his/her personal characteristics (e.g. adjusts the explanation to the intellectual level of the particular student say, giving a more elaborated explanation for a slow learner than for a quick learner). In our model, calibration is obtained through the appropriate selection of the amount, form, and timing of interventions. The questions of *when* to send an intervention is largely determined by the evolving activity of the student and reflects the dynamic aspect. The questions of *what* interventions to give and *how* to communicate them is determined by the characteristics of the learner and therefore are more adaptive in nature.

3.5.3 Fading

The final important element of scaffolding is fading. Gradually as the user is becoming more experienced the scaffolds should be reduced. The task model and the learner model register the advancements of the user which provides the main input for the fading of the interventions in this system. The user characteristic's play an important role in the decision towards fading. For example a user that is registered as a low ability user and has performed a task well two times before, will receive more interventions then a user that is registered as high ability user that has performed the same task well only once. The fading decision of the system take into account different types of information collected in the learner model and will act accordingly. As soon as the diagnostics of the system and the learner model contradict each other the fading will be reduced, and possibly the learner model will be updated. For example, if the learner model indicates that the user is an experienced user, and the diagnostics of the system show that the user does not perform the task in the right way, the system will reduce the fading and send the supporting intervention to the user.

3.6 Discussion of the framework

The framework described shows how, by detecting and reasoning about the attentional state of the learner, it is possible to provide scaffolding interventions that better reflect the traditional approach. Diagnosis, calibration and fading processes are, in fact, appropriately implemented by selecting suitable intervention and the most appropriate timing and mode for their presentation.
Furthermore, the model allows taking into account the limitation of human cognitive abilities as discussed in section 2. For example, in order to limit task-switching costs, it is possible to track the task the learner is currently focussing on and, depending on its level of complexity, evaluating the best time for intervening (see section 4.1). This type of behaviour allows fine-tuning of the introduction of scaffolds so to lower the risk of increasing cognitive load. Another example of cognitive support is related to cueing. As discussed in section 3.3, Atgentive's task model includes the possibility to associate *help tasks* and *help messages* to tasks. Some of this help is explicitly defined as *pre-task* help which may take the form of cues to the learner about the next task to be performed so to reduce cognitive load (e.g. Metacognitive orientation interventions described in section 4.5.1).

4 A System for Adaptive Scaffolding supported by an attention aware system

The framework described in section 3 was partially implemented in a system that we describe in this section. The system is composed of three reusable components: the reasoning module, the environment tracking modules, and the embodied agent module. These components are customised to serve an application, in this case the Ontdeknet e-learning environment (see 3.4.1.1). The application is, in turn, augmented with an interface to

the reusable components. The complete system was called AtgentSchool. On the basis of the observation of the learners actions, the system proposes *interventions* aimed at supporting the learning.

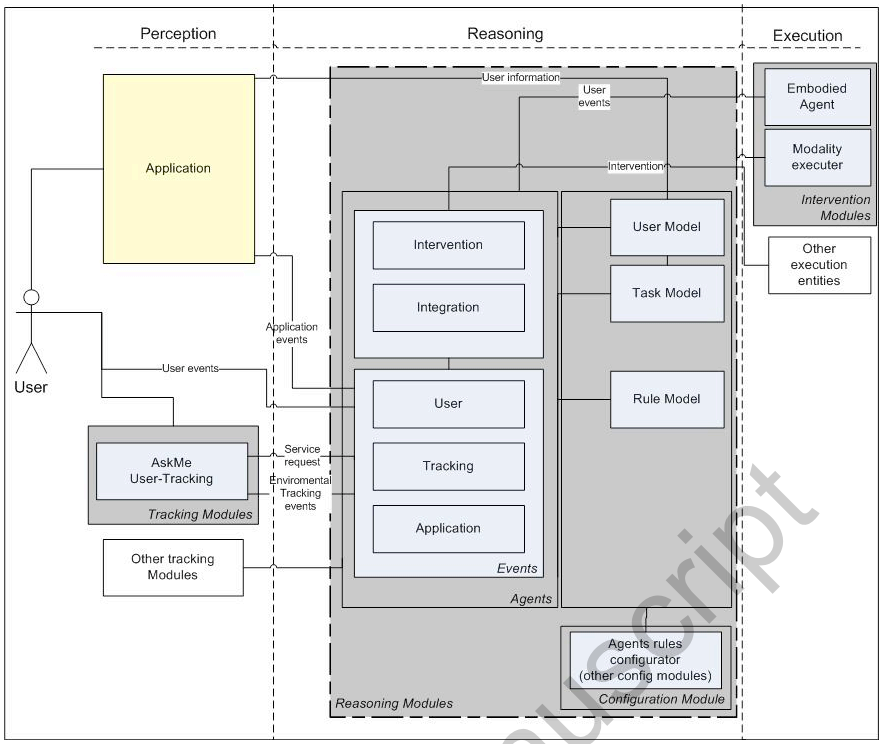

Figure 1. Generic attentive system

Figure 1 depicts a generic Atgentive system. The overall system monitors the environment of the learner and reasons towards scaffolds that are supportive for the learning process of a specific learner in a specific context. In the centre of the image is the application independent attention management component, the Reasoning Module. The **Reasoning Module** is employed to diagnose the situation of the learner, calibrate the support to the current situation, and fade the support when the learner is capable of self sustaining his/her learning. The Reasoning Module enables the selection of the **appropriate interventions**, of the correct **timing** for the interventions, and of the correct **form** for communication to the user. Another application independent module, the **embodied agent module** (on the right of figure 1), is used to communicate the interventions to the user(s). The left side of figure 1 shows the *perception* components: the (Atgentive enabled) **application**, and the **AskMe** tracking module; these components provide input to the reasoning module. The users' attentional choices, preferences, and possible future foci, are revealed by *events* (depicted as lines from input components to reasoning module in figure 1) that are then analysed in the Reasoning Module. This analysis results in *interventions* depicted as a line from the Reasoning Module to the *execution* components.

4.1 The reasoning module

The Reasoning Module is composed of a set of ***Agents*** (shown on the left-hand side of the Reasoning Module component in figure 1). These agents base their reasoning on the input received by the perception modules, on the content of the user/learner model, of the task model (shown on the right-hand side of the Reasoning Module component in figure 1). The agents may also update the content of the user/learner model and task model as they acquire information about the learners activity and the environment. *Event agents* (user, tracking, and application) are capable of reasoning about *events* describing the learner's attentional state and generate hypothesis on the current learner's focus as well as possible alternative foci. The *integration agent* mediates the hypothesis generated by the event agents and creates a prioritised list of the most suitable foci for the learner. Finally, the *intervention agent* decides when and how (time and modality) to intervene with the learner and generates the appropriate *interventions*.
The rules guiding the agents' reasoning are customisable through a configuration module (shown on the bottom-right side of the Reasoning Module component in figure 1) and form the *rule model*.

In the current implementation *event agents* are capable of processing a sub-set of the events described in the conceptual framework. In particular all *application events* listed in table 1, except the *resume* and *continue* events, are managed; amongst the *user events,* the *set time available*, the *help event*, and the *mood event* listed in

table 2 are managed; finally for the *tracking events,* only the *idle input* event is managed.
We have chosen to start with the implementation of these events for several reasons. The fact that we planned to test our application with children has influenced the choice in two manners. First, we have chosen to implement only those *user-tracking events* that, given the current technologies, could have been realised with un-intrusive interfaces (i.e. we have avoided all tracking that would have required the children to wear special devices). Second, we have chosen to delay the implementation of *user events* that would have required the children to provide complex input (i.e. many of the *user events* have not been implemented); and for the implemented *user events* a simple interface is provided that allows children to request for help (*help event)* by clicking on a question mark button, and generate *mood events* by clicking on smiley faces (see figure 3). Also, because the surrounding environment for the students did not provide particular distractions such as telephones, or people entering the room, we have not implemented the *environment tracking* devices and events.

The processing of each of the implemented events enables several of the scaffolding behaviours described earlier. The implementation of the *event agents* amounts to the implementation of a set of rules similar to those exemplified in table 5. For example for case 1a in table 5, when the AskMe module signals that the user is idle (*idle-input event*), the *tracking agents* consider information such as what is the level of experience of the learners, how long they have been active on the task, and how much work they have already performed; and if appropriate, generate the proposal for a new focus that eventually will trigger the cognitive interventions simulating the behaviour of a teacher who would intervene with scaffolding actions for students who are taking too long to complete a task or get distracted.

Event agents are mainly responsible for the generation of possible foci for the learner. Subsequently the *integration agent* and *intervention agent* will actually generate the interventions. For example, on the onset of a *user-application event*, the objective is to determine whether there are alternative foci for the learner. If this is the case, the agents decide how to best propose such alternative foci to the learner.
The handling mechanism for *user-application events* follows a five steps process (in brackets are indicated the agents responsible for the processing):

1. If the event reports a focus switch, the context of the interrupted task is saved to allow for easy resume. (*event agent)*
2. The list of alternative foci in the *learner model* is updated (*event agent)*.
3. The current learner's focus is evaluated against the alternative foci taking into consideration the complexity and advancement state of the current task and the likelihood that the focussed task will be completed within the available time (*integration agent*)
4. The best time for intervention is determined on the basis of the urgency of the focussed task, the progression state of the task, and the complexity of the focussed task. As a result the system will either immediately propose an intervention or wait for a *breakpoint*. A *breakpoint* is a natural pause caused by some change in the learner's activity. It has been demonstrated that interruptions presented at breakpoints are less disruptive for the user (Bailey & Konstan, 2006) and the system uses both task structure and sensory based input to detect breakpoints (Laukkanen, Roda, & Molenaar, 2007) (*intervention agent*).
5. Determine the best modality for intervention on the basis of the user preferences, the current task, and the intervention type (*intervention agent*).

4.2 The tracking modules

In section 3.1.3 we have introduced the assumption that some attention-related events may result from tracking application-independent user activities or changes in the environment. This requires two types of tracking modules: *environment-tracking modules* capable of tracking changes in the environment (e.g. a person enters the room, an email arrives, the telephone rings, etc.) and *user-tracking modules* capable of detecting user cognitive and physical state or activity (e.g. the user is typing, or he/she is talking to someone). Currently only one of the many possible tracking modules has been implemented: the AskMe module (depicted on the left-hand side of figure 1). This module tracks mouse and keyboard activity. Currently only one of the events generated by this module is processed, the *idle input event* (the user has not produced any input for a certain amount of time).

4.3 The e-learning application

Existing **e-learning applications** (top-left of figure 1) can use the services of the Reasoning Module by implementing an *Interface to the Atgentive system,* which sends events describing the user activity in the application, and receives proposed interventions. In the specific case of the system described in this paper the e-learning application is the OntdekNet application which has been augmented with an interface to the Atgentive system. The augmented application generates all the events listed in table 1 except the *resume* and *continue*

events. Currently AtgentSchool is available in three languages Dutch, Czech, and English. The AtgentSchool system (both the Reasoning Module and the augmented Ontdeknet learning application) was developed in an incremental manner and on the basis of recurrent formative evaluation studies, i.e. studies that allowed us to feedback the results of the system evaluation in its conceptualisation, design and implementation.

4.4 The embodied agent

In section 3.4.3 we have briefly indicated how, associated to each intervention, the model generates a suggestion of modality, mood, and strength for presentation of the intervention. In the current implementation, we only generate intervention in the *embodied agent* modality (this is because children find it more difficult to read text as compared to listening to a message spoken by an embodied agent). The system includes an **embodied agent module** (on the right hand side of figure 1) that is capable of implementing presentations of interventions in different *moods* and *strengths* using predefined scripts selected at run-time (Clauzel, Roda, Ach, & Morel, 2007). As a result, in the Atgentive system the scaffolder is an embodied character (shown in the center of figure 2) that communicates the interventions to the learner. This character is a three dimensional animated character, which speaks to the user with a human language; it shows emotions and moves across the screen and is powered by Living Actor© technology.

4.5 Intervention model

Below we describe the 16 intervention types within the four different intervention categories that were actually implemented in the system. Each section details an intervention category; we provide examples of the different intervention types and the relation with the events model as they were implemented.

4.5.1 Metacognitive Interventions

Our system aims at dynamically providing metacognitive interventions at the appropriate moments to help students becoming aware of the metacognitive activities that could help them regulate their learning. The following intervention types are implemented in the first version of the system (see also the left column in figure 4);

1. Metacognitive orientation interventions introduce learners to a new task. Experts are known to spend more time in orientation on a task than novices (Schmidt & Boshuizen, 1993). A better orientation on the task allows for a better comprehension of the tasks elements which influences the time and performance on the task. An example of an orientation intervention introducing a new task is illustrated in figure 2 and generates the following message to the learner: *Your expert would like to know what your learnin goal is, could you tell him? Please click here to write your learning goal.* These interventions are provided to the users in the project screen overview just before the user is about to commence on the task (pre-task support).

2. *Metacogntive explanation interventions* exemplify the task for the learner. This is expected to help students in the effective execution of the task. An example of explanation intervention for the "introduction" task is the following message to the learner: *Here you will introduce yourself, I will give an example: "My name is David, I live in Prague, I am 16 years old. My hobbies are skating and chatting. I have one older brother named Karl."* These interventions are provided to the user right after the task page is opened (on task support).

3. *Metacognitive monitoring interventions* clearly indicate to the user that the current task is finished and reassert what the system or the expert will do with the provided information. The clear closure on the task helps students continue on the next task. Monitoring interventions are provided right after saving the task (post-task support). An example of a monitoring intervention after the completion of the "learning goal definition" task is the following: *I'll directly go to your expert and explain what you would like to learn*.

Figure 2.Example of metacognitive orientation support

To summarize we anticipate that the agent's interventions on the level of metacognition will help students becoming aware about the metacognitive activities that can be performed around different learning tasks. We expect that the help on this level will support students in constructing a better understanding of tasks and their relation with the main assignment.

4.5.2 Cognitive Interventions

These interventions are specifically adjusted to the learning activity at hand to support the learner with the current task (see lower right section of figure 4). Cognitive interventions are triggered by *idle user* events generated by the ASKME module, or by *help events* generated by the user clicking on the question mark icon. There are two types of cognitive interventions implemented in the system: *cognitive support interventions* and *cognitive resources interventions*. *Cognitive support* is directed at helping the learner with the current learning activity whereas, *cognitive resource interventions* provide students with links to resources in the learning environment that can help them perform the task. For example a cognitive support intervention for the activity concept map (students have to write down all topics that are related to the subject that they are studying) may say: *What do you already know about the subject you are going to study?* An example of a cognitive resource for the same learning activity would be: *Need some ideas? You can read the introduction diary of the expert.* These interventions are given to users when they become idle within a learning task or when they click on the question mark when they are working on a learning task.

Cognitive interventions are designed to support the thinking process of the students in relation to the task they are performing. We expect that learners will perform the tasks more successfully after receiving the cognitive interventions.

4.5.3 Motivational Intervention

Motivational interventions support the motivation of the user. There are four types of motivational interventions implemented in the system: *motivational support, emotional support happy, sad and neutral.* They are triggered by two events: the *idle user* event and the *mood* event. When the user has become idle in a task and there are no more cognitive interventions for this user, the motivational interventions will be shown. An example is: *You can do it! Just start writing*. The user can indicate his current emotional state with the smiley's: happy, neutral, sad which results in *mood* events. When the user clicks on the emoticons the agents mirrors the state of the user showing an animation and expression resembling the state of the user. These three emotional feedback lead to 3 emotional support interventions with the embodied agent responding to a user notification of an emotional state: sad, happy, and neutral; an example of *emotional support* intervention is shown in figure 3 mirroring the user state sad.

The motivational interventions are expected to increase the motivation of the learners who receive them.

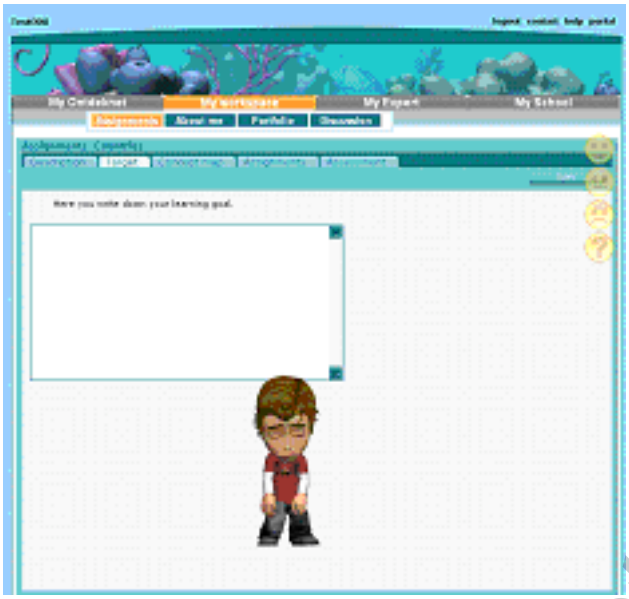

Figure 3. Example of motivational intervention

4.5.4 Behavioral interventions

Behavioural interventions are directed towards simple behavioural user actions. Two types of behavioural interventions are implemented in the system: *external events notifications* and *navigational support*. External events notifications are generated by *new information available* events, e.g. "*Your expert has answered your question"*. *Navigational support* interventions are simple navigational statements that direct the user to certain elements in the system for instance "*click here to go back to the project screen"*.

The effect of behavioural interventions is difficult to predict. We expect that external events communicated to the user will enhance the virtual communication with other users, the expert and the teacher. We do not anticipate an effect of the navigational support interventions because these are only provided in exceptional cases when users are not showing any pattern in their behaviour.

4.5.5 Summary of the interventions by category

The 4 intervention categories and 16 intervention types are summarized in Table 6.

Table 6 - A summary of the intervention categories

Type	**Name**	**Description**
Metacognitive	MC orientation	Introduces the activity to the user
Metacognitive	MC explanation	Explains the activity to the user, preferably with an example
Metacognitive	MC monitoring	Provides general feedback to the user about the finished activity
Cognitive	Cognitive support	Provides additional explanation with respect to content issues to the user
Cognitive	Cognitive resources	Provides additional explanation by redirecting the user to an example of another user or additional information provided by another user
Motivation	Motivation support	Provides a motivational incentive to the user
Motivation	ES Happy	Reaction to happy user
Motivation	ES sad	Question to sad user
Motivation	ES neutral	Reaction to neutral user
Behavioural	External events notifications	Provides notification about an relevant external event plus the link
Behavioural	Navigational support	Provides support in navigation to certain learning activities

Figure 4 below displays the relationships between the event information and the intervention categories and types. Metacognitive interventions may provide pre-task support, on task support, or post task support. The positioning of these types of interventions is determined by the state of advancement of the learning process of the user. Metacognitive interventions are always related to a learning task and they communicate to the learner information related to this task. Cognitive and motivational interventions provide on task support and they are

always directly related to the learner's current task and current behaviour. Behavioural interventions are not task related however the learner's current task determines the timing of these interventions.

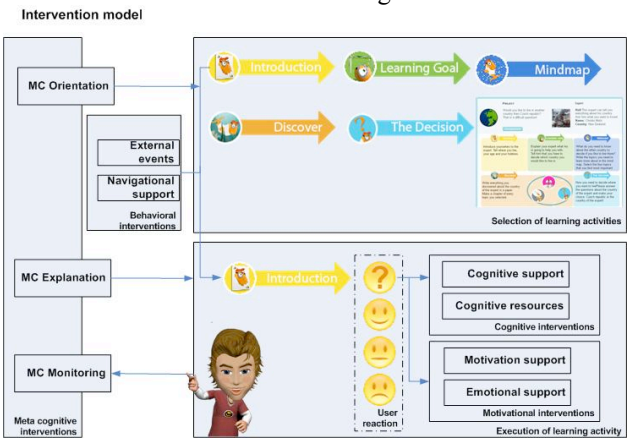

Figure 4. Overview of the Intervention Model

5 *In practice; first test with the system*

The sections above explains how our attention aware system is giving form to dynamic scaffolding for the user. In this section we describe how adaptive scaffolding results from the interaction between the e-learning application and the Reasoning Module. Several assessment tools were employed to ensure that the resulting system would in fact provide dynamic and adaptive scaffolding on the basis of attention management. The adherence of the final system to these requirements is described in this section through the analysis of our two main assessment studies:, (1) classroom test runs and (2) the pilot study in Chzech Republic. The central question we addressed throughout the assessment process was if and how attention management was providing appropriate input for dynamic and adaptive scaffolding.

5.1 The test runs: user perception

In order to test the stability and functioning of Atgentschool before the pilot in the Czech Republic, pre-pilot tests were run in 6 schools in the Netherlands. The main purpose of these tests was to ensure the proper functioning of the system with real users and a representative user load, as well as collecting preliminary results on how learners perceived working with the system.

5.1.1 Context of the test runs

These testruns were one hour sessions in which children were asked to work on the project “Where do you want to live?’ They worked on the project for 45 minutes performing the following learning activities: 1. introducing themselves to the expert, 2. setting a learning goal, 3. filling in the concept map, 4. reading the first diary of the expert and 5. asking a question. This was a shorter version of the project later used in the pilot.

5.1.2 Procedure of the test runs

Six test runs were performed with 108 students aged between 9 and 12. Students received a 5 to 10 minute introduction to the task as testers of AtgentSchool and to the project “where do you want to live?”. During the sessions they were asked to use the smiley’s in the screen (happy, neutral, sad) to indicate how they felt about the agent. After their session they filled out a questionnaire about their perception of the agent and a short interview was conducted to further asses their perceptions of the system. In testrun 3, students were also shown interventions on a digital school board and they were asked to rate the interventions and to write down any comment they had.

The following measurements were analysed after the testruns:

- the log files of the students including feedback with the smileys,
- A questionnaire about the agent with 15 items,
- the discussion notes after the sessions,
- the class session rating and discussion of the interventions

5.1.3 Results of the test runs

We analysed the logs of the sessions to confirm that all interventions selected conformed to the conceptual framework. A few interventions were studied in more detail and some debugging was done in relation to these

findings. The children were asked to indicate how they felt with the smiley buttons. Unfortunately, these were used very little, because students were not able to attend a new task, read the interventions and act accordingly, and also indicate how they felt with the smileys. Based on these pilot-test findings, the feedback acquisition was redefined and we developed a session with children judging the interventions on the smart board in a classroom session after the test run session. The students were asked to rate the interventions on a five point Likert scale and to write down their comments. The cognitive and metacognitive interventions were judged to be very good; the motivation interventions were judged neutral towards bad see table7.

Table 7 – Judgement of the students of the Interventions shown.

Interventions shown	**Cumulated average judgement of student**
Metacognitive interventions	4.03 = good
Cognitive interventions	3,71 = good
Motivational interventions	2,70 = not good not bad

The analysis of the questionnaires produced very encouraging results. 90.5% of the children wanted to work with the agent Matthew again; 62% wanted to work with an agent more often; 9.5% would have liked to work with a different agent then Matthew. The agent provided good help according to 90% of the children, and the two students that disliked the agent found that more help could have been provided. Students gave Matthew a 7.5 average grade (girls a 8 and boys a 7)

5.1.4 Conclusion

Based on these test runs we ensured the proper functioning of the software for the pilot. We improved the motivation interventions trying to address the children's feedbacks. We also adjusted some aspects of the original configuration of the motivational support and added the behavioural navigation support interventions as described in section 4.5. The configuration of the metacognitive and cognitive support was judged positively by the users and therefore maintained. The agent Mathew (which had been developed within the Atgentive project with the purpose of supporting the AtgentSchool application) was well liked and accepted by the Dutch students.

5.2 The pilot

The pilot study was an experimental study in which the *experimental* group received scaffolds from the agent and the *control* group did not receive scaffolds. In order to prevent a Hawthorne effects, both groups had the agent in their screen. The main research question was: What is the effect of dynamic scaffolding based on the attention management system in the context of Atgentschool? We only briefly report the main effects below, the complete analysis will appear in a forthcoming publication.

5.2.1 Context of the pilot

These pilot study was conducted in 4 schools in the Czech Republic; a total of 134 Czech students aged 11 have used the system. The student worked in five 45 minute sessions in which they were asked to work on the project “Where do you want to live?’. They were performing the following learning activities: 1. introducing themselves to the expert, 2. setting a learning goal, 3. filling in the concept map, 4. reading the diaries of the expert living in another country, 5. asking questions to the expert, and 6. writing a paper and answering a questionnaire.

5.2.2 Procedure of the pilot

This study had an experimental design. The experimental group received interventions from the agent and a control group did not receive any interventions from the agent. Students worked on the project in groups consisting of 2 students. The groups of two students were randomly assigned to the conditions. This entails a within classes design controlling for in class differences. The experimental group consisted of 28 groups (56 students) and the control group of 27 groups (54 students).
The following measurements were taken before, during, and after the pilot run:

- Student questionnaires after 3 weeks and at the end of the pilot with questions measuring motivation and students' opinions about Atgentschool,
- teacher questionnaires after 3 weeks and at the end of the pilot with questions measuring motivation of the teachers and the teachers' opinions about Atgentschool
- the log files of the students including feedback with the smileys,
- the structured diaries filled in after the lessons by the teachers,
- the work produced by the students
- the blind assessment of the students' work by two graders

- a discussion workshop with the teachers at the end of the pilot

5.2.3 Results of the pilot

We only report the main results on student performance, learning and motivation in this section.

5.2.3.1 Performance

The performance of the experimental group and the control group was compared to see if there were significant differences between the performance of the students in the two conditions.
We first looked at the data evaluating the results obtained by groups of students on each one of the six tasks as described above. With respect to the paper the length of the paper in the number of paragraphs was measured and the quality of the paper was judged (bad, medium or good).
A Logistic Regression Analysis on the data relative to the evaluation of the results obtained by students on the six tasks above revealed that **children in the Experimental group asked significantly more questions to the experts (P=0.0491) and produced papers of significantly better quality (P=0.0506) than children in the Control group** (see table 8).

Table 8 . The differences on task performance between the experimental and control group.

Independent Variable	**Parameter Estimates**	**P-value**
Intercept	-4.0116	0.3969
Introduction	-0.0787	0.6627
Setting a learning goal	1.3687	0.0926
Concept map	-0.0355	0.7758
Number of paragraphs in paper	-0.1831	0.4584
Quality of the paper	**0.9135**	**0.0506**
Questionsasked	**0.4777**	**0.0491**
Questionnaire	-0.0999	0.3033

5.2.3.2 Motivation

The motivation of the experimental group and the control group was compared to see if there were significant differences between the motivation of the students in the two conditions. The questionnaires were conducted in week 3 and week 6 of the pilot including 12 questions that were concerned with the motivation of the students. Students in the Control and Experimental groups were analysed separately with a Wilcoxon Signed Ranks Test to assess whether a significant change in motivation had taken place between the first and second questionnaire. Significant results (at the 5% level) are reported below in tables 9 and 10 (taken from Rudman, 2007). The control group students did not change in their answers on the questionnaire but on one item whereas the experimental group shows a positive development on the questionnaire over 9 items.

. Table 9 - Wilcoxon Signed Ranks Test showing significant items for first and second questionnaires for the Control group

Control Group	Mean (Q1)	Std. Dev (Q1)	Mean (Q2)	Std. Dev (Q2)	Z	Signif-icance
4.Honza looks great	2.50	1.102	3.05	1.495	-1.999	.046 (+)

Table 10 - Wilcoxon Signed Ranks Test showing significant items for first and second questionnaires for the experimental group

Experimental Group	Mean (Q1)	Std. Dev (Q1)	Mean (Q2)	Std. Dev (Q2)	Z	Signif-icance
2.Software does what I want	2.43	.756	3.29	.994	-2.070	.038 (+)
3.Software does nothing I want	4.00	.784	3.14	1.167	-2.235	.025 (-)
5.Honza really friendly	2.14	1.027	3.14	1.351	-2.038	.042 (+)
6.Honza very helpful	2.50	1.019	3.36	1.151	-2.165	.030 (+)
7.Honza very annoying	3.64	.929	2.50	1.225	-2.073	.038 (-)
9.Immediate response	3.07	1.141	3.93	.997	-1.996	.046 (+)
11.I like the look of the software	1.79	.699	2.86	1.406	-2.223	.026 (+)
14.Screen instructions helpful	2.57	.938	3.43	.852	-1.997	.046 (+)

18.I really enjoyed the lesson	2.14	1.512	3.07	1.492	-2.214	.027 (+)

5.2.3.3 Learning

The students filled a 15 items pre and post test on their knowledge about the country studied. The means (using 0 as wrong and 1 as right) on the pre-test and post-test are displayed below in table 11. We found a significant learning effect but no significant difference between the experimental and the control group.

Table 11. learning results of control group and experimental group

Means	**Pre test**	**Std. Deviation**	**Post test**	**Std. Deviation**
Control group	0.42	0.38	0.70	0.41
Experimental group	0.40	0.40	0.72	0.37

5.2.4 **Discussion**

The results show performance differences on two out of six learning activities. These performance differences are particularly important, because they measure the direct effects of our attention-based scaffolding framework on the performance of the students (i.e. improvements can be seen in the experimental group but not in the control group). The two learning activities on which the effects were significant are the two activities students work on the longest time during the project. The introduction, goal setting, concept map and the questionnaire are activities students only work on for one consecutive session during the pilot. The paper and asking questions re-occurs for 4 sessions and constitutes the main and largest tasks the student perform during the project. These results indicate a more proactive attitude of learners supported by the adaptive and dynamic scaffolding. The results in motivation show a motivation increase in the experimental group, whereas in the control group the motivation remains stable. This indicates that the system has a positive effect on the motivation of the students. Finally, the results on overall learning do not show us a difference between the two groups. Both groups show a significant increase in factual knowledge about the country studied. If there are learning differences between the conditions, they are more subtitle then the measurements means used can indicate. As pointed out in the introduction we expected students to show a more positive development on the ability to self regulate the learning; better knowledge transfer due to a better connection between the prior knowledge and the learning content; higher motivation of the students. We can confirm the higher motivation, also the quality of the papers of the experimental group indicates a better knowledge transfer. This pilot did not collect any data on the self regulations, but the teachers in the workshop indicated that the experimental group asked far less for help and was more actively engaged in the pilot then the control group. This would indicate a better ability to self regulate learning.

The attention management system based on the model proposed seems to be a powerful tool towards adaptive scaffolding. The encouraging results of the design and effect studies of the AtgentSchool system give us reasons to belief that attention management is an adequate basis to provide adaptive and dynamic scaffolding to learners.

6 Conclusions

The fundamental hypothesis of our research has been that scaffolds support learning by steering the tutee's attention to the appropriate information and tools, and that the selection of the appropriate scaffolds may be based on the knowledge of the history of the tutee attention allocation processes.

In this framework, the main elements of scaffolding as described in the classic literature (diagnosis, calibration and fading) are all immediately related to attentional processes. The progress of the students is diagnosed based on the current and historical attention-relevant events occurring in the learning environment (where the history is subsumed in a learner model). Calibration is obtained by *intervening* with the learner in a manner that is *adapted* to both his/her current attentional focus and his/her characteristics (e.g. history of interaction, needs, abilities, etc.); intervening with the learner amounts to either supporting the learner's current attentional focus or proposing some more effective alternative foci. Fading interventions from the adaptation process of calibration. Furthermore, the timing of scaffolding interventions is evaluated on a very fine-grained scale in order to minimise disruption and maximise understanding of the scaffold. Both exogenous and endogenous attentional processes are taken into account in the selection and timing of scaffolding interventions in order to ensure that the learner correctly perceives the interventions and is motivated to exploit it.

(Puntambekar & Hübscher, 2005) have proposed a table summarising the interpretation of scaffolding features in the modern and traditional environments. In table 12 below we extend Puntambekar's and Hübscher's table to

also include a comparison with our attention-aware scaffolding.

Table 125. Interpretation of scaffolding features in the modern, traditional, and attention-aware Atgentive system - Extended from (Puntambekar & Hübscher, 2005)

Feature of scaffolding	Modern	Traditional	Attention-aware Atgentive system
Scaffolder	Tools and resources	Multimodal assistance provided by a knowledgeable human	Embodied agent
Diagnosis	Stable blanket	Adaptive support, sensitive to the needs of the student	Monitor of to personal behaviour through attention-related events
Calibration	Passive support	Dynamic support tuned on ongoing assessment of the learner	Reacting on personal behaviour and differences based on attention-related events
Fading	Permanent and unchanging	Fading reducing support over time	Monitor of personal advancement by event tracking and user model

Although we have presented the implementation and evaluation of our framework within a specific e-learning system, the model we propose has been designed as a general purpose one for digital learning environments. The Reasoning Module, capable of tracking, modelling, and reasoning about events describing the attentional state of the learner is of general applicability (both its conceptualisation and implementation). The interventions taxonomy organised in meta-cognitive, cognitive, motivational, and behavioural interventions, is designed to cover a wide range of scaffolding interventions in learning environments. The attention-based dynamic and adaptive scaffolding system we propose rest on a mapping of attention-related events to scaffolding interventions.

During the conceptualisation phase we have run several formative evaluation studies (including case studies and test runs) that have guided the design and development of the system. We have also run a pilot study that has allowed us to perform effect studies. The results obtained so far are encouraging and show that students supplied with attention-based scaffolding interventions produce better results, a more proactive attitude towards the learning activity, and a higher motivation.

The effects of our system on the learners need to be researched in more detail. Our future research will start by assessing if the interventions proposed cause the learning activities anticipated; i.e. behavioural interventions should initiate regulative learning activities; cognitive interventions should initiate cognitive learning activities; meta-cognitive interventions should initiate meta-cognitive learning activities. Another area of research will concentrate on a more detailed analysis of the effects of interventions "tones". Currently all our interventions have a directive tone (although they may be presented by the virtual agent using different strengths and moods). We will analyse the effects of using tones different from the directive one (e.g. suggestive or questioning). Overall, we are aware of the need to gain a better understanding of the results obtained and further refine the system, as well as implement those features that were not included in the first prototype, the results obtained so far however, demonstrate that attention based scaffolding has the potential to adapt better to the needs of learners, supporting motivation and performance on the more complex activities.

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9 Notes

[i] Note that the first column of table 1 implies that
USER_APPLICATION_EVENT ::= START_EVENT | CONTINUE_EVENT | COMPLETE_EVENT | RESUME_EVENT
For sake of brevity we do not expand the grammar to this level of detail.
[ii] Note that this means that, following the given grammar, the LEARNER_MODEL_ELEMENT_VALUE can correctly replace the LEARNER_MODEL_ELEMENT