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Computer-based Reflective Writing Studios

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Abstract

The environments within which we write are undergoing critical change. Writing in the 21st century is typically performed using digital devices connected to the Internet, enabling writers to interact with content and with other people in completely new ways. This increased interconnectedness opens the door to new opportunities as well as challenges. This paper proposes a new type of tool, Reflective Writing Studios, that can be used to study writing phenomena in a most encompassing way, taking into account the writer's physical and social surroundings, their emotions and mental states in addition to the cognitive processes generally studied. The paper introduces the architecture for a multimodal interaction system, its components and their evaluation: structured information about the activity is provided by our writing activity management system; multimodal sensor data from the writer and the environment (e.g. webcam) is collected through a browser extension; data fusion and user interaction (e.g. visualizations) are performed using affective computing techniques. We discuss how RWS can support novice writers reflect on the context, process and outcomes, aspects acknowledged as key for developing writing skills. The framework opens avenues for research in terms of multimodal data collection and interpretation.

Keywords: writing, cognitive technologies, affective computing, ubiquitous computing, reflection

1. Introduction

Writing skills are required to varying degrees in all professional disciplines, not only as a method of communication, but also as a catalyst for higher cognitive functions such as analysis and synthesis [1]. Teaching writing is notoriously challenging and the development of writing skills in learners at any level has been acknowledged as one of the biggest challenges in education [2]. The challenges are now compounded by the disruptive changes produced by ubiquitous new technologies. The Internet has become an external memory, changing the ways we remember the facts needed for writing [3]; social networking changes the way we work, feel and relate to others (as shown by a myriad of cyberpsychology studies) and technologies designed to grab our attention (e.g. mobile phones) are embedded in the environment that surround us [4]. Although writing was rarely done in complete isolation, new technologies are now interjecting all its underlying processes: cognitive, social and behavioral.

New tools and theories that help us understand the effect of this new context, and tools that support writers deal with it are gaining urgency. Even before these new developments researchers acknowledged that writing environments had not helped improve writing skills or learning [5], rather focusing on improving productivity and presentation. This limitation was first raised soon after word processors became widely available [5], and still applies. Back in the 80s, authors like Pea and Kurkland posed the challenge to develop tools that help writers express or refine their thoughts. They coined the term cognitive technologies for writing to describe tools that connect thinking and writing. The proposal for cognitive tools were based on Flower and Hayes cognitive model of writing [6], other theoretical perspectives have since then produced different proposals for improving writing tools.

Current methods used to collect data about writing processes include: screen capture, eye tracking, keystroke logging [7] that help understand behaviour, qualitative methods, field and ethnographical studies that help understand the cultural and environmental conditions, natural language processing to study on features, and think-aloud protocols that help understand, among other things, the subjective experience of writers. So far, analysing the data collected through these methods requires a researcher's time and expertise, and this means that individual writers do not generally see, and benefit, from the outcome of such analysis. One exception has been applications that use Natural Language Processing, for example for the automated analysis of the quality features of writing products. In this case advances on data mining and information retrieval techniques (e.g. Latent Semantic Analysis) created in the 1990's opened the possibility of automated essay scoring (AES, also known as Automated Writing Evaluation), and span a significant area of research and commercial innovation.

Engineering automated systems to process large amounts of data is in itself challenging, specially when the data is multimodal (i.e. video, text and sound) as the one described in this article. Only when the tools can produce accurate enough analysis, and they are scalable, they can then be of value to end-users (i.e. writers). In this study we focus on the evaluation of the software components while leaving the evaluation of its impact on reflection for future studies. Although measuring the impact of new technologies on learning is important, in complex problems it requires multiple studies. For example, after 20 years of research and extensive use, the impact of AES on student learning is still debated [8].

Writers make a myriad of complex decisions regarding the composing activity (e.g. topic and argument), the reading, the environment and tools, the timing and so forth. We argue that current sensing and computational intelligence techniques can be used gather empirical evidence for new writing theories, and automated feedback that goes beyond the document's quality features. Learning about these many issues requires reflection, particularly reflection-in-action [9], as a transformative element. The literature on reflection is used as a framework for our proposal on how to build systems that help novice writers develop their skills.

Thanks to the introduction of novel sensing and data mining techniques, it is now possible to record significant amounts of data from almost any human activity. The HCI community has used this as an opportunity to develop new 'personal informatics' tools that support reflection [10]. We aim to develop these ideas further and contribute to the design of novel writing support tools.

This paper first offers a way to study writing activities through a more comprehensive description of the writer's environment, experience and behaviour. Most educational research assumes that the learner/writer is continuously engaged in the activity for the length of the study, for example, composing a document or in the dialogue with a tutor. If a learner is engaged in a face-to-face discussion these assumptions make sense. But in a networked environment the learner is physically surrounded by devices that call for his attention, so this assumption might not hold. For example, while writing a literature review, a writer might use a combination of Google Scholar and email, while receiving phone calls, text messages and tweets from friends and colleagues. Alternatively, she might decide to be disconnected while she writes. All these environmental variables will impact on the writing experience and the outcomes and hence, they should be aspects that the writer reflects upon.

This paper contributes a theoretical framework and the architecture of computer-based 'Reflective Writing Studios', a category of tools that supports writers reflect on their writing and learning process. The system architecture described builds on our own work developing automated feedback tools for writing and affective computing systems.

The idea of Reflective Writing Studios takes into account behavioural and emotional expressions. As often found in descriptions of learning interactions, like the dialogues between coach and student described by Schön, the behavioural and emotional expressions of the subjects are key to understanding the writing and reflection phenomena. For example, these reports describe how the learner may express 'surprise' at something the coach says or mention the perceived approval/disapproval in the coach's voice. These emotional variables are being increasingly studied in the literature. Computer-based approaches to detecting emotions and behavioural information are progressing rapidly [11] and specifically in the context of learning interactions [12].

In section 2, we first discuss how these six perspectives come together around the idea of reflective writing studios: the cognitive model of Flower and Hayes and information processing and dual-task interference of Gailbraith [13], the theories that focus on the social aspects or on the materiality of writing [14] that highlights the importance of the environment in which writing takes place, the reflection and modelling processes of Schön, and those that study the affective/emotional aspects of writing. Comprehensive descriptions of these theories are out of the scope but available, for example, in the Handbook of Writing Research [15] and the Sage Handbook of Writing Development [16]. The focus of each section is on how the particular theoretical perspective may influence the way supporting technologies can be built. We also discuss how formative feedback [17] can be used to facilitate reflection. In Section 3 we discuss a series of questions that a writer can reflect on. These include conceptions and motivation, the process and outcomes of the activity, the environment, mental states and ancillary activities that arise during the activity. In section 4 we describe the system architecture of our Reflective Writing Studios and review four projects that form the key components of the system. The first one, iWrite, focuses on managing the writing activity: deadlines, topic and genre, group members (if collaborative) and integrating tools for peer and tutor feedback, and disciplinary specific tutorials for the support of writing in different genres. This component covers the formal structure of the activity (i.e. what the tutor had planned). The second component described represents an ongoing effort to build systems that collect extensive information about the computer-human interaction taking place while the user is writing. This component covers what actually happens during the activity, the aspects that the instructional design did not consider. For example, the environment in which the writer is physically located and the ancillary activities in which she engages on (e.g. reading email). The third project is the engine that fuses together the information sources from the above two. The fourth component provides the user interface with questions that scaffold the reflection and interactive visualizations generated from the data analysed. In Section 5 we discuss the results and forthcoming challenges.

2. Theoretical perspectives and enabling technologies

We ground our discussion on some of the extensive literature at the intersection of writing research, psychology and human-computer interaction. In this section we review the theoretical models that have been used to understand writing processes, and the technologies that afford functionalities suggested by these models. The most widely used models of writing since the 1980's are probably the cognitive models of writing [6] which inform the design of functionalities found in today's word-processing tools such as tools for writing outlines, online thesaurus and spelling checkers. Debates about the human information processing limits and dual task interference have driven research into attentive computing. Socially situated models of writing were proposed to address the cognitive model's emphasis on the solitary author [18]. These models led human-computer interaction researchers to develop social-awareness tools [19]. Other researchers have focused on the materiality of literacies [14] by studying the actual places and situations where writing takes place. Human-computer interaction researchers have since worked on ubiquitous computing to improve the interaction by using information from the environment. Often linked to the increased attention to the embodiment of cognition these views have led HCI researchers to use behavioural [20] and physiological or multimodal [21] information. This section discusses each of these in more detail.

2.1 Cognitive technologies in writing

Pea and Kurkland [5] used the cognitive model of Flower and Hayes [6]. Figure 1 displays this model, extended to include affect, ancillary activities and the physical environment and state of the writer. Evidence supporting this model has generally been based on cognitive studies of how people write. They generally follow a "think-aloud" protocol where participants describe what they are thinking while they engage in the activity. The model represents the kinds of mental acts that people engage in, namely: planning, translating, reviewing and monitoring.

Writing technologies can be included as resources in what Pea and Kurkland called the 'task environment'. They include those that support the *processes* described above: planning (e.g. tools for brainstorming or for organising ideas by creating outlines), translating (e.g. speech-to-text systems), reviewing (e.g. 'rereading facilitators') and monitoring (e.g. planning systems). Many of these resources have been integrated into word processors and used frequently (e.g. planning, through outline views or embedded comments), while others not as often (i.e. speech-recognition-systems). Tools that help evaluate against certain standards are available (e.g. Automatic Essay Scoring), but rarely used as writing support. Some tools that provide cognitive visualizations [22], [23] of the document can also be considered as supporting reviewing processes.

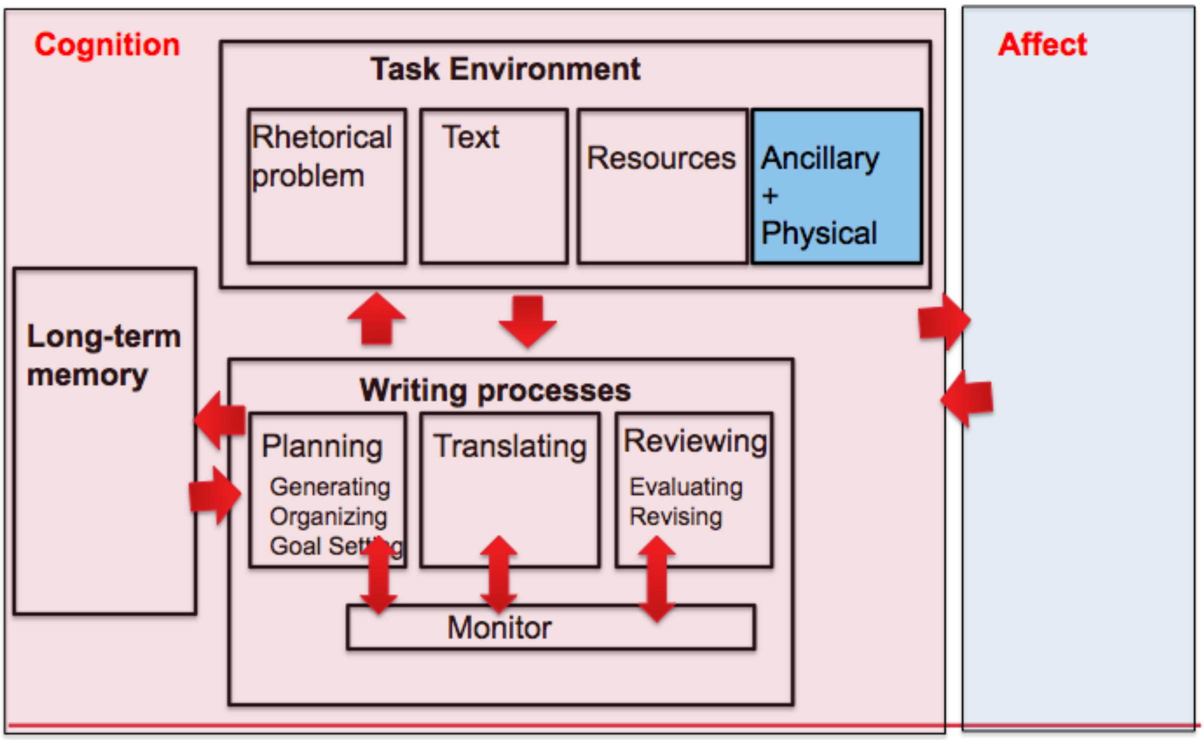

Figure 1: Extended version of the Flower and Hayes [6] **cognitive model of writing. We have added the Ancillary and Physical components to the task environment (in blue), and Affect (in grey).**

Some tools can also provide support (i.e. resources) for the rhetorical problem, that is, how to express the topic in terms that have a certain effect on a specific audience. Tools that might support this aspect of writing include automatic visualizations of the topics prominent in the composition (according to some algorithm such as Latent Semantic Analysis). For example the automatically generated concept maps described in [22] provide useful visualizations that a writer can reflect with. Other tools in the writing environment include the word processor, where coding happens, and those for providing feedback (human or automated.

2.2 Writing and Information processing

Gailbraith and colleagues performed a series of studies in the 90's that explored the effectiveness of the "interactive" vs. the "outline first" strategy [24]. Their work has advanced the theoretical and empirical understanding on writing, particularly in understanding the processing limitations of the writer's mind [13]. Their theory is informed by two lines of research. First, studies on the effects of dual task interference, showing how when two tasks are temporally close, even when they are simple, their proximity has a negative effect on their performance. These studies provide evidence that activities such as listening to music, conversations or multitasking while writing is likely to degrade writing performance. When one of these 'secondary tasks' affects the writing performance the conclusion is that they share resources with the components of the writing system. This is driven, for example, by bottleneck or crosstalk effects. Their research has also been influenced by research on the limitations of short term memory, particularly how much we can keep available for processing.

Applications, like our RWS, that record and analyse cognitive, affective and behavioural processes will be able to contribute new empirical evidence on current writing research debates. For example, our writing activity management system component (described in detail later) has been used to analyse writing processes of hundreds of students [25], [26]. We are using the system to study the impact of different forms of feedback [27].

The research on dual task inference and the limitations of STM supports the idea that further research. Gailbraith notes how "*for most writing tasks, smooth flow is repeatedly interrupted… production of the 5th and 6th sentences of the previous paragraph (which were composed using a keystroke logging program) involved a total of 60 pauses of 2 or more seconds*" [13]. I would take this further, with the type of analysis proposed here, by noting that while I wrote this section I was distracted by a waitress who brought a coffee to my table and by a phone call. Furthermore, my emotional state changed when I overheard my wife talking about my son. During these 50 minutes I also went to my email software at least twice and checked if I had any urgent messages. All these events have a significant impact on the way I write, and all suggests that this type of writing environment is not an exception but a growing trend.

2.3 Social aspects of writing

Researchers have emphasized many social aspects of writing [13]. Some focused on individual writing and issues such as the socially driven motivation. Other aspects arise in collaborative writing, an area of great importance since much of writing is done collaboratively [19]. For example, Ede and Lundsford [28] showed that 85% of the documents produced in offices and universities had at least two authors. But managing the complexities of group work is a challenge, particularly for novice writers. One line of research within collaborative writing has focused on process loss, productivity, and quality of the outcomes [28]. In another line of research, computer supported collaborative learning, researchers have studied writing as a means to deepen learners' engagement with ideas and for knowledge building [29]. In studios, such as those described by Schön, students interact with an expert tutor. These studios are characterized by supporting a productive dialogue between the learner and instructor and therefore can be seen as developing socially constructed knowledge.

Coordination scientists have explored the activities that collaborative writers engage in, and evaluated how they can be supported with computer systems. The focus has been on helping members of a team to be more aware of what is happening around them, particularly of what their co-authors are doing. The basic tenet is that this awareness is critical to successful collaboration [30]. In this context Dourish defined awareness as 'an understanding of the activities of others, which provides a context for your own activity' [19]. Visualizations of group activities and their interactions seem to be valuable mirrors that help groups improve their effectiveness [31].

2.4 Self-regulated and Reflective writing

There is a general agreement that reflection is key to mastering academic skills such as writing. Both, cognitive researchers such as Bereiter and Scardamalia, and those following a socio-cultural perspective like Schön have emphasized the importance of reflection in writing. Bereiter and Scardamalia [32] following Piaget, described reflection as 'the dialectical process by which higher-order knowledge is created through the effort to reconcile lower elements of knowledge'. Their knowledge-transforming model has since been revised to a knowledge constituting model [33] and both have been used in the analysis of how writers revise their documents and self-regulate their learning [16]. But writers also need to reflect on elements of their external and internal worlds, and the tools they use. Both metacognition (awareness of our own thinking) and self-regulation (where students set specific goals for themselves) have shown to make a significant difference [34]. Zimmerman and others have studied self-regulation and modelled how students become self-regulated learners by following certain learning processes, with different level of self-awareness, and motivational beliefs. In particular by staging the process in three: *forethought* (processes and beliefs before learning), *performance* (during behavioural implementation) and *self-reflection* (after) [34].

Schön [35] uses design studios as the context for his analysis, because as in writing, there is no 'right' or 'wrong' design answer, and even the attributes that make a composition/design 'good' are hard to understand for non-experts. Designers use studios to learn a kind of tacit knowledge that their peers and seniors would find hard to communicate.

This learning happens while they engage in a form professional practice that is supported by a studio environment that reduces some of the complexities of practicing in the real-world, and allows novices to reflect and maintain meaningful conversations with others. This practice is essential for developing new skills, where the student does not understand what he needs to learn, and can only learn them by doing what he still does not understand [35].

Schön [9] argues that practitioners of a certain skill (e.g. writing) or profession (e.g. engineers) have a kind of knowledge-in-action that is revealed by the skilful execution of a task, and that they are generally not able to make explicit. These practitioners deal with novel experiences that arise in their practice (the one on which they have this knowledge-in-action) by experimenting / testing different behaviours. Schön's constructivist view of reflection-in-action sees the practitioner as constructing these situations as a way to reflect on his practice. Schön's work complements Pea and Kurkland's cognitive technologies, and provides a useful model for the design of environments that afford reflection. Schön describes four steps in a reflection ladder that are here adapted to writing: 1) Writing, where the student directly engages in reflection-in-action; 2) Description of writing, where the student describes what he meant to write, for example saying 'I related the work of A to the work of B'; 3) Reflection on the description of writing, where the student reflects on things mentioned in the description, possibly triggered by the questioning from the advisor, for example: 'What did you mean when you said your literature review describes the big picture' and 4) Reflection on the reflection of the description of writing. In this last level writer and advisor reflect on the conversation and reflection process they have just had.

Computer based writing studios aim to fill one of the key difficulties that children and novice writers often face: the lack of a conversational partner that scaffolds the mental processes around writing. There is clear evidence, such as in Schön's descriptions of students' interactions with an instructors or the body of research in CSCL, that 'dialogues' (or interactions) facilitate reflective processes.

Another type of dialectic scaffolding that these system can contribute to is feedback, defined by Shute [17] as "information communicated to the learner that is intended to modify his or her thinking or behaviour to improve learning". The literature on effective feedback strategies is extensive but short on certainties [17]. Following Black and William [36], Shute classifies feedback as *directive* (that tells the learner what needs to be revised) or *facilitative* (closer to what we call reflective). Reflective feedback supports the novice writer to make his or her own revisions, but more importantly to develop a "knowledge-transforming" approach to writing [32].

The studios described in the 80s' by Schön generally involved the novice, the expert and the paper-based tools they used, but did not take into account computer-based technologies that could have been used in the discussion. It is only recently that computers have been considered as tools for reflection, and this has been the subject of study by HCI researchers. Nonetheless, design guidelines for systems that promote reflection is still a considered a significant research question [10]. A number of systems that support reflection inform our design, including:

1) Affector [37], a system to support co-workers to maintain a sense of each other's moods through distorted video captures of their faces and environment.

2) Affective diary [38], [39], an extension of the traditional diary that collects information about 'bodily memorabilia' and information collected from users' mobile phones.

3) EmoteMail [40], a system that augments traditional email with design elements taken from facial expressions and typing speed was used for a discussion of ethical and comfort issues that arise in affective computing systems.

2.5 Affect and Writing

Emotions have not played a significant role in the research on cognitive accounts of writing, and generally only appeared on the sidelines of socio-cultural descriptions. Only recently has the impact of emotions on the way authors write (and on the impact of writing on our emotions) been systematically studied [41], [42], [43].Yet emotions have not been considered in the design of writing environments. The recent interest on affective phenomena has spread beyond psychology and into neuroscience and engineering. This increased interest has come with the development of new methodologies that can be used in the development of writing studios.

Emote aloud protocols [44] similar to think-aloud methods can be used to study what writers feel during the activity. The data collected using these methods can be used for automated affect detection techniques [11]. These techniques use machine learning models trained with self-reported labels and data from sensors that can then be used to automatically detect such affective states. Generally behavioural signals (e.g. posture and facial expressions), physiology and environmental data are merged together with the labels (or dimensions such as positive vs. negative feelings) to form the training set. The labels being produced from the emote-aloud methods or by trained annotators are used as input. The training set is used to adjust computational models (i.e. classifiers) that can map new data to emotion labels.

Affective computing techniques have been used in many tutoring systems recently reviewed in [12]. The application of these techniques to reflective writing studios will be described in more detail later.

2.6 Materiality of Writing.

The way the digital and physical environment affects our work has also been a burgeoning area in HCI and psychology. Early studies compared writing processes and outcomes when writing with pen vs. writing on a computer [14], [45]. When composing and revising with more advanced technologies ('advanced workstations' in Haas study) writers spent more time and wrote more words (although at the same rate) than when using a pen or personal computer. The type of tool also affected the quality of the outcomes, arguably because of the quality of the systems used: when people used a personal computer their documents were considered of lower quality. Although the results were based on technologies obsolete by current standards, the important fact is that the tools used were shown to have a significant influence on the process and outcomes of writing.

These results extend to tools and resources beyond those of production. For example, writing often involves many reading/researching activities that can have a significant impact on the writing itself. In a study of the interactions with material artefacts used during writing [46] the authors evaluated 1) how the attention moved between sources and composition, 2) how the physical layout of the sources (including of emails that writers printed) often mapped onto a process of mental representing and sense making of the sources, 3) annotation and markup of the sources showed that they were more than just information sources: the sources became part of a complex interaction between them, the compositions and the knowledge in the writer's head.

The Internet has provided immense opportunities for writers to easily find information relevant to what they are writing. In fact, studies have shown that up to 90% of the 'writing' time is actually spent reading related documents [46], and in many situations these would be found and downloaded from online repositories. But this interconnectedness and ease of access to information can have a negative effect (e.g. distractions from the goal). As a response to these concerns researchers are developing 'attentional interfaces' [4] that help users control the noxious interruptions that computer devices inflict on our attention. Using overt signals of attention (e.g. speech, activity or gaze), an attentive interface can infer the priorities that a user has during a task. It can then, for example, support subtle turn-taking interactions with groups of devices [47] or new visualization systems that use these inferences to increase or decrease information density.

The research on context-aware systems [48], [49], also informs the design of Reflective Writing Studios. Context-aware designs have been applied to mobile phones and communication systems [50], [51] to designing homes and appliances. In these systems, the sensors (e.g. a video camera) can be used to record environmental information. This is an area not often taken into account in writing research. Arguably we have to be somewhere when we write, but not all places are made equal. Possibly due to the inherent complexity of writing (and feedback) most studies see writing and feedback on writing as separate of the physical context were they happen. But arguably some contexts are more conducive to writing than others. Noise, external stimuli and other environmental variables are known to influence how we write. For example, biographical accounts of expert writers often highlight the importance assigned to their surroundings and other situational variables such as time, weather and so forth.

3. Analysis and reflection in writing

The previous section discussed different theoretical frameworks that focus on different aspects of writing, and computer tools that support the writer's reflection on each of those. This theoretically driven discussion helps ground the concept of reflective writing studios, but falls short in providing the specific use cases required to engineer a system. In this section we discuss aspects of writing, and issues that writers could reflect on, together with specific functionalities that studios provide.

Some of these elements arise before the writing activity has even begun and are driven by the literature on relational student learning [52] and motivation:

1. What is the purpose of this activity? (*Conceptions*).
2. How much effort do I need to invest? How likely am I to succeed? (*Motivation*).

Other questions are more closely related to the cognitive model and relate directly to the process and the outcomes of writing:

3. Have I addressed the requirements of the assignment? Covered the topics? Addressed the quality measures by which I will be assessed? (*Outcomes*)
4. How will/did I complete the assignment? Should I Google this term? (*Process*)

A third group of questions refers to the context of the cognitive activities, the environment and ancillary activities that surround the writing:

5. Should I work at home or in the café? Should I turn down the music? Should I turn off IM? (*Environment*)
6. Am I tired? Bored? Did I enjoy this task? (*Mental states*)
7. Should I take a break and read my email or Facebook? (*Ancillary activities*)

3.1 Conceptions

Relational student learning research [52] has shown how students' conceptions of a task influence what they do and what they learn. This body of research has provided particularly strong evidence that the way students think about a task, and the few qualitatively distinct strategies they adopt, are closely related to their levels of achievement. Studies have shown that writers have a few (2 - 4) qualitatively different conceptions of writing, and that these variations affect their learning outcomes. These views are also similar to those in other studies that explore the conceptions of writing in college students [53], [54]. What is of particular importance about this literature is that, at a certain level, the computer interfaces do not have to be particularly intelligent to help writers: since conceptions are so important, writing systems can be augmented to include content emphasizing the purpose (e.g. learning) and value of both writing and feedback [55].

Techniques used to help elicit learner conceptions of the purpose of writing can be used, not only as research tools, but also to scaffold reflection. Techniques such as the representational grid proposed in Kelly's Psychology of Personal constructs [56] have been put forward as instruments for supporting reflection. These two descriptions of students' experiences of learning (phenomenography and representational grid) provide a new insight for building reflective systems: what matters most in many activities is not reality as such, but how people view or experience it. Future research should provide a better understanding of how novice writers conceive reflection on the writing activity, and the tools built. This design approach for the design of learning technologies was discussed in [57]

3.2 Motivation

There is extensive psychological research on the socio-cultural influences on motivation and learning, and comprehensive surveys of the literature [58]. Some of these models of motivation have been extensively evaluated. One example is Keller's ARCS model, which is based on the expectancy-value theory that assumes that an individual will be motivated (i.e. engaged) with an activity in proportion to how much *value* (something to gain from it) she perceives there is, and in proportion to the perceived likelihood of being successful (the *expectancy* component). The model defines four conditions: Attention, Relevance, Confidence and Satisfaction.

Although the literature provides a number of models like ARCS for understanding the major influences on the motivation to learn, the understanding that students have about their own motivation, or the effect of reflecting on this, has not been as frequently studied. To the discussion here these metamotivational drivers may be more relevant than the motivation itself. As examples of how motivational drivers can be used by reflective writers this paper takes the three first conditions of the ARCS model.

Attention. One of the main concerns for instructional designers has been to sustain attention during an activity. According to the ARCS model novice writers would benefit by reflecting on how certain external events, for example, external stimuli (e.g. environmental noise) affects their attention. This can be achieved using the type of sensing devices and software discussed in the next section.

Relevance. This is a condition that includes experience, present worth, future usefulness, need matching, modelling and choice [59], [60]. In addition to explaining how the outcomes of the activity will help them in the future, and helping them enjoy the activity *per-se*, Keller recommends supporting the process rather than only the activity's outcomes. Reflective writing systems can help writers understand how their attitudes towards aspects of the process (e.g. group participation) affect their outcomes. This is particularly useful if an instructor also highlights the importance of such types of skills outside the activity itself.

Confidence. The confidence a writer has on her skills can influence her persistence and the quality of the outcomes. Confident people tend to believe that the outcomes depend directly on their actions and not on luck or external factors. Those with a lack of confidence tend to be risk averse and worry about failing. Keller proposed several categories of possible actions that can be used to improve confidence: make clear the learning requirements, organize the materials in increasing levels of difficulty, clarify the expectations and help set realistic goals, help learners make the right attributions for success and develop self-confidence by providing learning opportunities with low risk conditions.

3.3 Outcomes.

Once the writing task is completed, writers need metacognitive skills to assess the quality of the final product. Students should reflect and deepen their understanding of how well their writing fulfils expectations.

The Glosser system -discussed in more detail later- provides several tools for helping writers identify the topics they have covered, for example through concept maps [22], and whether those topics they form a coherent argument [23]. These visual and text representations are complemented with trigger questions such as: *Could the ideas in the essay be organized in a clearer way*? *Does the composition address the topics requested*?

3.4 Process

Reflection on questions such as 'How will/did I complete the assignment?' can help develop meta-cognitive understanding on the process followed. Log files can be analysed to produce process models [61], an approach that is increasingly popular in educational data mining [62], [63]. In the context of teaching writing, this type of feedback is being provided in the WriteProc project [64] described in more detail later. Most writing activities are assessed on their product (i.e. the student's submission) rather than on the process. It should then not be a surprise that students mostly focus on the document they must submit. Their time-on-task and their reflection would not likely be on the process they followed.

Feedback does not generally promote this type of reflection either. In the classroom, students and instructors are accustomed to receiving feedback on the assignment that was submitted, but not often on what the student did in order to get to that outcome. For example, if a team working on a proposal for an innovative product does not engage in a brainstorming session and writes on the first idea that came to a member's mind, the outcome might not be as innovative, and the learning experience not as valuable.

Moreover, since plagiarism -a common problem in writing assignments- is the means to an end (i.e. to skip the process that requires effort), one could argue that the focus on outcomes is one main factor that drives students to plagiarize. If the focus was more on the process, the learning experience might transfer better to other activities and inappropriate behaviours could be eliminated.

Most automated feedback tools, and all those that focus on summative assessment only analyze the writing product. Technically providing feedback on the process of writing is only possible when the document's history is stored and mined. Writing processes can be studied to improve the effectiveness of an individual or team. Fortunately, there are modern day writing tools (e.g. Google Docs) that record the revision history in a way that we can use in feedback systems.

3.5 Surroundings: Physical and social

Ede and Lundsford [28] showed that 85% of the documents produced in offices and universities had at least two authors. This line of research has raised the awareness on the impact of social environment on writing activities. Most of the progress has come from the computer supported collaborative work area providing new forms social awareness and collaboration tools. Interestingly, despite the importance of learning to write as part of a group, students tend to dislike these activities, or consider them as requiring more effort than they are worth [65].

Another line of research, particularly that around designing physical learning spaces, has shown how the physical context influences behaviour and learning outcomes. Yet, there is not much research in designing systems that help students decide about the appropriate physical spaces for certain activity.

The systems proposed here will combine sensor data about the social and physical context in which an activity happens. The HCI community is increasingly interested in building tools for reflecting on data collected through sensors and self-reports [66], but as far as we know none has been on writing.

3.6 Emotions and mental states

There has been a surge of research on affect among learning technologies [12]. Until now, the focus of most research had been on issues such as exam anxiety [67], [68], but new affective computing and sensor technologies allow computer models that can detect emotions and mental states automatically. They require self-report data to be collected, arguably for each subject, and used to train supervised models. These models then ‘recognize’ the mental state from facial expressions, physiology, posture or other expressive and behavioural channels, some no more invasive than a webcam. Visualizations of such states, for example a view of mental states across the timeline, can provide significant avenues for reflection.

3.7 Ancillary activities: distractions and breaks.

Writing activities often require many hours of work. Writers must stage their work in phases between which rest and other activities occur. These activities will influence the way we approach the writing task and its outcomes. If we do not rest when we are tired we cannot be productive, but if the rest time is used for other cognitive activities this may not have the desired effect. On the other hand if rest becomes procrastination, these interruptions might not be as fruitful either.

To our knowledge there is no systematic research on how ancillary activities, those not directly related to the writing task, influence the writing itself. This also means that there is no research on feedback provided to improve the way writers use their time outside of the activity *per-se*.

Although there is little research about the influence of electronic media on students' learning outcomes, what we know [69] suggests that there is a negative relationship between the time students spend interacting with electronic media and their grades.

4. System Design

Our Reflective Writing Studio is made of four components shown in Figure 2. Each component, and its evaluation(s) is described in the following subsections. Each of the components maps to a set of requirements:

1) Structured information about the activity (e.g. deadlines and genre) are provided by a writing activity management system (iWrite [25] described later). This component also manages structured content that learners can use for modelling (e.g. sample documents), and that the system can use to infer the topics automatically. The information is generally provided by the instructor.

2) The system also needs to collect contextual information - including information not specified by the instructor – about the user and the environment using sensors and ubiquitous computing methods, not included in the original specification by the instructor. In our system this is to be performed by WebEmo [70] a browser extension that records multimodal information (e.g. from a webcam) together with the actual writing.

3) Machine learning techniques are used to process and integrate the multimodal signals coming from the sensors and the structured information from the activities (in our implementation this is provided by Siento).

4) The aim of the RWS is to provide feedback to writers. This is done through a framework that uses the processed data to provide automated or human feedback and scaffold reflection. In our writing environment this would be an extension of the current Glosser project. Figure 5 shows a Gloss built around a timeline of writing activities.

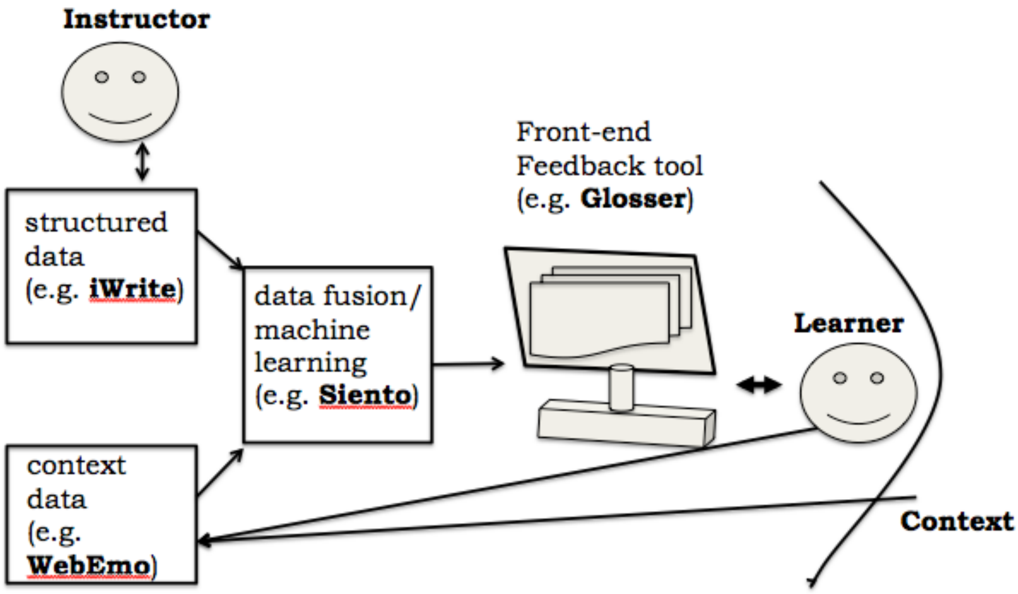

Figure 2: Reflective Writing Studio components

4.1 Writing activity management system

A reflective writing studio requires knowledge about the context of the activity to provide meaningful feedback. Our iWrite [25] writing activity management system, uses genre, deadlines, and the nature of the activity (e.g. individual vs. collaborative) to customize feedback. iWrite is a web-based application that supports individual and collaborative writing. For students, it is the main point of access to the writing activity, collaboration and instructor provided resources. It also allows researchers and instructors to learn more about the student writing activities, particularly about features of individual and group writing activities that correlate with quality outcomes. It leverages mainstream writing tools (e.g. Google Docs) within which students do the actual writing, and facilitates the provision of human (peer and tutor) and automated feedback. iWrite is currently used to support the teaching of academic writing at the Faculty of Engineering and IT, The University of Sydney, to around 600 undergraduate and postgraduate students each semester.

The instructional feedback provided aims to advance the students' conceptual understanding, beyond surface features of writing and grammar, to greater awareness of the writing process and textual practices.

The system provides these innovative elements:

- Features to manage writing activities in large cohorts, particularly the management and allocation of groups, peer reviewing and assessment.

- Combines synchronous and asynchronous modes of collaborative writing.
- Uses of computer-based process discovery methods to provide additional information on the team process. The combination of these methods with text mining is particularly novel, and will allow feedback about the team processes based not only on events but on their semantic significance.

The system uses Google Docs revision management and APIs, to record detailed information on the process of writing. In a recent study [25] involving 491 students who wrote 642 individual and collaborative assignments, 102,538 revisions representing over 51,000 minutes of students writing work were recorded (revisions are saved only when a change is made). The revisions of a document are used to identify different ‘activities’ (e.g. editing, outlining) that students engage in at different stages of the writing process [64]. These activities are used to produce visualizations that show writers what they have done, and aid reflection about which sequence of activities leads to better outcomes.

The revision data also allows for inferences and reflection on time-management issues. Analysis of the data [25] suggested that:

- Students with low grades engage in more revisions (individually and as a group) compared to those with medium grades.
- Students with low and medium grades engaged in fewer writing sessions compared to students with high grades.
- Students with low and medium grades engaged in fewer writing days compared to students with high grades.

These results suggest that it is not *whether*, but *how* students interact with tools such as iWrite that makes a difference in their writing performance. Students who obtained high grades were in teams that engaged more frequently in sustained writing sessions. In contrast, shorter burst of document revisions were associated with lower grades. These results seem to agree with those documented by Galbraith.

We are planning an integration of iWrite with two Learning Management Systems (Moodle and Blackboard) to collect information about prior experiences of the student. This will be used to provide a user model useful to generate better feedback.

4.2 Recording platform

Reading, writing and collaborative activities are generally computer-based. The writer can engage in the prewriting activities (e.g. research on the topic to write about), collaborate with peers and tutors, and do the writing itself, all on a browser connected to the Internet. Given the central role of the browser, we used it as a platform for WebEmo [70] to manage the collection of environmental information while a person reads and writes.

The tool consists of several components shown in Figure 2. The client-side component works as an extension in Google's Chrome browser and does not require any code in the web page to be altered. Through integration with other systems it currently records physiological signals such as ECG (heart), EMG (facial) and respiration patterns. It also records video of the user currently coming from a webcam and using the openCV library. The actual recording is left to third party software managed by an *acquisition system controller* allowing for the framework to be extended to include other modalities. All data collected from each sensor (different physiological modalities and camera) is stored locally and uploaded to the processing server at the end of the session. Recording video can be done with any webcam or with a range camera like Microsoft Kinect. For physiological recording, WebEmo integrates in-house and commercial systems. We generally use the BIOPAC MP150 system with AcqKnowledge software to capture data. Biopac's Matlab API can also be used for real-time data acquisition. The Biopac system can be used to record a variety of physiological signals (ECG, GSR, EMG, EEG etc).

When self-reports of the affective impact of a page or activity need to be recorded the framework can intervene with psychometric questionnaires such as the Self Assessment Mannequin [71]. Some studies, those which examine writing in complex realistic settings, would require all of the user's activities to be recorded (perceptions might be affected by what happened immediately before or after the task). For example, a student writing an activity on Google Docs would visit Wikipedia for information on a particular topic, so when testing such a system the interaction on both websites needs to be recorded. A challenge for the system is that the user can be interacting with different websites running on different browser tabs. To address this issue the system records the interaction of each session on the data repository with a web interface (i.e. web server).

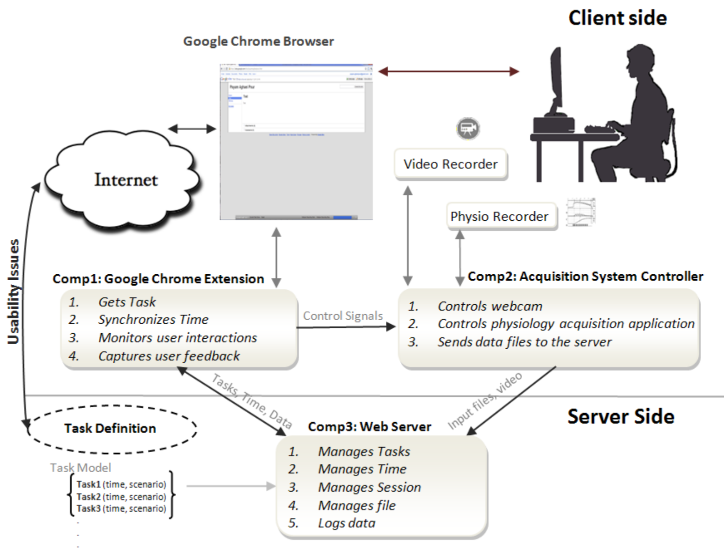

Figure 3: WebEmo architecture for recording users' video, physiology and web interaction data.

4.3 Data fusion and processing

The systems above can be used to collect vast amounts of multimodal information on what writers do, think and feel, and the environment that surrounds them. The data is complex, highly dimensional and dynamic, a situation increasingly common in ubiquitous computing scenarios. Researchers of different fields are trying to make sense of this data.

In the area of emotion detection, 'affective computing' techniques [11] are being used. They examine data produced in the recording of different modalities (sensory features) to train computational models that can be used to recognize patterns that correlate with what people report as emotional states. Facial expressions and speech and metalinguistic information were among the earliest types of data to be analyzed; currently behaviour, posture, breathing and physiology are all commonly used in affective computing. Many researchers believe that computers that aim to have similar detection accuracy should also use multimodal approaches [21].

We have built Siento, a system to record and process multimodal signals and predict affective states. The tool has been used in several affective computing studies combining physiological signals, and physiology with facial expressions. The system allows for dimensional or categorical models of emotions, self-reported vs. third party reporting and can record and process multiple types of modalities including video, physiology and text. This type of system can improve the repeatability of experiments. The system is also used for data acquisition, feature extraction and data analysis applying machine learning techniques.

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A design principle in Siento is to use other available libraries and tools. We have integrated Weka that has a collection of machine learning algorithms for data analysis. We also found it faster for evaluating different techniques and algorithms. Siento uses machine learning libraries in Matlab including PRTools for feature selection and classification and AuBT for extracting statistical features from physiological signals. As for other modalities, tools like eMotion by Visual Recognition are used for extracting facial features. The interaction with the participants is recorded by saving a screen-cam using Snagit, but data collected using WebEmo or iWrite can also be used. The applications for running experiments (e.g. logs, protocols), presenting stimulus (e.g. IAPS images) and self-reports (e.g. video annotations) are implemented in-house with Matlab.

4.4 Automated feedback

Glosser is a web-based framework for providing automated feedback on writing [55], [72]. Any version of a document can be processed to produce a wide range of feedback on collaborative or individual writing activities spanning, visual and text modalities. Feedback can be on surface or content features, on the writing product (the final document) or on the process.

For each activity one or more forms of feedback can be selected by the instructor. Each form of feedback, such as the one shown in Figure 3, is made of 1) a set of guiding questions aimed at scaffolding reflection on particular aspects of the writing; 2) a 'gloss', a visual or text-based representation of automatically generated feedback specific to the student's composition; 3) guiding text explaining how to use the gloss to reflect on the questions. The architecture incorporates features for feedback forms such as argument quality, features of text (such as coherence), automatic generation of questions and feedback on the process. Computer-based text analysis methods are used to provide additional information on text surface level and concept level to writing groups.

A number of feedback tools have been built using the framework. These include two for helping writers reflect on flow: one using interactive text and another a map [55], [72]. Three tools support reflection on the topics and concepts: two visual representations using different computational approaches and a textual one. One tool is for reflecting on the social and time related aspects (i.e. the process) [73] and one generates questions automatically [74].

The automatic question generation techniques [74][75] are used to support research students reflect on different aspects of their literature reviews. The system scaffolds students reflection on their academic writing with content-related trigger questions automatically generated (using NLP techniques) from citations. A taxonomy of different types of citations relevant to literature review papers [74] is used (with categories for Opinion, Result, Aim of Study, System, Method, and Application). For example, if a student (citer) cites the following opinion in his review: "Cannon (1927) challenged this view mentioning that physiological changes were not sufficient to discriminate emotions", the system can generate the following trigger questions that help the writer reflect on the relevance to the project at hand: *Why did Cannon challenge this view mentioning that physiological changes were not sufficient to discriminate emotions? How is this relevant to your project?*

The system was evaluated in a study with 57 participants (33 PhD students-writers and 24 supervisors), where each PhD student submitted a research proposal to iWrite, our writing management system. Each proposal was read by a peer and the PhD supervisor, both of whom provided feedback in the form of reflection questions. The peer and supervisor questions were compared to the automatic questions and also to a set of generic questions. A total of 615 questions were generated based on the 33 literature review papers. Each student was then asked to rate the quality of questions received on measures of 'acceptability' (whether it is grammatically correct, not vague, and makes sense according to the context) and 'usefulness' (whether it is helpful to trigger reflection). These ratings were used to evaluate the system's performance and to analyze human expert generated questions. We compared automatically generated questions with human-generated and generic questions using a Bystander Turing test and the top questions (selected using an automated ranking system) were reported to be as useful as those generated by peers and supervisors (after removing questions with surface errors).

The computational techniques (e.g. Latent Semantic Analysis) used in Glosser are similar to those in automatic essay assessment systems. Criterion (by ETS Technologies), MyAccess (by Vantage Learning) and WriteToLearn by Pearson Knowledge Technologies are all commercial products increasingly used in classrooms. These programs sometimes provide an editing tool with grammar, spelling and low-level mechanical feedback. Some of them can also be integrated with university systems using Application Programming Interfaces (APIs). Some provide resources such as thesaurus and graphic features, many of which would be available in tools such as MS Word. Glosser is distinct in several ways including that it is the only one that provides support for collaborative writing activities, and the only one that can analyse (and provide feedback on) writing processes.

With regards to process, recent work such as our Writeproc system [64], a component of Glosser, shows that the writing processes can be analysed by detecting writing 'activities'.

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WriteProc uses a taxonomy of writing activities, proposed by Lowry et al. [29]. We plan to study how such information can help students reflect on their own processes. If the results of these observations can be generalized to other learning situations, students may benefit from the realization of how important it is to work on an assignment for dedicated stretches of time, and this is a key outcome of learning time management skills.

We have evaluated how students' conceptions of automated feedback such as Glosser affect the way they use it, and what the quality of the learning outcomes, i.e. the grades obtained is [55].

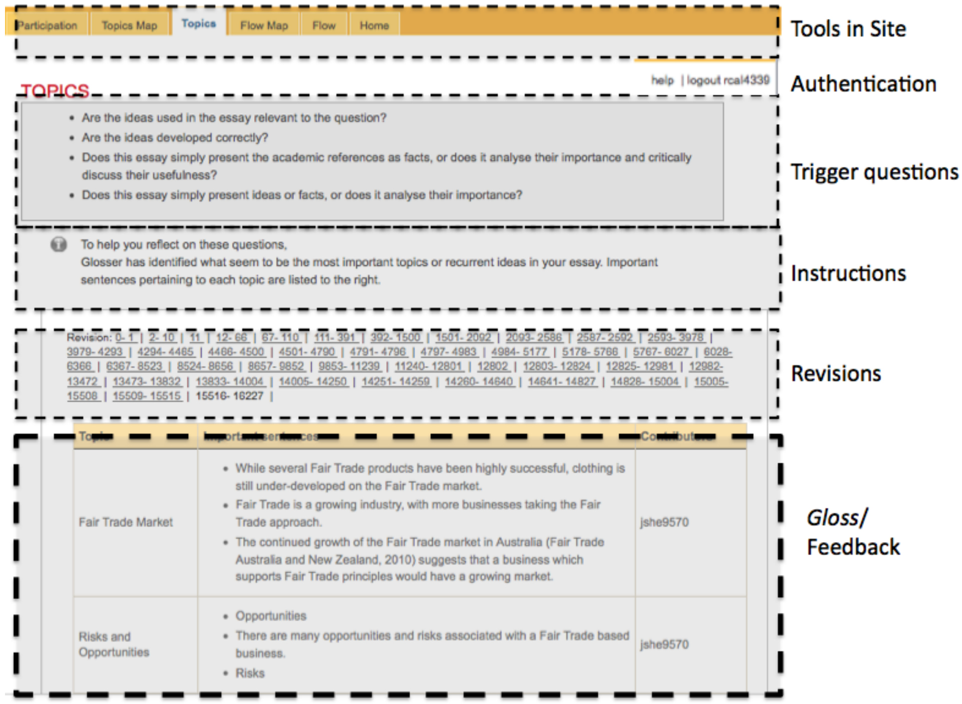

Figure 4: Glosser feedback

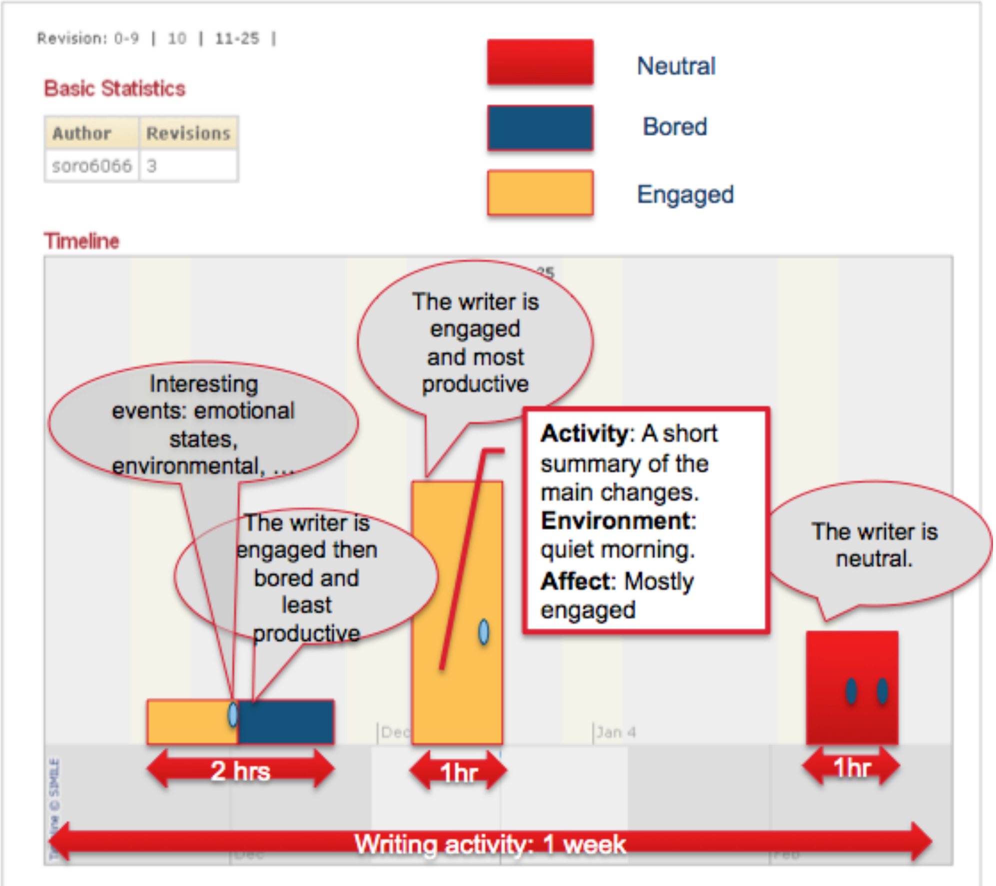

Figure 5: Reflective Timeline

5. Discussion and Conclusions

Each of the four components of our Reflective Writing Studios has been evaluated in the studies described earlier. The integration of these software/hardware components is a significant engineering challenge, so an evaluation of its impact on learning is still some time away. As a way of discussing some of these challenges I provide an account of how I personally used the system. In a recent session, I wrote a blog post during a 1hr session. The Kinect camera recorded my facial expressions, voice and environmental situation, the writing tool (used by iWrite) was Google Docs that keep a history of the document (a very simplified version of keystroke logging), WebEmo recorded my interactions with the browser. The purpose of the blog post was to summarize a research project of which I was learning about. During the session a phone call interrupted my work and I had to stop when someone came in the room. I was following a think-aloud protocol so my speech could be automatically transcribed using a speech recognition system and key events in the writing process could be identified. Speech recognition systems are not 100% accurate but produce a stream of words that can be used by text mining algorithms. The same happens with facial expression recognition. About 20 behavioural events were identified in the video by an annotator. These included affective states, such as surprise and engagement that we have detected automatically, typing, 'habits' (e.g. playing with my ear). My posture was used to detect when a phone call and a visitor interrupted my work. My research (e.g. reading webpages about the project) and writing strategies (e.g. copy and paste of certain details) were all recorded. All this information can be used as evidence in writing research studies, furthermore it can be used to generate visualizations (integrated into Glosser) that support reflection.

Figure 5 shows a timeline of significant events, such as the ones above, that can help a writer reflect on positive and negative aspects across multiple sessions. The height of bars represents a measure of productivity, the width is the amount of time averaged over 30min or 1hour blocks. The color of the bars represents the most common automatically detected mental state, and the square dialog box (that appears on a rollover) provides a description of the block. This description summarizes the structured information coming from iWrite with process data. Small markers can appear on the timeline (e.g. in the first block) highlighting specific meaningful events (e.g. a phone call that may have produced distraction). The curved bubbles are explanatory material to support new users of the interface.

There are two sets of challenges for reflective writing studios. First are the technical issues of building a reliable, accurate and scalable platform. The second is to produce visualizations and feedback that summarize the massive amount of data being collected in a way that is meaningful to the researcher and/or reflective user.

Automated feedback systems have focused on the writing product rather than the process, for example those based on automated essays scoring. It is not yet clear that students benefit from seeing how their writing products measure against certain scales, but the results are still useful to inform educational design decisions. We speculate that the weak relationship of such systems to student learning may be due to their focus on the final writing product, and the neglect of process factors used to decide on topic and argument, supporting reading activities, the selection of environment and tools, the timing and so forth. The pervasiveness of computing devices, the easy access to supporting material and social interaction, makes many factors -not previously included in the study of writing phenomena- influential in the way we think, feel and write.

As a consequence this paper argues that the writer's affect and her environment must also be taken into account when designing systems that support writing. With rare exceptions this has not been the case. One of the reasons researchers have not taken this inclusive approach is that such a complex system is hard to study using traditional methods. It is not possible to control for all possible variables happening in the mind, body and world around the writer.

The reflective writing studios described here aim to support novice writers through data-driven functionalities that scaffold their reflection. The functionalities described can help novice writers reflect on questions such as *why* they are engaged in the activity, *how* they are going about it, *what* are the attributes of outcomes are (so they can be improved on), and *who* is doing what (when working in a team). This paper first reviewed the literature coming from different pedagogical traditions, including cognitive, social, situated and embodied cognition perspectives and argued for approaches that take into account a wider set of variables. New enabling technologies such as affective and ubiquitous computing allow researchers to develop new type of interfaces that can support new forms of reflective feedback.

We have described the different components of the system and their evaluations: the writing activity management system (currently used by over 1,000 students at the university of Sydney) manages activities were writers use Google Docs, and structured data about the activity is stored. Since most of the writing and the ancillary reading activities happen on the browser, the recording platform was built as an extension of Google Chrome, and integrates the webcam (with video and sound), screen recording and other sensing devices. The data collected by the extension and its devices is then merged and mined. We have summarized the numerous evaluations of these components. The final component is the user interface used to provide feedback to the student. We are building this as an extension to Glosser, an open source feedback framework, which we have already described and evaluated elsewhere. A timeline visualization was proposed, but not yet evaluated, to represent the data provided to writers.

Due to the significant amount of information that reflective writing studios collect, such as data about the writing process, it is important that writers do not get distracted or feel overwhelmed by it, it is also important that they do not see it as surveillance of their activities. They must feel in control of their data. An approach we have used for tackling this challenge is to make anonymous all process data shown to academics. In this condition, students can get feedback at any stage of their writing process but know that academics only access the final product (as occurs traditionally).

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