Learning Extended Writing: Designing for Children's Collaboration

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ABSTRACT
We describe the learner-centered design of an application for collocated collaborative writing on digital tabletops. Learning writing is an activity that is traditionally undertaken as a non-collaborative, non-visuospatial activity. We demonstrate how framing writing as a visuospatial manipulation of elements of writing sub-tasks can promote collaboration. While collaborative visuospatial activities lend themselves to digital tabletops in particular, not all activities naturally translate into such tasks. Our application allows for (or supports) writing as a collaborative task, as well as providing a platform for students to learn extended writing. We describe the mapping between the design principles used, and the pedagogical and thinking theories that are incorporated into the design. The design is described at each iteration, including the associated user studies, and we conclude with a discussion of more widely applicable design implications. This research shows how traditional non-collaborative learning activities can, using visuospatial representations, be reconfigured as collocated collaborative learning activities.

Categories and Subject Descriptors
H.5.3 [**Group and Organization Interfaces**]: Computer-supported cooperative work. K.3.1 [**Computer Uses in Education**]: Collaborative learning.

General Terms
Design, Experimentation, Human Factors.

Keywords
Digital Tabletops, Distributed Cognition, Collaboration.

1. INTRODUCTION
Many skills are taught on an individual basis, where a learner engages in activities without collaborating with peers. Canoncial examples include writing and reading (both language and technical comprehension). Writing, and in particular extended writing, is a way of representing, externalising, communicating and recording information, and is a fundamental communication skill taught in schools (and other institutional learning settings). Current teaching methods are focused on individual, practice based learning [10,18].

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Figure 1: Collaborative Writing Task

Co-located collaboration has significant pedagogical benefits [21,34]. Working together encourages learners to externalise their thoughts, clarify their understanding of concepts and come to a shared understanding through social interaction. In supporting collaboration, it can be beneficial for learners to be able to communicate their knowledge and understanding visuospatially. The benefits of using shared visuospatial representations include reduced cognitive load through externalisation, a deeper understanding of the problem through re-representation and a means of distributing thoughts and ideas between collaborators [15,20].

Designing for visuospatial (VS) interaction can therefore be thought of as an effective strategy for the design of interfaces to promote collocated collaborative learning. The benefits of collaborative learning are well established [35], and our goal was to exploit these aspects of "social learning" by developing a collaborative writing application in order to: i) facilitate collaboration; ii) allow externalisation (and internalisation) of cognitive processes; and iii) incorporate the use of scaffolding (and fading) [38]. We investigated potential collaborative technologies that would support a co-located, VS writing application, and then by working with groups of learners aged 12-13 in an iterative learner-centred design (LCD) process; we developed the extended-writing application. We also describe how the LCD was particularly valuable in providing insights into how best to translate the non-VS extended writing task, into a VS one. The resulting collaborative writing application (see Figure 1), based on these principles, stands as an exemplar of how learning tasks normally considered non-collaborative can be re-framed using VS representations to exploit the benefits of collaborative learning.

2. BACKGROUND

2.1 Collaborative Learning

Dillenbourg provides an intuitive definition of collaboration: "a situation is termed 'collaborative' if peers are more or less at the same level, can perform the same actions, have a common goal and work together" [5]. Activities that have these characteristics, and also have the shared goal of learning, can be classified as collaborative learning.

Vygotsky [34] suggested that the process of learning involves the internalisation of previously externalised cognitive processes. This process is linked to communication in that learners first learn from others through communication (i.e. socially), then through "thinking out loud" (i.e. the learner has externalised part of the cognitive process), then finally through the internalisation of the "out loud" process. The act of writing itself is an example of this process [7], both as a way of expanding short term memory but more importantly as a way of changing thought processes in order to understand abstract concepts.

Vygotsky's "Zone of Proximal Development" (ZPD), outlines one of the major benefits of collaboration, i.e. working with peers with differing levels of expertise allows a learner to bridge the gap between their current ability and their potential. Collaborative activity also exposes learners to different viewpoints (and possible solutions), helping develop critical thinking skills and more complex understanding [21]. Wood et al. [36,37] described the expert assistance provided during the collaborative learning process as "scaffolding", and the process of gradually removing the assistance as the learner improves as "fading". Tabak [33] expands on this, describing the concept of Distributed Scaffolding that takes multiple forms to address different learning needs or across distributed settings.

2.2 Distributed Cognition

Communication of ideas is an essential part of collaboration, as well as building a shared understanding of the current state of the problem. Distributed Cognition (DC) [9,20,27] is a way of understanding and describing how large tasks are distributed across people, space, tools and time [4] to support collaboration. This framework is helpful when designing cognitive tools for such tasks, and specifically in terms of identifying how intermediate states are represented and modified. Using manipulatable elements that visually represent some part of the solution, and importantly change or alter the representation if necessary, is a useful tool for extending working memory; it allows simplification and communication of ideas through representation [30,39] and is the essence of VS thinking. For example, a complex incident such as a traffic accident can be explained through a much simplified representation, with visual props representing vehicles etc. [20]. Using manipulatable elements also affords appropriation [6]. The collaborative use of space aids joint decision making through reducing cognitive load (by simplifying choice, perception, and internal calculations) [15].

A DC account of the requirements of effective collocated collaboration include that users are working towards the same overall goal, and need to be able to act individually, at the same time, yet making sure that each is aware of the other's actions. In other words, all users should be aware of the current state-representation of the task, as well as aware of each other's actions and the resulting effect of these on the state. Individuals' actions should have clear consequences that are represented in a detectable change of task state. Actions should also be non-permanent, allowing collaborators to change or remove each other's actions. Large tasks should be distributed across stages [12,29], provided the actions remain non-permanent (i.e. the functionality of all stages can be re-visited).

2.3 Technology for Collaborative Learning

The development of technology to support collaborative learning has been a significant concern in both education research and human-computer interaction. The range and context of collaborative learning activities addressed to date is wide, and includes social media [1], virtual worlds [38] and specific classroom and group level interventions involving mobile computing [2] and digital tabletops [11,22,24,29].

Digital tabletops provide a collocated setting, and afford an interface suitable for shared VS manipulation. They have also been shown to have a positive effect on learning, to be engaging for learners, to promote awareness and by allowing concurrent input to afford parallelisation of tasks [12,25]. However, to realise these benefits requires more than a simple remediation of learning [8], and to be effective interfaces and activities must be designed to take advantage of the characteristic affordances of digital tabletops [13,25]. In the context of the digital tabletop, a key example of DC "in action" is users' externalization of their internal representations of a problem by visually representing it within a shared interface. This not only reduces users' cognitive load and promotes re-examination of the data through a different representation, but also allows collaborators access to their thinking processes both phonologically (i.e. through talk) and visuospatially (provided there is a mechanism to support this).

A number of researchers have attempted to charactertise the benefits of tabletops for learning and other applications. Scott et al [28] provide a number of useful specific guidelines for designing a co-located collaborative task for digital tabletops, including that allowing for natural interpersonal interaction (i.e. allow face to face communication), that objects should have shared access (i.e. no enforced roles through the interface), and that tabletops should support flexible user arrangements (e.g. their position and orientation around the table and support simultaneous user interactions). Dillenburg and Evans [3] provide a review of several digital tabletop applications specifically for learning, and suggest four high-level principles for exploiting tabletops for learning that have a bearing on the VS aspects we are seeking to exploit: (i) tables are designed for co-location; learners work together in the same place, allowing VS representations and interactions to be observed by collaborators; (ii) tables are a shared social space; what happens on the table should be available to and observable by all learners; (iii) tables are for hands on activities and are well suited to VS tasks and manipulation; and (iv) tables afford multi-modal communication and learners can communicate by talking, through gesture, through posture and through actions on the tabletop. They summarise the contrast between digital tabletops with other technology mediated learning settings as: "*desk(top)s are personal, table(top)s are social, and (digital) whiteboards are public*".

2.4 Designing for VS Tasks

Several prominent works within the field of tabletop interaction design have informed our design of the collaborative writing application. Most significant is Digital Mysteries [11,12,13] (Figure 3) a learning application based on "Mysteries" a (non-digital) co-located, collaborative paper based pedagogical exercise [17]. The main goal of Mysteries is to examine a body of information that is separated into slips and then use this information to formulate an answer to a particular question. The question and the slips are designed in such a way that the answer to the question is not unambiguously answered by the information slips. This encourages the learners to think analytically about the slips and their relationships with each other, and to perform higher order activities such as grouping and linking slips together to create evidence and arguments. "Mysteries" is an ideal candidate for transforming into a collaborative VS application on a digital tabletop in that the task is performed collaboratively in a small group by learners and it is already separated into VS components, allowing learners to spatially manipulate data slips in order to solve a mystery. The Digital Mysteries application allows more nuanced manipulation of the data (slips can be resized, explicitly grouped and connected) than is possible using paper alone. Digital Mysteries tasks also provide scaffolding and structure to the learning task with the task being explicitly split into stages (reading, grouping and connecting) that focus learners on the current sub-task they need to complete. This also allows the application to provide well-timed feedback at an appropriate level, including hints or even partial solutions.

Similarly, ArgueTable [31] investigated how a paper based prototype for a co-located collaborative VS task can be realised on a digital tabletop. Users externalise their arguments into a visual representations, showing how separating a task into components that can be visualised and manipulated by users can work to aid thinking about a "non visual" problem. The collaborative learning application DigiTile aimed to teach learners about fractions [16,25,26] and was developed from a single user application. DigiTile requires users to represent fractions by filling a canvas with tiles to divide the total area into specific ratios (e.g. 1/3 red, 1/3 blue, 1/3 green) and in this way the application was particularly suitable to the digital tabletop as it involves spatial manipulation of tiles.

Table 1: Previous Work Spatial-Visual Matrix

	Initial Task			Final Task		
	Spatial-Visual	Collaborative	Digital	Spatial-Visual	Collaborative	Motivation
Digital Mysteries	Y	Y	N	Y	Y	Collaboration
DigiTile	Y	N	Y	Y	Y	Collaboration
Argue Table	N	Y	N	Y	Y	Collaboration
ART	N	N	N	Y	N	Reflective Design

While Digital Mysteries, ArgueTable and Digitile all stand as valuable exemplars of interaction design for collocated collaborative learning, they are all essentially digital tabletop realisations (and enhancements) of what in essence were already intrinsically VS learning activities. By contrast Nakakoji et al's ART system [19] incorporated a shared VS manipulatable representation of a document as a collection of paragraphs. Its decomposition of a document as paragraphs, and the interaction ART supported, scaffolded dialogue between designers about the content and structure of a document, for example, allowing users to ask "what parts are missing?", "How confident am I that this part fits?", " How does this new part complement the rest?", " How does this new part affect my view of the other parts?", "Is the overall design proceeding according to my intuition and intention?". Although the motivation for the work differs (from learning structured writing), their work provides insight into how a document could be thought of in a VS context by identifying structural components that can be used as visual metaphors (i.e. paragraphs). They do not however indicate the benefits of this in a collaborative setting, or provide more general guidelines for creating a VS task from a non-VS task. The VS aspects of these works are summarised in **Error! Reference source not found.**.

3. DESIGNING FOR COLLABORATIVE WRITING

Our starting point was an extended writing task derived from the Writing Frames persuasive genre in which participants are required to write a persuasive argument across several paragraphs, use evidence to back up their interpretation and acknowledge (and argue against) alternative interpretations [18].

3.1 Extended Writing as a Learning Task

Extended (or structured) writing can be characterised as any non-fiction writing. Extended writing is more challenging than creative writing for many learners [14] due to specialist vocabulary requirements, the more formal structure of the writing itself and the ways in which parts of the writing are connected. Although some aspects of the overall extended writing task is taught collaboratively (through activities such as peers working together on document revision), planning and composition is generally taught as an individual activity. Writing Frames are a paper-based scaffold to support such forms of structured writing and Figure 2 shows an example of a Writing Frame for persuasive writing, which can itself be particularly difficult for learners as it requires the creation of a persuasive argument across several paragraphs, including supporting evidence and consideration of (and counterarguments to) alternative interpretations.

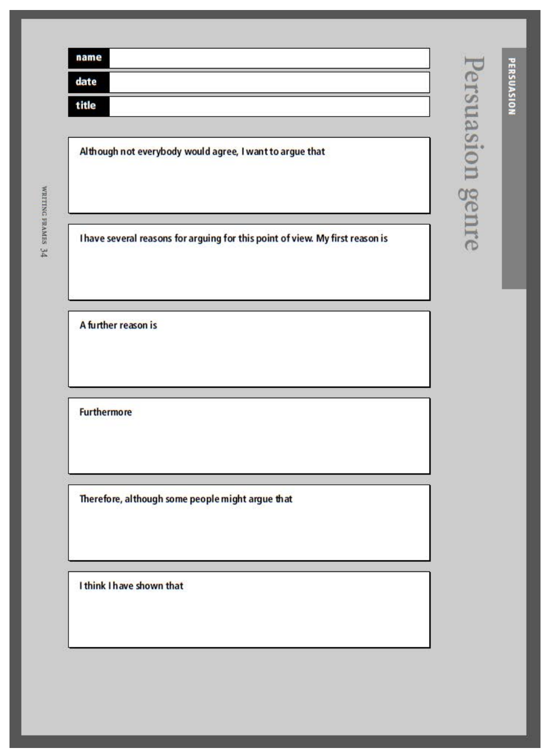

Figure 2: Example Writing Frame (persuasive genre).[18]

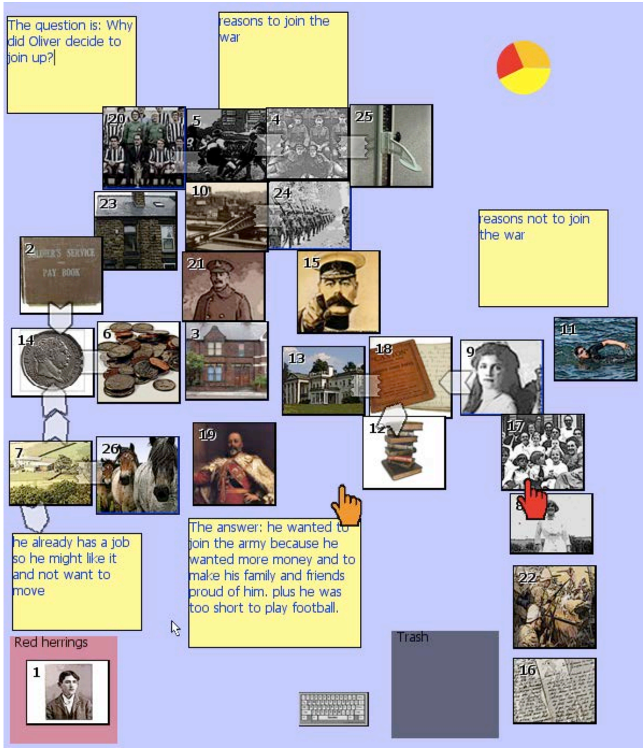

Figure 3: Digital Mysteries [12].

3.2 Design Goals

The design goals for our extended writing application are to repurpose Writing Frame-based extended writing as a collocated collaborative VS task thereby incorporating:

- co-located communication, i.e. discussion about the task;
- VS interaction that:
  - promotes representation & communication of ideas;
  - promotes externalisation of thinking;
  - helps decision making;
  - reduces cognitive load.

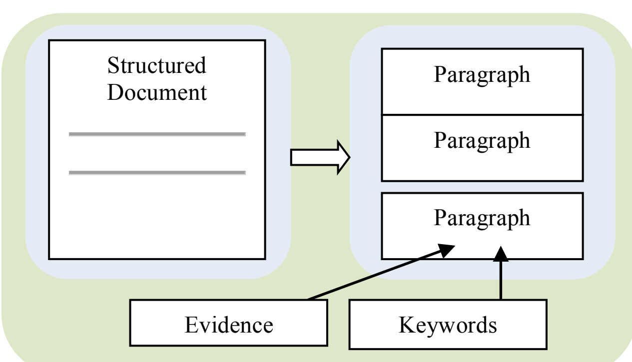

Figure 4: Structured document is separated into paragraphs. Paragraphs have evidence and keywords inserted.

The interface should also afford communication of the current state of a task, and users' actions should be clear and have consequences that affect the state. This allows a common understanding of the current state of the problem [4]. Finally, as extended writing is usually taught to children between the ages of 13 and 15 (depending on genre), the application should be designed to be appropriate for this group.

3.3 Converting Writing to a VS Task

In order to repurpose extended writing as a VS task, key elements of the task must be identified and assigned visual metaphors. This requires a clear understanding of the task structure and purpose – a process refined by the LCD process outlined in Section 4. Nevertheless, components should form parts of the overall task structure, as they will be used to represent the task or parts of the task. They should also be aligned with the purpose of the task for example, in the case of writing a persuasive document, an important component (one that we would want to see utilised in the final document) is evidence. If another kind of document were being produced, for example a recount (from Writing Frames [18]), then an equivalent component might be time stamped events.

As the users in this case will be learners between the ages of 13 and 15 years old, the application should use metaphors that are understandable by children of this age group. To this end, it is useful that the components are strongly tied to the task (so that a minimal amount of extra knowledge is required) and that manipulations are restricted to simple, familiar movements and gestures (moving, resizing and dropping components, along with basic menu choices and dialog boxes). Tasks aimed at different age groups are likely to have different requirement (e.g. simpler interaction for younger children). In order to afford the writing of a persuasive document, the application needs to facilitate the a number of key functionalities:

Create Paragraphs: for collaborative writing, the first stage is to separate the document structure into paragraphs, similar to Writing Frames [18] and the approach taken by Nakakoji et al.[19]. In Writing Frames the structure is rigid – the order and connections between paragraphs cannot be changed. In order for learners to be able to represent thinking with more flexibility, the paragraphs should be freely manipulatable (Figure 4).

Adding Evidence to Paragraphs: paragraphs need to contain evidence in order to produce a persuasive argument. Learners need to consider evidence (from existing information, or user generated keywords) spatial-visually and decide whether to add it to paragraphs.

Connect Paragraphs: learners construct documents by deciding how the paragraphs connect to each other. Connections should be labelled with appropriate connectives to show the relationship between paragraphs.

4. STUDY

We followed a learner-cented design process that led to an initial implementation that supported all functionalities, which was then refined based on observation, learner feedback and an examination of the results of the task. To produce a collaboratively written document, learners must first have some shared experience or activity to write about. For example, the shared task could be a lesson or activity delivered in a classroom, or some shared research project. Our first problem was to identify such a shared activity, the requirements of which we characterised as follows:

- a shared activity in which all the learners have participated;
- an activity that can be separated and thought about as a set of components;

- an activity that is appropriately large or complicated for the writing task, i.e. has some or all of the characteristics of higher-order thinking [23];
- an activity that is appropriate the genre of writing to be learnt (i.e. persuasive extended writing).

We identified the Digital Mysteries task [12] as an activity that both meets these requirements, in that it is a task that is performed collaboratively by a small group of learners, requires significant higher order thinking, and takes a reasonable time to complete (between 30 and 60 minutes). Digital Mysteries has the additional advantage that it is an activity that can be conducted on the same digital tabletop at which the collaborative writing will be conducted, thereby allowing a closer practical integration of learning activities for higher order thinking and writing.

4.1 Study Protocol

User studies were conducted in two parallel strands. For both strands the task involved two separate sessions: i) the completion of a Digital Mysteries Task (around 1 hour), and ii) the Collaborative Writing Task (around 1 hour). There was a break of 1 hour between sessions. The sessions were completed by a group of three participants between the ages of 13 and 15 years old. The studies were conducted on a Promethean ActivBoard Digital Tabletop. This is a pen based table, which allows identification of users and also allows users to touch or rest on the interface without affecting the application. All sessions were observed by two researchers. The system recorded users' interactions and groups were given a short (5–10 minutes) semi-structured interview after each session. One group (Group B) completed all 3 iterations. Group A completed iteration 1, and Group C completed iteration 2 (Table 2).

Table 2: Study Schedule

Iteration 1	Group A	Group B
Iteration 2	Group C	Group B
Iteration 3	-	Group B

Table 3: Results summary

	Iteration 1		Iteration 2		Iteration 3
	Group A	Group B	Group C	Group B	Group B
Planned Paragraphs	3	2	4	4	5
Total Paragraphs	4	4	10	6	5
Slips (Added - Removed)	3 (6 - 3)	7 (10 - 3)	8 (11 - 3)	6 (13 - 7)	12
Connections	3	9	12	9	4
Time Planning	< 1 min	< 1 min	14:12	06:07	14:35
Time Structuring	n/a	n/a	09:04	05:40	03:29
Time Typing	n/a	n/a	36:32	38:56	30:49
Time Total	23:13	1:03.00	59:48	50:43	48:53
Average Paragraph Length	n/a	64	42.25	65.75	52.40
Document Length (words)	n/a	256	169	263	262

4.2 Iteration One: design and rationale

The initial implementation was intended to be as open as possible; all the actions (paragraph creation, evidence insertion and paragraph connection) were available from the beginning of the task without restrictions. The intention was to use this first implementation with users, to observe their behaviour and the outcomes from their task to look for improvements in the subsequent iterations. In addition, learners could create "notes" to annotate their work. Users could create paragraphs, notes and connectors from a menu. A gestural menu system, based on the Attribute Gates system [32], allowed the selection of actions, as well as the manipulation of objects (e.g. resizing and rotation).When creating a new paragraph or connector, users must decide on their initial contents together. Like Digital Mysteries, evidence is represented as manipulatable slips. By including an evidence slip in a paragraph (through dragging a slip from the index tab) meta-data about that slip is automatically inserted into the paragraph (Figure 5). A document window shows the current text of the document, so when text is typed into a connected paragraph it also appears in the document.

In addition, in this first iteration, the writing application begins with a "planning" screen, in which users can decide how many initial paragraphs to create, along with their initial opening text (a single line of text). When the users have finished the document, a short reflection stage is presented to them showing the document window with their incremental changes over time.

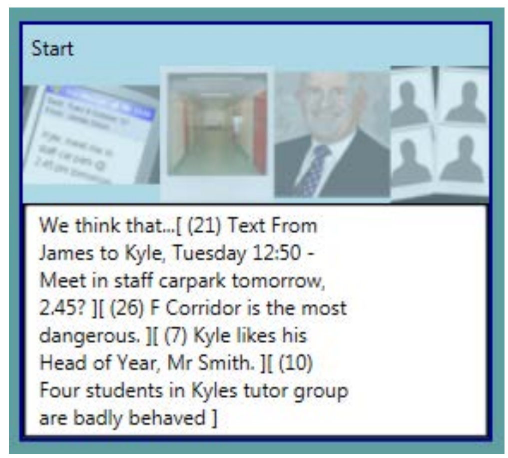

Figure 5: Paragraph with evidence and metadata. Evidence slip icons are inserted into group panel while meta data text is added to the main text.

4.3 Iteration One: findings

Both groups who completed this iteration (A & B) spent very little time in the planning stage, preferring instead to create paragraphs within the "main" application. The design of the software meant that the plan was "lost" after the initial stage (i.e. it is not explicitly represented in the main application). Interestingly, despite not completing the planning phase, group B proceeded to use notes to effectively write a document plan within the main application.

Both groups also began typing into the document from the beginning, without giving detailed consideration to the structure of the overall document, or even deciding on the number of paragraphs. Group B, despite their use of notes to make an outline, wrote their whole document in a single paragraph and only when prompted by the researcher did they make a small introduction and conclusion paragraph.

Another problem was that scaffolding was only injected at the end of the activity when a group decided that they had finished. Consequently, it was only at the end of the process that they realized they have made some poor decisions earlier, such as only making a single paragraph. Likewise, neither group used the evidence slips effectively, either ignoring them or only adding them at the end when the criterion (number of paragraphs created, length of document etc.) was not met.

Despite the fact that paragraphs were fully rotatable, neither group changed the angle to allow different members of a group to read them from their different vantage points around the table. Team members seemed happy to read from the side, or stand around the same side of the table to read, finding it easier to move themselves rather than rotate the paragraphs.

The reflection stage, along with the planning stage, was little used (see Table 3). Due to the nature of the reflection stage, that it only showed text typed into the document that had properly been connected, a full picture of the task was not made apparent to the learners whereas it might have been useful for learners to see their intermediate spatial representations of their paragraph and evidence usage during reflection in addition to the text.

4.4 Iteration Two: design and rationale

As the planning stage was not fully utilized by the users in the user studies of the first iteration, we took the decision to move the planning phase into the main application, and to allow more freedom as to what a plan could contain. Therefore paragraphs had an added "outline" textbox that allowed users to write an outline as well as the main text for each paragraph. Outlines were added to the paragraph creation window when a new paragraph was created (Figure 6), so users had to think about how they would use a paragraph at the point of its creation. Outlines were visible as long as the paragraph was maximized (i.e. full size) and an extra outline window (mirroring the document window) that showed the whole document outline was also added, reducing the likelihood that the plan would get "lost" (Figure 7).

To counteract the problems of skipping or rushing through important subtasks, we decided to explicitly separate the process into stages. Digital Mysteries [12] provides guidelines for separating a task into stages in order to regulate progression and provide opportunities for scaffolding. Even in non-learning scenarios, the separation of a large task into subtasks allows users to focus on parts of the problem as needed [29]. This structuring was implemented through decision points, where each group member had to agree they were ready to progress to the next stage together – at these points in the process all other parallel interaction is suspended, forcing the group to focus on the decision together, and encouraging discussion. However, it is important that this separation into stages should not remove functionality, so that actions can be returned to when necessary.

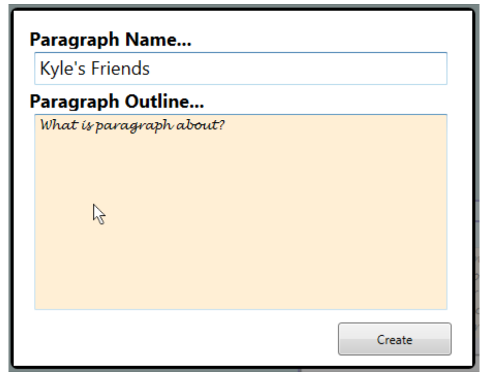

Figure 6: Adding outlines to paragraphs. When a paragraph is created, users type a description of what the paragraph should contain.

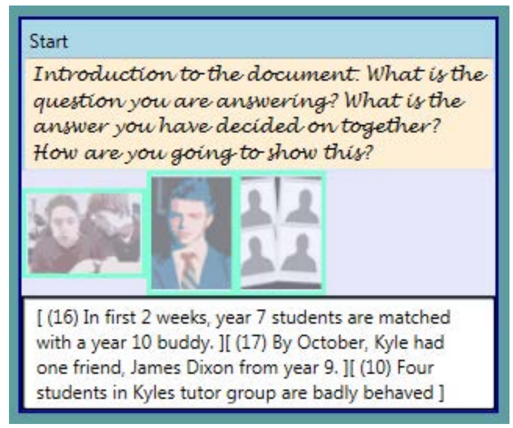

Figure 7: Paragraph outline separate from main text. Paragraphs now contain the initial outline text separate from the main text.

The learners' work had to pass certain criteria before they could continue (a paragraph creation, connection and text entry stage). Again, each stage required the learners to collectively assess and come to an agreement that they were ready for the next stage. This allows scaffolding to be injected closer to the error points, and made sure the learners' focus was drawn to key points in the document construction process that we previously found they had a tendency to overlook.

4.5 Iteration Two: findings

While the extended writing process did improve in the second iteration in that more paragraphs were created, more evidence used and more relevant connections made (see Table 3), there were still a number of aspects of the application that required improvement.

The outline feature made the need for planning more explicit, but both groups (B and C) were confused about what and how much they should be writing for an outline, and in some cases wrote more in the outline than in the main text of the paragraph. It was also confusing for the learners that the evidence slips were associated with the main text but not really with the outline, which led to low levels of slip usage overall (Table 3).

Screen space became an additional problem within in this second iteration – with the addition of outlines to every paragraph and a separate outline and document window, the screen became quickly cluttered and confusing (although both groups stated that they didn't find it confusing, it appeared to be the case to the researchers observing the session, for example, see Figure 8). This was particularly apparent during the connection stage, which was already poorly understood by the users (i.e. it was hard for them to associate the text of the connectors with the text of the paragraphs as they were visually quite separate, they were seen as simply a way of chaining the paragraphs together). Again neither group made use of the functionality that allowed paragraphs to be rotated, even with the more cluttered interface. Also, despite the enforced stages, the reflection stage still did not present a sufficiently comprehensive picture of the process, and we concluded that the reflection stage should show more of the VS manipulations of the learners rather than just the text generation.

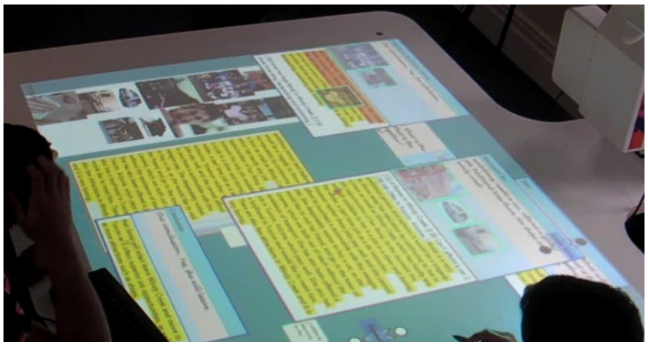

Figure 8: Cluttered, overlapping element of the interface.

4.6 Final Design

The final design (8) of the application was informed by the shortcomings of previous iterations while maintaining the features stated by Dillenbourg & Evans [3] and Scott et al. [28]. In addition to the features incorporated in the previous iterations, the final design's interface also shows the current state of the task at all times. The process is additive, meaning that all previous completed actions (i.e. ones that have not been explicitly undone by users) are visible in the current state. This means that at a glance, an observer can see what the users have done previously in the task, and where they may have missed some actions.

4.6.1 Stages

As in the second design iteration, the task was separated into three stages, where each stage is designed to enforce a key element of the extended writing process. These stages are: Paragraph Creation; Outline Creation & Planning; and Connecting and Typing. Each stage adds more functionality and does not remove actions in the previous stage. Users self-assess when they have finished a stage (by selecting from the menu and agreeing at a decision point), and if they have met the required criteria they proceed to the next stage. If the criteria are not met, the application injects scaffolding in the form of a help note, feedback suggesting what might be wrong. Help is *graded* so that repeated failure leads to help notes of increasing specificity and include detailed reasoning about why the criteria is important, (e.g. level one: "you need more paragraphs; level two: "more paragraphs would produce a better structure for your document"; etc.) Having differing levels of scaffolding also means that the application automatically provides scaffolding based on their actual performance, but also allows scaffolding to be pre-configured based on prior knowledge of a group's expected performance level [37].

4.6.2 Paragraph Creation

Paragraphs were designed so that the outline points (which are now bullet point based rather than purely textual), and paragraph text, are displayed side-by-side rather than one above the other (see Figure 7). Generally the groups worked with the digital tabletop so that it was in a landscape orientation relative to where they stood, so it seemed sensible to sacrifice horizontal space rather than vertical. Creating a new paragraph from the menu invokes a decision point at which the group has to decide together on a name for the paragraph.

4.6.3 Including Evidence

The outline process now associates the evidence slips and keywords with a paragraph outline rather than the paragraph text. The outline is a series of short bullet points (rather than a text box), with instructions to create at least two points per paragraph (users could add more). When a slip is added to a paragraph it creates a new outline point rather than being added to the main text. It would be up to the users to refer to this in the main text. Users can also type keywords as evidence.

4.6.4 Creating Connections

Connectivity was handled by moving a paragraph onto another one, rather than having a separate connector object. Placing one paragraph over another places it subsequently in the structure, the paragraphs are then be locked together. When a paragraph ordering occurs, a decision point is created where users have to decide what word or phrase would connect the two paragraphs. This is displayed directly in line with the main text of the paragraph. This structure renders the separate document and outline windows unnecessary, as they are effectively on the screen as the two columns of paragraphs. However it removes some freedom about how the structure is laid out, with implications for viewing the document from multiple angles, and maintaining the VS representation created by users. However, even in cases where the learners worked from three sides of the table, they preferred not to rotate the text, and as the paragraph structure also separates the text into small sections text reading appeared not be an issue [35].

4.6.5 Using Collaborative Writing: A Use-Scenario

Three learners, Alice, Bob, Claire take part in the exercise. They first complete a Digital Mysteries [12] exercise, working together to come up with their answer as a connected representation of the data slips. They then move onto the collaborative VS writing application, where they will write a document to persuade the reader that they have solved the mystery.

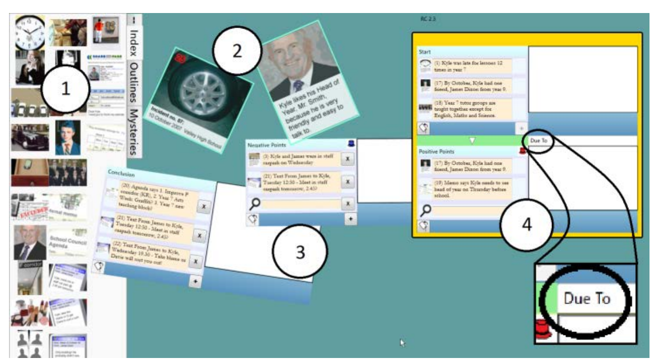

Figure 9: Collaborative Writing Interface: 1. Evidence Palette from which users may Create Evidence. 2. Evidence Slips ready to be added to Paragraphs. 3. Paragraphs, already containing some Evidence, 4. Connected Paragraphs (showing Connection Text "Due To").

After entering their names, they are presented with the instructions for the first stage: creating paragraphs and inserting evidence. The learners are asked to agree to proceed (by touching named buttons). The interface (Figure 9) allows the group to create evidence slips (based on the data slips from the Digital Mysteries) from a palette. They can also view their final mystery representation if desired. The activity begins with two paragraphs, "start" and "conclusion". Alice decides to create evidence by selecting evidence from the palette that supports their opening argument, while simultaneously Bob creates evidence for the conclusion. Evidence slips are VS elements that can be manipulated to make representations. At the same time Claire and Bob arrange the paragraphs and add the evidence (by dropping an evidence slip onto a paragraph). The group works in parallel but each member is aware of each other's actions through the shared interface. Bob selects 'create paragraph' from the menu, which freezes the interface and produces a dialogue box. This is a decision point, bringing the group back together again. Decision points help regulate the task, and bring the group together. The group discusses what the new paragraph should be called. Once the paragraph ("positive evidence") is created the interface is unfrozen and the group continues. The paragraph becomes a VS element that can be used for thinking and representation. After another paragraph ("negative evidence") is made and populated with evidence, Claire arranges the paragraphs in a sequence as an informal representation of the document, and then decides from the menu to move to the next stage. Another decision point appears and the group needs to agree to continue (or cancel).

The next stage (connecting paragraphs) is introduced with instructions. Bob connects the "positive evidence" to the "start" paragraph by dropping it onto the "start" paragraph. This brings up another decision point – a dialog asking for a connecting phrase to go between the paragraphs (to show the learners comprehension of the relationship between the paragraphs). After group discussion, Alice types the word "due to". Similarly the group connects the other paragraphs, and Claire selects the next stage (text entry) from the menu.

In the final writing stage, Bob decides there is another paragraph that can be added, and selects create paragraph from the menu. After discussion, this is named "other issues", evidence is inserted and the paragraph is connected to the other paragraphs as before. The group then plans what text to include in each paragraph, which (as the paragraphs still shows the evidence they chose to include) contains references to the evidence to strengthen their persuasive argument. Finally, Bob selects 'Finished' from the menu, and the group agrees to complete the exercise by writing the document in full based on their collaboratively agreed structure.

4.7 Final design: main findings

A preliminary evaluation of the third iteration was undertaken by only one group, who had previously completed the other iterations (B). Their use of the outline and planning phase was significantly better than in their previous session – evidence was used more readily and was correctly referred to in the main text (Figure 10).

The paragraph structure was readily apparent (see Figure 10), and clearly showed the progress of the document. Having the outline points and the document side-by-side made it easier to relate the document to the plan, allowing more ready evaluation of task progress and deviations from the plan (i.e. spot documents that don't follow the plan, documents with short paragraphs etc.). Apart from the benefits this affords to observers (e.g. teachers or classroom assistants in a real-world deployment), learners stated that the new fixed structure was easier to create and follow. The observable nature of the state of the learners' progress should make the task easy for a teacher to regulate in a classroom environment, where multiple groups would be working on the task. The disadvantage of having the text in a more rigid single viewpoint did not seem to be a significant factor, though this may be more of an issue if learners were sitting rather than standing, or when working on larger documents. It may also be an issue for lower performing groups, whose initial VS representations will be transformed, potentially causing confusion. For longer documents, there may also be a need to allow parts of the document to be hidden, either by moving off the screen or minimising finished sections.

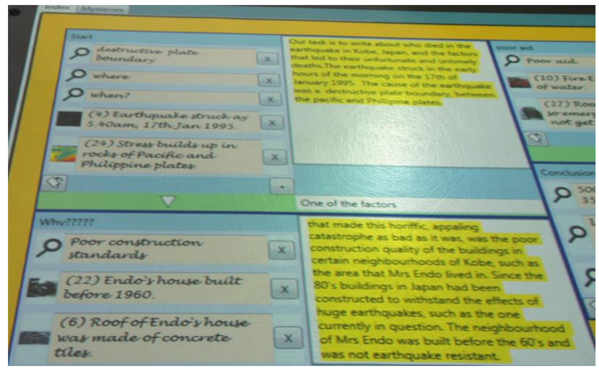

Figure 10: Final iteration document layout. Observers can see all components of the document, including evidence usage.

5. DISCUSSION

5.1 Overview

We have presented an iterative learner-centred design of a collaborative VS tool for learning extended writing. This required converting a non-collaborative, non-VS task, in this case extended writing, into a collaborative, VS one. Subtasks were chosen in order to regulate collaboration – that is the subtasks are designed to be completed with learners working mainly in parallel, but at key points where the group needs to come together to make a decision, parallel action is suspended in favour of a decision point (where the group must agree in order to proceed). Elements of the task were also given VS representations for which the digital tabletop provided an appropriate environment their manipulation and transformation..

The final design incorporated three stages: Paragraph Creation; Outline Creation & Planning; and Connecting and typing the document text with reference to the evidence used. Visually, the interface produced a cumulative representation of the progress of the learners, culminating in a representation of the final document that incorporated all the decisions made to produce it. This is beneficial in a learning environment where it enables educators to base their feedback and assessment not only on the outcome, but on the process as well. In a classroom environment where teachers have to provide scaffolding to a number of groups at the same time, this type of visualization can be particularly beneficial and more practical than alternatives that focus only on the final outcome.

5.2 Designing For VS Learning Tasks

The design lessons learned from creating the application for the collaborative writing task can be abstracted for repurposing non-collaborative, non-VS learning activities as collocated collaborative activities at a digital tabletop, and thus potentially applied to less structured tasks, such as creative writing or creative activities such as music composition. To do so requires designers to pay particular attention to three aspects of the problem and process: (i) the creation of VS elements of the task; (ii) through iterative prototyping and evaluation the appropriate balance between structured and unstructured interaction can be appropriately achieved; and (iii) the division of the activity into meaningful stages and decision points that promote collaboration.

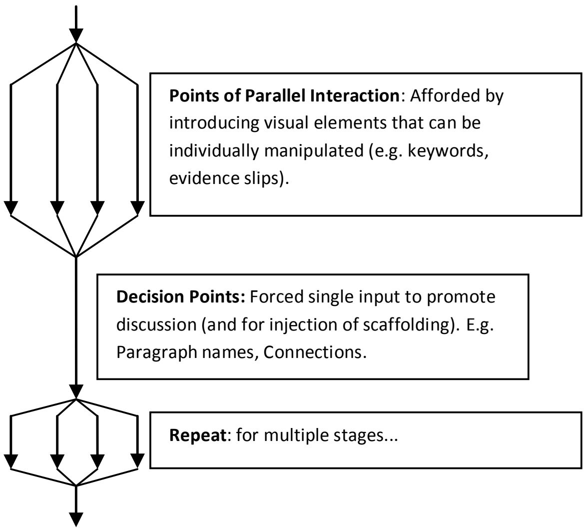

Figure 11: Interaction Process

5.2.1 Task Focused VS Elements
Subtasks should be constructed with VS elements, as this affords collaboration and increases awareness of action (collaborators are more aware of each other's externalized thinking and task progression). Having a shared concept of the task and the processes within it is a key tenet of DC. However the choice of what constitutes a VS element should not be arbitrary (or indeed exhaustive) – it should be based on the goals of the activity. The persuasive writing task could have been broken down into many different VS elements, such as paragraphs, connectives, sentences, words, evidence etc. The elements that were chosen (paragraphs, connectives and evidence) were directly informed by the intention of the task. From the outset, the purpose of completing the task was to learn the use of these specific elements, with less focus being placed on language, sentence structure, etc.

5.2.2 Structure vs. Unstructured Interaction
Within a learner-cented design and prototyping process, initial prototypes should avoid imposing undue structure on the nature and order of learners' interaction – and instead allow multiple different (but correct) approaches to be explored. This has the affect of shedding light on aspects of the tasks that are not being performed as intended, or are not being given the correct importance with regard to the overall task, for example, inclusion of evidence in our extended writing application. These neglected elements that are not being used as planned can be redesigned, combined, omitted (if not important) or explicitly enforced (if they are important for the overall task). Adding structure by splitting the task into stages ensures that a particular area is given the required focus and effort, but should be used minimally, i.e. for areas that are integral to the overall task.

5.2.3 Decisions Regulate Collaboration
The task or process, provided it is non-trivial, can be separated into sub-tasks. Sub-tasks should be chosen so that they regulate collaboration (Figure 11):

- There will be parts of the task that can be executed in parallel without impeding other parallel action (this often involves the spatial organisation of information, including actions such as grouping, connecting etc.)
- There may also be resources that are only appropriate for a single user to have access to. These singular tasks do not impede other user's parallel tasks.
- There will also be *key* subtasks that the collaborators must act on together, for example a decision point that affects the overall task. All parallel subtasks should be suspended to emphasise the importance of the task.

6. Conclusion
We have presented an account of a learner-centred design and development of a collaborative digital tabletop application for learning extended writing and in doing so we have identified and demonstrated a number of key consideration in the repurposing of non-VS learning activities (such as writing) to collocated collaborative learning settings. As collaboration is know to have a number of significant learning benefits, and the application affords mediation and regulation of collaboration, along with the possibility of injecting scaffolding, these guidelines and the learning reported here are likely to be applicable to other learning tasks that are also not usually not taught in a collaborative manor. For example, reading, language acquisition, music or art composition may also benefit from a similar approach. Although in the work presented, the focus was on children learning structured writing, we see now reason why the approach could not work equally well for adult learners or indeed for collaborative tasks outside the realm of education and learning..

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