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# The affordances of process-tracing technologies for supporting L2 writing instruction

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## Abstract

The research literature on L2 writing processes contains a multitude of insights that could inform writing instruction, but writing teachers are constrained in their capacity to make use of these insights insofar as they lack detailed information about how their students' actually engage in the processes of writing. At the same time, writing-process researchers have been using powerful technologies to trace writers' process engagement—namely, keystroke-logging and eye-tracking—that are potentially applicable in educational settings. In this article, we describe a pilot effort to integrate these technologies into L2 writing instruction with college-level ESL students. In addition to illustrating three key affordances of these technologies that emerged from the piloting, we discuss the conceptual framework that informed our efforts as well as challenges that will need to be addressed to facilitate further integration of process tracing into L2 writing pedagogy.

## Keywords

## Disciplines

Graphics and Human Computer Interfaces | Higher Education | Operational Research | Optometry | Software Engineering

## Comments

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## Abstract

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## Introduction

Even a cursory review of L2 writing process research yields a variety of insights of potential interest to writing instructors; for example, the findings that L2 writers: produce more and better ideas, and do so at a faster rate, when using free-writing rather than pre-task planning in the development of argumentative essays (Ong, 2013); allocate time to various cognitive processes differently depending on their proficiency level, with planning and revising time increasing as they become more skilled (Roca de Larios et al., 2008); rescan their texts, notes, and task prompts in varied ways depending on individualized approaches to task completion (Manchón, Roca de Larios, & Murphy, 2000); tend to make more lower- than higher-level revisions when writing under time pressure, with the latter usually consisting of adding as opposed to substituting or reordering content (Barkaoui, 2016).

As such findings suggest, there are no writing-process formulae that reliably lead to high-quality writing, a fact which even early proponents of the process-writing approach recognized. Liebman-Klein, for example, noted that "different writers, different tasks, and different situations demand different strategies, which the teacher must help the students develop" (1986, p. 786). This is difficult, however, in the absence of information about how L2 students actually go about producing the texts they ultimately submit for feedback and evaluation. For example, most instructors know little about what type of planning, if any, their students performed and how it contributed to the production of texts; how much time was allocated to engagement in other writing processes and whether that engagement was effective and efficient; or whether

students even read their texts all the way through before turning them in. The dearth of data on students' uptake of process-oriented instruction can lead to instructors becoming disillusioned with process-writing approaches (Racelis & Matsuda, 2014) while also limiting their opportunities to exploit the rich knowledge base of the L2 writing-process literature.

Meanwhile, writing-process research has evolved from being based in methods that would be impracticable in classroom situations, such as direct or video-based observations and concurrent verbal reports, to less obtrusive methods such as keystroke logging (KL) and eye tracking (ET). Indeed, software and cost issues related to the latter are being addressed such that pedagogical applications are fast approaching practical reality. In a recent project, we explored the affordances of such technologies for supporting L2 writing instruction, which we report here. First, we describe CyWrite, a KL-ET system that we used on an experimental basis in our instructional context and the conceptual framework that informed the development and use of this application. We then document what we see as three of its main pedagogical affordances: diagnosing individuals' process-related challenges, modeling efficacious approaches and strategies, and providing formative feedback on student practice with processes and strategies. Finally, we discuss several challenges that remain in integrating this type of innovation further into L2 writing instruction.

## Conceptual Framework

In this project, we adopted a cognitive developmental perspective, basing our understanding of student writing behavior on the pair of models proposed by Bereiter and Scardamalia (1987) to account for differences between novice and skilled writers. Although these models are based in L1 research, they have informed theorizing about L2 writing (Weigle, 2002). In this distinction, the *knowledge-telling* model describes the novice approach, wherein writing is a simple act of retrieving information from memory and "telling" what you know. By contrast, skilled writers exhibit *knowledge-transforming*, which involves an interaction between the author's mental representation of her ideas and a separate mental representation of the text, with discrepancies between the two occasioning problem-solving and rethinking of the original ideas. Kellogg (2008) extended this conceptualization to include a third, top-tier level, *knowledge-crafting*, which characterizes the work of professional writers, wherein an additional representation, an anticipated reader's interpretation of the text, is considered alongside the other two.

Two features of these developmental models are important for our purposes. First, as noted by Kellogg (2008), the two higher-level approaches require considerable amounts of cognitive control to maintain multiple representations in working memory while simultaneously generating ideas, formulating ideas into words, evaluating and revising one's work, and monitoring and self-regulating the overall process. Skilled writers have managed to reduce the cognitive resources needed for these processes through learning and maturation (Kellogg, 2008). L2 writers face a unique challenge in that the language processing that native speakers manage effortlessly is for them as-yet unautomatized and therefore effortful. This reduces L2 writers' attentional capacity available for the other requirements of skilled writing (Roca de Larios, Murphy, & Marín, 2002).

Secondly, according to Bereiter and Scardamalia (1987), it is not possible to identify a writer's current state of development simply by studying a given text because knowledge of topic, genre, and language affects writing outcomes. Rather, it is cognitive processes and the different ways they are enacted that make such differentiation possible. A partial taxonomy of these processes, which was adapted from Roca de Larios et al. (2008) and which informed the current project, includes:

- *task definition*: trying to understand the requirements of the writing task
- *planning*: generating, organizing, and making connections between ideas; setting goals
- *formulation*: encoding ideas into words on a page or computer screen
- *evaluation*: assessing "the efficacy of [one's] pragmatic, textual, and linguistic decisions" (2008, p. 37)

- *revision*: adding, deleting, or otherwise changing previously formulated text

A summary of research on these processes is beyond the scope of this paper, but see, for example, Roca de Larios et al. (2002) and Roca de Larios, Nicolas-Conesa, and Coyle (2016) for reviews.

One major goal of the approach described here was to allow writing instructors to exploit the potential value of this knowledge base by increasing the information they have about their students' engagement in writing processes; specifically, information that could be used for diagnostic and formative assessment. Following the Association of Language Testers of Europe (ALTE), we define diagnostic assessments as those used for "discovering a learner's specific strengths or weaknesses [in order to make] decisions on future training, learning or teachings," (ALTE, 1998, p. 142) whereas formative assessments take place "during ... a course or programme of instruction" and allow the teacher to give remedial help or change the emphasis of instruction (1998, p. 146). In this distinction, then, diagnostic assessment is seen as occurring before an intervention commences whereas formative assessment occurs in the course of the intervention.

## Context, Students, and Tasks

The context for this project is an ESL writing program at a large Midwestern research university, which includes two sequenced courses in writing for academic purposes. The lower-level course focuses on shorter essays and process writing while the higher-level course assigns longer papers and emphasizes genre. In every course, one class session per week is assigned to take place in a computer lab. Most students enrolled in these courses are Chinese L1 speakers, with the second most common L1s being Korean and Arabic. Due to ethical considerations, we were not allowed to base the current project in these courses, so instead, we recruited students from these courses and paid them to perform additional writing tasks outside of class. We envisioned the integration as a component of a writing course effectuated in terms of an individual writing conference. The participants were assigned a series of four, 400-word argumentative writing tasks, which we chose because they have been found to elicit more complex combinations of processes (Roca de Larios et al., 2002) compared to narratives, for example.

Participants wrote their essays in a computer lab on campus on machines equipped with eye trackers and web browsers running the CyWrite software. They were encouraged to take as much time and as many sessions as needed to complete the writing tasks to their satisfaction. After completing each task, the participants met individually with the first author, who served as the writing instructor. These 60-90 minute sessions, dubbed "follow-up sessions" to reflect the formative assessment focus, followed a similar procedure each time. First, we discussed the finished product, as would take place in a normal writing conference. Then, we reviewed the students' process data with them, trying to make connections between the features of the written products and the combinations of processes that had gone into their creation. Next, some instruction related to the processes, such as a specific strategy for planning or formulating, might be conducted. Finally, the instructor would set process-related goals for the next writing task.

## The Technologies

Writing and process tracing were conducted in the CyWrite system, a web-based tool developed by the authors. CyWrite features a text editor that provides a familiar word-processing experience while also permitting capturing of the process of composition with combined keystroke logging and eye tracking. As the user responds to a writing task, the CyWrite editor unobtrusively records time-aligned logs of keystrokes, text changes, and eye fixations. Millisecond keystroke timings are obtained programmatically via event handlers in the JavaScript code running in the user's web browser. In our pilot, eye tracking was performed by a GazePoint GP3, a consumer-grade device available for about $700, mounted under the computer screen. The editor interfaces with the eye tracker via a protocol that provides a real-time feed of eye-fixation coordinates (Chukharev-Hudilainen, forthcoming; Chukharev-Hudilainen, Saricaoglu, Torrance, & Feng, forthcoming).

The keystroke, text-change, and eye-tracking logs are streamed live to a server where they are analyzed and persistently stored. The logged events are then rendered in a post-session viewer (Figure 1), in which user activity is reconstructed in an animated visualization called *playback* that resembles high-fidelity screen-capture recordings with an overlaid gaze-point marker. Above the playback area, a static visualization called the *process graph* is rendered, containing variables measured in characters of text on the Y-axis and time on the X-axis. The plotted variables are: total number of typed characters, including deleted ones ("process" in blue); total length of text ("product" in green); offset in text of the character rendered in the top-left corner of the viewport ("scrolling" in pink); offset in text of the fixated character ("fixation" in yellow); and offset in text of the cursor position ("cursor" in red). Gaps in the plotted lines indicate periods when the writer has switched focus to another window in the operating system (such as an online dictionary page) or when the eye tracker was being recalibrated.
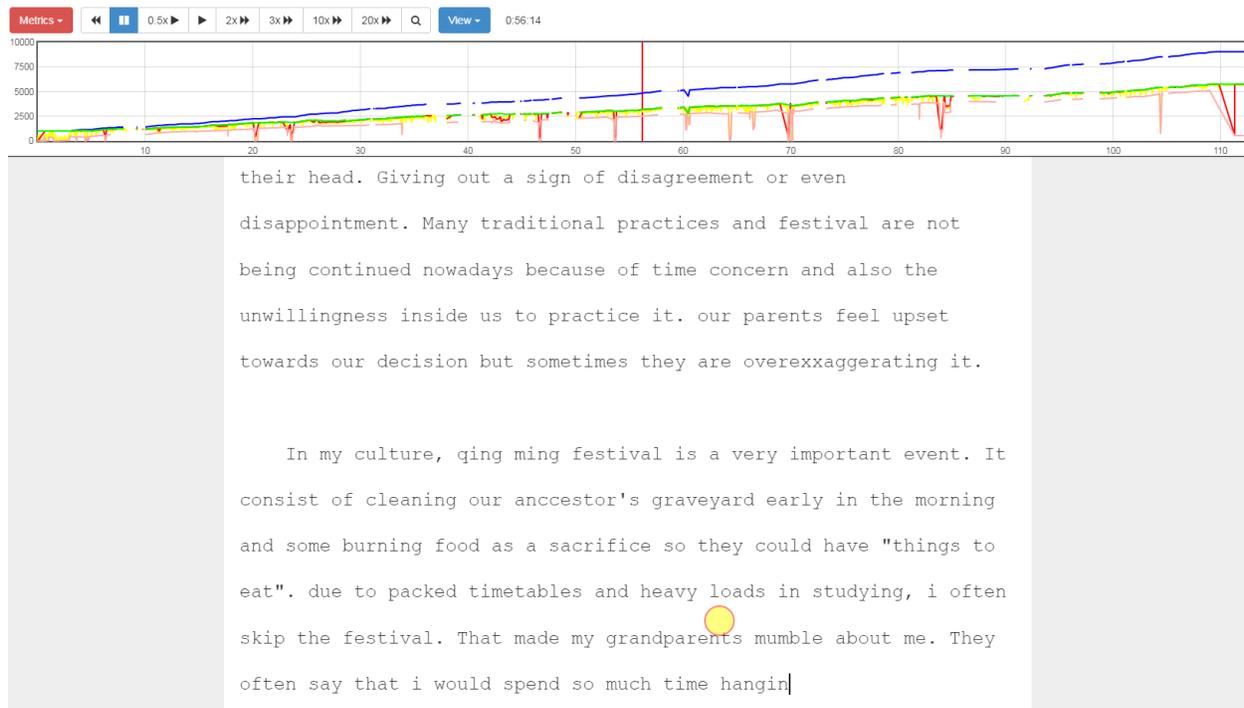


Figure 1. *Post-session viewer with process graph above and playback area below*

The process graph can be viewed as "mirroring" things shown in playback such that the farther one moves down in the text, the higher that activity is represented in the graph. Likewise, when one scrolls up or moves the cursor from the point of inscription into previously written text, this is represented as downward movement in the graph. Importantly, the process graph and playback features are dynamically linked such that moving the playhead to a point in the graph will show what was happening in playback at that moment. This allows quick and coordinated movement between macro- and micro-level perspectives on writing behavior.

## Three Main Affordances of Process Visualizations

In this section, we describe the technology's three main affordances for supporting L2 writing instruction, using screenshots and links to online videos of the process visualizations to illustrate our points.

### 1. Diagnosing individuals' process-related challenges

The first and most essential affordance of this technology is that it allows individual students' engagement in processes to be observed in great detail and problems with that engagement to be diagnosed. The process

graph and playback allow instructors to see how students are actually producing what they will ultimately submit for evaluation. Particularly if students have been asked to do all their planning work (brainstorming, outlining, etc.) in the CyWrite editor, all major stages of the writing process are traced and then made available via web-based, interactive visualizations for review and assessment.

For example, Figure 2 shows a lower-level student's process graph for the first writing task. This student, whom we will call Adam, produced this essay in a single session lasting approximately 90 minutes. The first 12 minutes show Adam reading and rereading the prompt (dense yellow area), after which, as shown in the accompanying playback, he immediately begins formulating his response in the absence of an external plan and embarking on what might be considered a textbook case of knowledge telling (see video excerpt).

Adam's formulation continues in fits and starts, with several instances of "flatlining" evident where no formulation or other activity is detected (e.g., between the 40- and 45-minute marks) and numerous points where he left the text editor (represented by gaps in the colored lines), which playback showed to be dictionary and translation-tool consultations. Formulation continues until the 76-minute mark, at which point Adam scrolls back up to the top of the file to reread the prompt and instructions. Following a large gap during which the eye-tracker was being recalibrated, Adam did more formulating and rereading of the prompt and then engaged in the only distinct revision episode of the entire writing session, adding a second headword to create a compound noun phrase and substituting the word "disappointed" for "sad" in the second sentence (see video excerpt). No rereading of the entire text is evident.
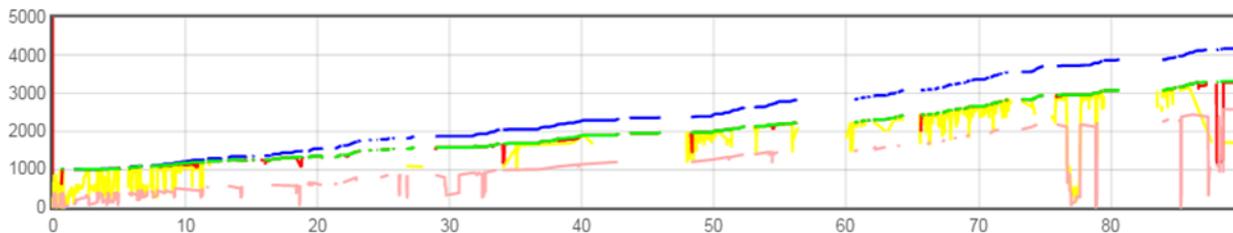


Figure 2. *Adam's process graph for the first writing task, comprising a single session evidencing no external planning and minimal revision*

A different lower-level student also completed the first writing task in a single session, spending about 80 minutes formulating after about 10 minutes of (re)reading the prompt while not engaging in any external planning. However, this student, whom we shall call Eve, devoted an additional 30 minutes to revision at the end, as is evident from the area of red and yellow below green (Figure 3). Playback showed these revisions to comprise only word- and phrase-level changes, but many were improvements that enhanced the quality of the final product. Thus, while we would characterize this student as also closer to the knowledge-telling stage of development, she is farther along the continuum than Adam. Whereas the second writer needs more help in the area of global (i.e., above sentence-level) evaluation and revision, the first needs support in incorporating *any* form of revision. Both, meanwhile, were deemed to need help in terms of external planning. Part of the diagnosis afforded by process tracing, therefore, is the ability to position students in relation to models of writing-skills development, which is informative for instruction.
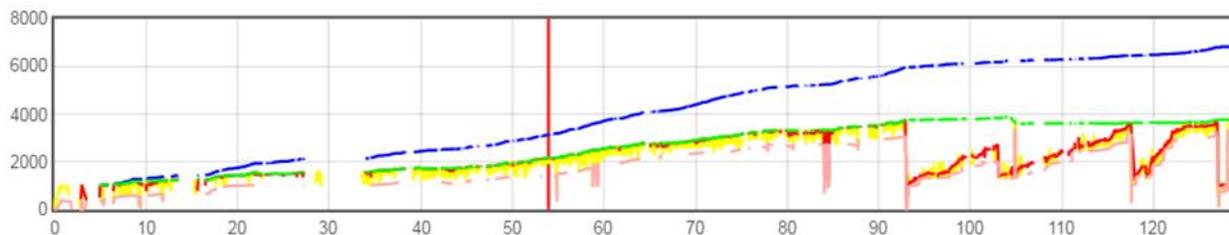
. *Eve's process graph for the first session showing a large process-product differential and more than 30 minutes worth of revision activity at the end*

These process data also depict both writers experiencing disfluencies that led to inefficient formulation. Both ended up with between 2200-2400 characters (about 450 words). Both displayed periods of "flatlining" where no activity was taking place. In addition, their graphs are replete with small gaps indicating task switching to other windows; in Adam's case, these were primarily language-oriented searches in online dictionaries and translation tools whereas for Eve, they were content-related searches. Interestingly, Eve is seen to have typed twice as many characters that ended up being deleted as did Adam, indicating a great deal of revising at the point of inscription. These disfluencies have similar effects (i.e., slowing down formulation) but different primary causes: in Adam's case, a lack of language, and for Eve, a shortage of ideas. Addressing these issues requires different, individualized approaches, which is related to the next affordance.

## 2. Modeling efficacious approaches and strategies

Research supports the value of observation in learning to write (Braaksma et al., 2004; Couzjin, 1998; Rijlaarsdam et al., 2008). However, the modeling of engagement in writing processes or strategy use is often performed by the teacher live in class (Wette, 2014) such that it (1) only provides micro-level views of skilled writing behavior, and (2) is ephemeral; that is, it cannot be reviewed by students multiple times and at times of their choosing to support spaced learning.

With this in mind, we had an English native-speaking member of the research team (the first author), as well as a skilled L2 writer whom we had identified among participants in a previous research project, serve as model writers. Both models responded to the same writing tasks as the participants while the KL-ET technology traced their processes. The post-session viewer data that resulted then became instructional material that could be used during the follow-up sessions and also made available to students via hyperlinks so they could review this data at their convenience.

In this video excerpt, the native-speaking model writer is seen demonstrating advanced planning—that is, planning conducted before the writer starts formulating text—including brainstorming and organizing ideas. Another video excerpt shows the L2 model writer using the external plan he has developed at the top of the file to replenish his ideas when he comes to the juncture between finishing one paragraph and starting a new one. As can be seen from the process graph, this allows a relatively smooth and consistent form of formulation to continue. Yet another video excerpt shows the L2 model writer demonstrating emergent planning; specifically, pausing formulation first to review the prompt and then to update the plan by revising the thesis statement. This example was also used to show how a writer's understanding of the task and ideas can change in the course of writing, thus requiring modifications to the original plan. Such iterative cycling through processes is characteristic of knowledge-transforming approaches, and these process visualizations provide learners with concrete examples.

Model-writer data was also used to demonstrate the processes of evaluation and revision, which we found to be particularly problematic for our students. This video excerpt shows a writing session of more than 50 minutes that was entirely given over to these processes, in which the first and major stage is devoted to addressing higher-level issues of content and discourse; and the second, shorter session is spent dealing with local issues of grammar and expression. This example is also useful for showing how, as evaluation

and revision progress, and as ideas are expressed more succinctly, and unnecessary material is edited out, the text becomes shorter, as reflected in the downward movement of the green "product" line. Some students found this particularly revelatory since their own revisions are restricted to adding, substituting, or, occasionally, repositioning material.

Besides different approaches to the main processes, model-writer data was also used to demonstrate specific behaviors such as the "placeholder" strategy, in which a writer types in L1 lexical items to stand in for L2 items, which are tagged with a notation such as "##" so they can easily be found and replaced later during a designated language-resourcing stage. This technique obviates the need to interrupt formulation to perform dictionary searches that run the risk of throwing writers off their train of thought.

Finally, and perhaps most importantly, the expert-model data allows students to see the sort of commitment, in terms of time and effort, that skilled writing generally requires. Beginner students in our program often start with a mental model of academic writing as akin to the sort of timed writing tests they took to enter university. Speed is considered a virtue and spending multiple hours across multiple writing sessions is deemed inefficient and a waste of time. Our experience suggests to us that these ideas can be deeply ingrained and the accompanying habits difficult to modify on the basis of admonition alone. It is one thing for students to hear an instructor explain this point and quite another to see visual evidence, from both macro and micro perspectives, of skilled writers laboring through their response to the same task that the student was assigned.

## 3. Providing formative feedback on student practice with processes and strategies

The last major affordance of process-tracing feedback is the provision of formative assessment of students' practice of new strategies and methods of process engagement. Indeed, this may be the most valuable contribution of process tracing to L2 writing-strategy instruction, which in its conventional forms has lacked ways to provide detailed, individualized feedback on students' attempts to put new behaviors into practice. Studies of writing-strategy instruction have made reference to feedback on students' practice with new strategies (e.g., Graham, Harris, & McKeown, 2013), but no data is collected or at least reported. Evidence, to the extent it is provided, is anecdotal, usually based on instructors' live observations of a limited number of students.

In this video excerpt, for example, Eve is trying out different planning approaches at the beginning of her response to the second writing task. Responding to instruction to try advanced planning, she had started by developing an outline, but in the course of elaborating on an example, her outlining transformed into freewriting, as she switched from keywords and phrases to complete sentences and paragraphs. Her fluent text production during this stage was a marked contrast to her performance on the first task. This freewriting consumed nearly all of the first session (Figure 4). In the second and final session for the second task, she spent about 20 minutes reviewing, modifying, and adding to her ideas via sentence-level changes, and then spent the remaining time trying to organize this unwieldy jumble of text into an essay. The editing task proved too much for her, resulting in a final product that displayed organizational problems, contradictory ideas, and audience-awareness issues. Notably, the eye-tracking data showed that she did not evaluate a full draft of her essay before finishing. Flower et al. (1986) say that skilled writers in such situations will usually formulate the text anew based on good ideas they extract from their freewriting, as opposed to trying to edit this text because the latter strategy is too costly in cognitive processing terms.
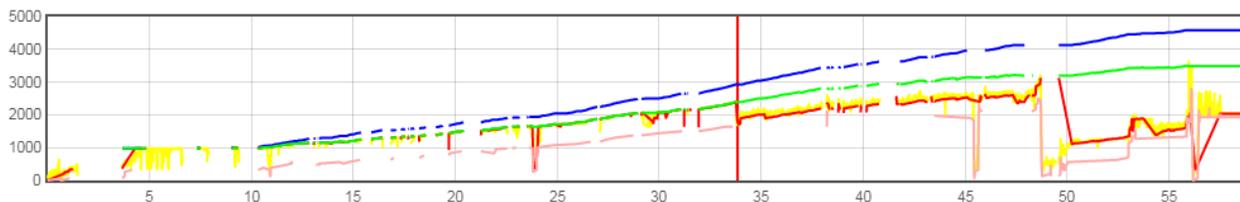
*Figure* 4*. Eve's first writing session for the second writing task, during which she fluently engaged in freewriting.*

In our feedback to Eve, we pointed out these issues and the resulting negative effects on her final product. Then, with the help of model process data, we demonstrated how to extract ideas from freewriting that could be incorporated into an outline, which was later used as the basis of new formulation. With such guidance, Eve continued to experiment with outlining and freewriting in the subsequent tasks. In the third task, she started by evaluating the loosely ordered notes she had come up with in the first session and distilling them into a more concise and structured outline with main points and specific types of support. She used both of these plans to formulate. By the fourth task, she was engaging in outlining and interactive planning—that is, updating of her plan with new ideas that occurred to her as she wrote, and then formulating on the basis of the updated plan—while also evidencing global evaluation and revision. In this video excerpt, she can be seen discarding the introductory paragraph she has just written, then updating her plan and starting to formulate again. The process graph in Figure 5 shows Eve formulating more efficiently (evidenced by the number of characters per minute and the relative absence of flat-lining) with intermittent instances of scrolling upward, represented in the graph as pink downward spikes, during which she returned to her plan at the top of the file to replenish her ideas.
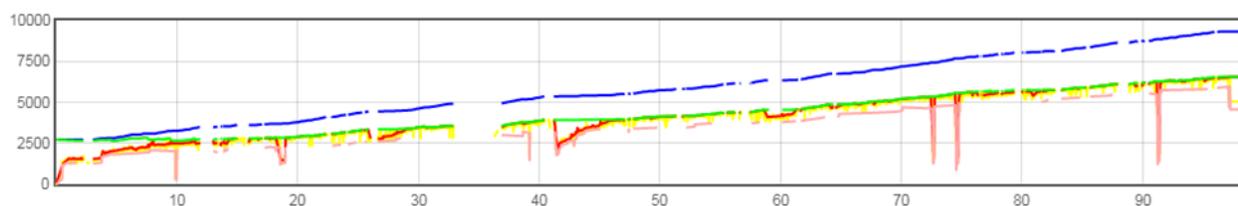


*Figure* 5*. Eve's relatively efficient formulating in the fourth writing task, punctuated by instances of replenishing of her ideas while looking back at her planning notes (downward pink spikes)*

Our point here is that the development of Eve's planning skills was not linear and predictable, nor was it based on a formula or standardized set of instructional moves. Instead, it was a gradual and contingent refinement based on observation and consultation, facilitated by the detailed information available in her process data. By contrast, other preferred behaviors may be much more easily taken up and incorporated into writers' routines. For example, Adam quickly became an avid user of the placeholder strategy (see video excerpt) to maintain a smoother rate of formulation by relegating his dictionary searches to a later stage of writing. Indeed, patterns of process engagement will almost certainly be idiosyncratic across students since, just as there is a multitude of correct ways to produce good writing, there is a multitude of ways for things to go wrong. Instructors need good information about students' actual engagement in writing tasks in order to attempt to turn it right.

## Challenges to Integration of Process-Tracing in L2 writing classes

In this paper, we have reported the piloting of this innovation through a pedagogical, practice-oriented lens. An accompanying empirical study (Ranalli, Feng, & Chukharev-Hudilainen, 2018) provided more systematic and detailed documentation of these affordances but also highlighted two main issues that need to be addressed before this innovation can be implemented in real L2 writing classrooms.

Firstly, there is a need to find ways to make process-tracing fit within the constraints of conventional writing courses. Instruction in this pilot project followed an individual tutorial approach, which is a luxury few if any college-level L2 writing programs can afford. In our context, students generally meet only twice with their instructors for individual writing conferences: once at the beginning of the term after completing the first major writing assignment and once at the end of the term while working on the final major assignment. Integration of process-tracing would somehow have to manage within such constraints. This could be achieved, in part, by using written and graphical feedback on process engagement and by handling some of

the process- and strategy-related instruction through whole-class presentation and practice. Care must be taken, however, to avoid overwhelming instructors with a huge, additional feedback burden; that is, conventional feedback on the products of writing with a new layer of process-feedback. Process tracing already allows for some amelioration of the feedback burden by obviating the need for multiple drafts since instructors get detailed information about how students engage in both revision and the evaluation that precedes it. In addition, some analysis of the process data could be automated so as not to require the teacher to interpret it manually; instead, it could be made available directly to the student. We have experimented, for example, with a visualization of relative measures of formulation, revision, and task definition activity across time, although the validity of these measures needs to be better established.

Secondly, and relatedly, there is a pressing need to support students' abilities to self-assess and self-regulate their engagement in writing processes. In addition to strategy or process knowledge, students need conditional knowledge so that they know when it is appropriate or not to enact a particular strategy. In the approach described here, monitoring, evaluation, goal setting, and strategy selection were directed by the instructor—appropriately so, we believe, given the exploratory nature of the activities. However, to ensure transfer of learning and the development of learner autonomy, students need scaffolding and formative assessment of the metacognitive as well as the cognitive elements of process engagement. They also need to develop skills in interpreting process data for themselves and incorporating this information into the way they manage their involvement in writing tasks. We are currently exploring ways to achieve these aims by providing process visualizations directly to students alongside other forms of feedback and by assigning reflection tasks that involve integrating this feedback into the development of their goals for the next writing task.

The following reflection, written by a student who had been able to make connections between shortcomings in his process engagement and coherence and relevance problems in his essay submission, suggests how development might proceed from this approach:

> What I learned [from the feedback] is the importance of making a good outline, get to write it entirely before starting the essay. And also the importance of the revision and evaluation; I thought this was not an essential part of the writing process, but it helps to see the missing connections and when some parts seem to be out of context.  For my next writing task, I'll prepare a good outline and make sure to have the time for the revision and evaluation.

To support the integration of this new approach, teachers will need not only professional development but also support from materials developers and textbook authors. Some coursebooks contain information about planning and revising, but this is often generic, not addressing the myriad problems students may face and the many options they have for engaging in these processes. In the meantime, the difficulties our students experienced with other processes, such as task definition and evaluation, are rarely addressed at all. Materials that teach self-regulation of L2 writing are likewise in short supply. A recently published resource to help writing teachers incorporate self-regulation into the curriculum (Andrade & Evans, 2013), while a welcome addition, focuses on input from instructors and provides little guidance that could be useful in exploiting the abundance of information made available by process tracing. New materials will be needed that put greater emphasis on helping students appropriately self-assess—on the basis of actual data—their strengths and weaknesses and find individualized ways of addressing the latter and building on the former.

## Conclusion

The motivation for this project was to explore whether process-tracing technologies used in writing research could usefully be repurposed to serve diagnostic and formative functions in L2 writing instruction. Based on the piloting efforts described here, we believe such potential clearly exists, not only for helping students come to grips with the behaviors through which writing is necessarily achieved but also for building on the strengths of existing process-writing pedagogy and allowing teachers wholly new perspectives on their students' engagement with writing tasks. The writing-process theorists Linda Flower and John Hayes noted

that "part of the drama of writing is seeing how writers juggle and integrate the multiple constraints of their knowledge, their plans, and their text into the production of each new sentence" (1981, p. 371). Such juggling is, as previously noted, even more difficult for L2 student writers because of their additional language-processing burden. Incorporating process data into our teaching can open a window into the drama of L2 students' writing-process engagement and cast their efforts in a much different light. We hope this report inspires other researchers and practitioners to carry this line of exploration forward.

## Acknowledgments

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