USE OF THE CMAPTOOLS RECORDER TO EXPLORE ACQUISITION OF SKILL IN CONCEPT MAPPING

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Abstract. This article presents results from a study that explored skill acquisition in computer-mediated concept-mapping by Panamanian schoolteachers being trained at the Conéctate Project. The CmapTools Recorder was used for the first time as a research tool, and provided copious information concerning the human-machine interaction taking place during Cmap construction. Subjects were found to greatly emphasize form over content: most of their efforts were directed towards moving objects, experimenting with styles, and making relatively inconsequential alterations to text which had no substantial effect on meaning. Moreover, the probability of significantly altering a concept once it had been placed in a Cmap was computed and found to be quite slim, suggesting little rethinking of ideas. All of these results held true independently of level of computer expertise. Such behaviors are consistent with what would be expected from rote learners who begin training in concept mapping.

1   Introduction

Since the development of concept maps in the early 70's, a vast body of research on their use and impact in educational settings has accumulated. This research has provided much evidence that concept mapping can indeed support meaningful learning in many different ways (Coffey, et al., 2003; Novak & Cañas, 2006; Novak & Gowin, 1984, Ch. 2). And yet, aside from the fact that effective concept mapping requires time and practice (Lin, Strickland, Ray, & Denner, 2004; Pankratius, 1990; Wandersee, 2001, pp. 135-137), little else is known about how learners actually acquire this skill. To the best of our knowledge, no formal studies have expressly investigated this question, though anecdotal information has been collected and in some cases has been published (e.g., Pines et al., 1978).

The time required for learners to become proficient concept mappers and thus be able to accurately represent their knowledge and understanding of a topic in a concept map is also unknown (Coffey et al., 2003). Pankratius (1990) considered the 8-week period of his study too short. Novak et al. (1983) concluded that after more than five months experience, more than half the students participating in their study still did not master the strategy. Novak (in Pankratius, 1990) recommended as long as six months to master the skill.

Evidently, attention needs to be paid to the concept mapping training phase. This article is based on a research program that explored the question of skill acquisition in computer-mediated concept mapping. Progress in skill acquisition was measured along three dimensions, one pertaining to Cmap[1] *construction process*, and the other two to *completed* Cmaps. This article reports on findings with respect to the first dimension, namely, the human interaction with the concept mapping program CmapTools (Cañas et al, 2004), and gathered via the CmapTools Recorder.

2   Cmap construction process data

Educational researchers (e.g., Kozma, 2001; Siegler & Crowley, 1991) have pointed out that understanding cognitive changes requires going beyond the products of educational interventions to examine the processes that led to these products. With regard to concept mapping in particular, this was pointed out by Dutra, Fagundes & Cañas (2004), who note that in spite of the voluminous amount of research on concept maps, "there is a need for studies that consider the mechanisms involved during the construction process" (p. 218). Our work took advantage of the development of the CmapTools Recorder, which afforded us the possibility to observe and analyze many details of the human-machine interaction that occur during Cmap construction. This in turn provided an opportunity to gain a better understanding of cognitive processes taking place in our subjects while acquiring skill in concept mapping.

2.1 CmapTools Recorder and log files

The CmapTools Recorder is a relatively new feature of CmapTools. It generates a record of every action taken by the user in the process of constructing his or her Cmap. The entire recording can be played back, thereby

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[1] The term "Cmap" is used to refer specifically to computer-mediated concept maps.

giving a visual reconstruction of the Cmap creation process. Simultaneously, the Recorder generates a text log file that can be imported into a spreadsheet or statistical analysis package for data processing.[2]

The Recorder logs include eight different data categories of which two are particularly relevant in trying to understand the events that take place during Cmap construction: action type and entity type. Action type refers to the actual operation carried out (adding, deleting, moving, modifying text, etc.), whereas entity type refers to the object upon which that operation was performed (concepts, linking phrases, connecting lines, and Cmaps, principally). Since we were interested in being able to trace simultaneously both the action performed and the entity upon which it was performed, we concatenated the data in these two categories into a single new *entity-action* category. For simplicity, however, we will refer to this combined category as the *action type* category.

Within the action type category we focused on the 9 mechanical operations considered most necessary to create a reasonably good Cmap: *concept addition*, *concept text modification*, *concept deletion*, *linking phrase addition*, *linking phrase text modification*, *linking phrase deletion*, *object movement*, *styles addition*, and *resource addition*. Most of these are self-explanatory; however, two require some clarification. First, concept and linking phrase text modification refer to writing actions within concept and linking phrase boxes, respectively, regardless of whether text is being modified or written for the first time. Second, concerning linking phrase addition it should be noted that linking phrase boxes appear automatically whenever two existing concepts are joined. The process of joining two concepts requires a certain amount of care, though. If not done carefully, one might end up either moving a concept box or creating a new one.

3   Methods and procedures

Subjects for this study consisted of in-service Panamanian public elementary schoolteachers participating in the Conéctate al Conocimiento Project (Tarté, 2006), where they are being trained in concept mapping as a means to foster meaningful learning. Workshops at Conéctate last for 2 consecutive weeks. The first week is devoted almost exclusively to concept maps, while the second week focuses on collaborative projects, using concept maps as a tool to plan, organize, and make public these projects. The first concept map is usually created on day 1 using pencil and paper. CmapTools is introduced, and the first computer-mediated Cmap is created, on day 2, when teachers are deemed to be less apprehensive about the workshop. From then on, all[3] other concept maps are constructed using CmapTools. The study at hand recorded and analyzed the first and last Cmaps. The first map was constructed individually in all training groups, and with the exception of 4 groups, the topic freely chosen by the teachers.[4] The final map was individually constructed and free-topic for all 18 training groups.

The initial Cmap gave us a sense of teachers' starting point and served as baseline against which skill acquired in the course of the workshop was measured; comparison with the final Cmap allowed us to determine progress during the workshop. While teachers were engaged in building these two Cmaps, facilitators were required to abstain from providing any help concerning Cmap structure or content. Facilitators could offer comments and suggestions for Cmap improvement only *after* the completed maps had been saved. However, questions or problems concerning the use of the computer itself and/or the software program could be answered during Cmap construction.

Several factors limited the scope of our work. First, subjects represent of a fairly restricted universe: Panamanian teachers from public elementary schools. This population may well have a great deal in common with elementary schoolteachers in other countries, particularly, underdeveloped countries with similar educational systems; in general, though, care must be taken in extrapolating results to other populations. Secondly, our setup was quasi-experimental. We had no control over the way schools were chosen to be included in the Project, or over the way participating teachers were grouped. Furthermore, different training groups were exposed to different facilitators, and once again we had no control over the assignment process. And thirdly, the two concept mapping tasks we analyzed were "one-shot deals." It would have been preferable to have been able to follow the evolution of teachers' concept maps over the course of two or more sessions, rather than a single map-construction session; however, this would have required facilitators not to offer teachers any feedback, which evidently was not an option given the purpose of the workshops.

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[2] All the data gathered during the course of our studies were processed using a combination of Excel and STATA.
[3] The only exception is a team map created using paper cards for concepts and linking phrases, and wool string for connecting lines.
[4] These training groups based their first Cmap on an assigned reading.

4   Results

A total of 350 teachers in 18 training groups participated in the study. Ultimately, though, the set of teachers for whom recordings of their first and final Cmaps were available was reduced to 258. Thus, our sample contained 516 Cmaps, half corresponding to the initial Cmap and half to the final one. Teacher background information confirmed earlier data by Miller, Cañas & Novak (2006). By and large, schoolteachers in Panama are familiar with concept maps (97%). However, most of them have misconceptions regarding their correct structure and usage, and thus work with them in ways that tend to reinforce rote learning modes. For instance, a majority (72%) of teachers either give students concept maps they themselves have built or build them in class, with some student input, and then ask students to memorize these "correct" maps for their exams. When using concept maps as an evaluation tool, most teachers (68%) provide partially-filled-in structures and asked students to fill-in blanks from a given list or from memorized concepts, linking phrases or both. These facts are perhaps not too surprising given the prevalence of rote learning among Panamanian schoolteachers themselves, as reported by the National Council on Education (Consejo Nacional de Educación [CONACED], 2006).

Previous experience with computers was an important variable to control for. Assuming that greater experience corresponds to higher frequency of use, and considering the possession of an e-mail account as indicative of frequent use, teachers were classified as *experienced* if they possessed an e-mail account and *inexperienced* if they did not. With this characterization, 23% of teachers turned out to be experienced users.[5]

4.1   Teacher interaction with CmapTools

As previously mentioned, our study measured acquisition of skill in computer-mediated concept mapping along three distinct dimensions, one of which was the human interaction with the concept mapping program during the Cmap construction process. This interaction was captured via the CmapTools Recorder. The resulting log files, containing over 250,000 lines of data, furnished information about all actions performed, as well as the times at which they took place. We now describe our results.

Analysis of the CmapTools logs revealed that the average construction time was 1hr 32 min for the first Cmap and 1 hr 58 min for the final Cmap.[6] The total number of actions performed on the initial Cmap ranged from a minimum of 71 to maximum of 2028, with an average of 483 actions per map (5.25 actions per min); on the final Cmap the range went from 82 to 2431, with a mean of 750 (6.36 actions per min). Figures 1 and 2 below summarize our findings regarding the 9 basic actions types. Values in the figure 1 represent mean number of actions performed in each category. It is clear from the graph that most of the increase in the total number of actions on the final Cmap came from object movement[7] and especially styles addition. The mean number of concept boxes added remained essentially the same on the first and final Cmaps; linking phrase addition, however, decreased significantly,[8] as did concept box deletion and linking phrase box deletion. Concept text modification, linking phrase text modification and resource addition increased slightly but significantly. It should be noted that resources are not discussed until day 3 sometimes day 4 of the workshop, hence we did not expect them to appear on initial Cmaps.

Given that the total number of actions varied greatly across individual teachers, in order to compare behavior patterns we looked at mean percentages relative to the total number of actions. Inspection of the bar chart in figure 2 reveals a great similarity between the patterns in figures 1 and 2. As before, we note the low percentages associated with the first 6 categories, notably modifying text, both of concepts and linking phrases. Patterns for initial and final maps are very similar. However, comparison tests produced statistically significant differences for all 9 categories, even though differences were just a couple of percentage points.

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[5] Again, this percentage is similar to the 20% statistic obtained by Miller et al. (2006).
[6] It should be noted that although facilitators determine a general time frame during which a given Cmap construction activity takes place, teachers are free to stop earlier, if they wish. Sometimes they might go a little over as well.
[7] Objects being moved were generally concepts and linking phrases; though other objects, like annotations, were included as well, these would have been few and far apart.
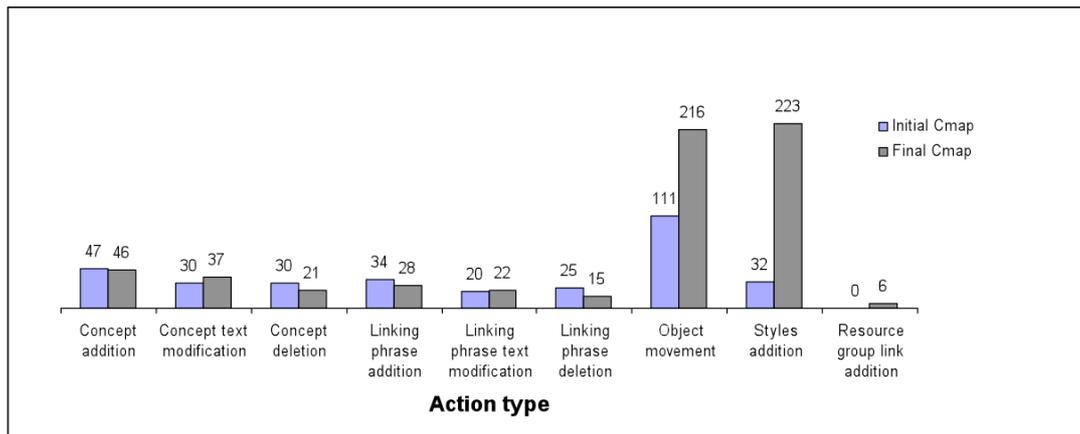[8] All results were considered "significant" at the 0.05 level.

Figure 1. Mean number of actions in each of the 9 action type categories
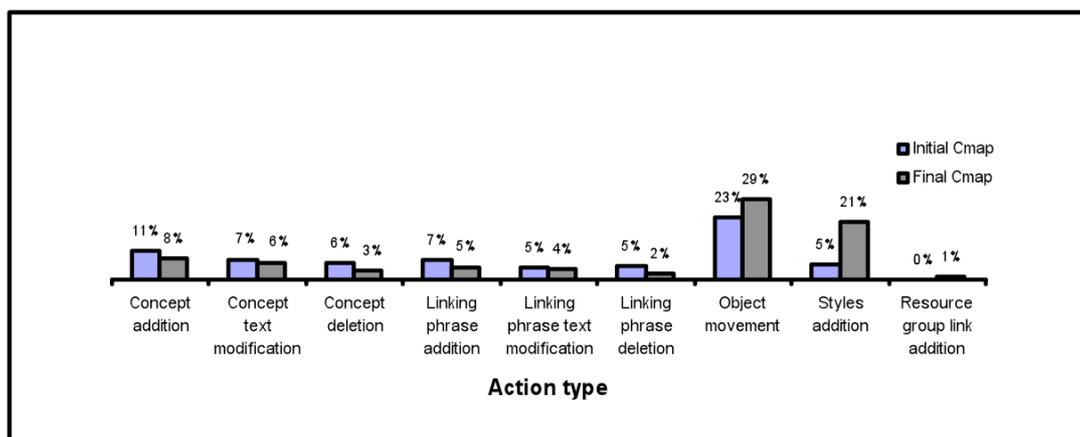

Figure 2. Mean percentages with respect to total number of actions of each of the 9 action type categories

4.1.1   Action type versus computer experience

It seems evident that the more experience one has had with computers, the easier it becomes to acquire the necessary skills to operate comfortably, at a mechanical level, with a new program. Hence, that experienced users performed significantly more actions (on average) than their inexperienced counterparts, and that differences showed up in both Cmaps with respect to many action type categories, was no surprise. Most of these could be explained by either emotional factors, difficulties with the fine motor skills required to manipulate the mouse (specifically, the ability to click, double click and drag-and-drop), or both

Indeed, what caught our attention were not the *differences* but the *similarities* between the two groups. On the first Cmap linking phrase text modification and resource group link addition were statistically equivalent for experienced and inexperienced users. These similarities persisted on the final map, and two more appeared in the categories of concept text modification and object movement. Similarities with respect to resources probably result from the fact that resource addition represents a very small fraction of the total number of actions, and that at the time the first map was constructed neither group knew that resources could be attached to Cmaps.

The fact that percentages of text modification, be it of concepts or linking phrases, ended up equivalent in the final Cmap is more intriguing, and suggests that neither experienced nor inexperienced users were particularly inclined to rewriting their concepts or linking phrases once they were placed in the map. Two factors that might contribute to this lack of interest in modifying text are a rote style of learning and, related to that, an emphasis on form over content. Learners accustomed to learning by rote generally do not question, and do not attempt to relate new information to previous knowledge; hence one would predict little or no modification of text once it has been written down. On the other hand, rote learners may prefer to deal with the way things (propositions, in this case) *look* rather than with what they actually *say*. This would appear to be supported by the fact that the most common actions performed by all subjects, regardless of their experience with computers, were moving objects and adding styles.

4.1.2 Transformation sequences of concepts and linking phrases

So far, the analysis of our data has shed some light on what goes on in computer-mediated concept mapping when teachers are first acquiring the skill; however, the picture that emerges is still rather vague. For instance, we may know what fraction of a teacher's actions corresponds to writing text within a concept box, but we cannot distinguish between text that was written for the first time and modifications of previously written text. This is an important distinction if one is interested, as are we, in understanding thought processes occurring during Cmap construction.

To better infer the cognitive processes taking place during the concept map creation process, one must follow the progression or evolution of each and every concept box and linking phrase box. The enormity of this task, compounded by real time constraints, forced us to limit our analysis to a subset of the full sample set. A sub-sample of 25 teachers was selected at random from the original pool, for a total of 50 Cmaps. Every single concept and linking phrase box created in these 50 Cmaps was followed, from its initial appearance in the map, through all text modifications, to its final form in the completed map. Since we were interested mainly in following semantic transformations, we overlooked style and layout modifications performed on the box. Altogether, 2499 distinct concept boxes (1334 in the initial map and 1165 in the final map) and 1533 distinct linking phrase boxes (893 in the initial map and 640 in the final map) were tracked.

Table 1 describes the six different evolution patterns that were possible (for concept boxes as well as linking phrase boxes), and shows the results of our analysis.[9] The numbers in this table are quite revealing. We note for instance that 54% of concept boxes were created and deleted with no writing in them in the first Cmap; this value decreased to 35% in the final Cmap. The large decrease (approximately 20 percentage points) suggests that many of these boxes may have been created unwittingly, perhaps due to lack of manual dexterity in using the mouse. Of course, it is also possible that some of these boxes were created purposefully, but were deleted for some reason, (for instance, wanting to move the concept box somewhere else and finding it easier to delete and start again, than to drag the already existing box). An identical pattern, with very similar percentages, is observed for linking phrase boxes.

EVOLUTION PATTERN	CONCEPT BOXES		LINKING PHRASE BOXES	
	Initial Cmap (n=1334)	Final Cmap (n=1165)	Initial Cmap (n=893)	Final Cmap (n=640)
Box created, left empty	1%	1%	1%	1%
Box created, deleted with no writing	54%	35%	54%	30%
Box created, text written never modified	25%	43%	19%	40%
Box created, text written, text modified (once or more)	5%	10%	4%	7%
Box created, text written, box deleted	14%	9%	20%	19%
Box created, text written, text modified (once ore more), box deleted	2%	2%	2%	3%

Table 1. Percentages of concept and linking phrase boxes following each of the 6 possible evolution paths in the initial and final Cmaps.

Also worth noting are the percentages of concept and linking phrase boxes written in exactly once: in the first Cmap, 25% and 19%, respectively. These percentages actually increased on the final Cmap to 43% and 40%, respectively. Much more modest are the numbers associated with boxes written in more than once, i.e., boxes in which original text was actually modified. Finally, we observe the nontrivial percentages of boxes written in and subsequently deleted, around the order of 10% for concept boxes and 20% for linking phrases. None of the above numbers were found to vary in a statistically significant manner between experienced and inexperienced users; nonetheless, this result must be interpreted with some caution, given the small fraction (16%) of experienced users in the sub-sample.

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[9] Percentages represent averages per map.

4.1.3 Specific text modifications of concepts and linking phrases

Next we focus our attention on those boxes in which text was written and subsequently modified, but not deleted. Pooling together the maps in the sub-sample, we identified a total of 151 distinct sequences of text modifications, 56 in the initial and 95 in the final Cmap. Inspection of these modifications suggested a classification scheme, ranging from trivial changes of format to deep alterations of content. Results are presented in table 2.[10]

As table 2 makes clear, more than half of all changes (59% in the first and 52% in the final Cmap) fell into the first 5 categories, corresponding to changes that essentially have no effect on a concept's meaning.[11] Substantial modifications involved increased concept specificity, which rose from 9% to 18%; complete change in concept, which increased from 11% to 14%; and better concept definition, which decreased from 18% to 9%, presumably as a result of a better understanding of the notion of "concept" by the end of the workshop.

An analogous categorization was carried out for 74 distinct text modification sequences of linking phrases found in the pooled sub-sample (table 3). Classification categories were again suggested by our observations, and are similar but not identical to the ones for concepts. Compared to concepts, modifications of linking phrases were somewhat more substantial: 59% of changes in the initial map, and 68% in the final map, actually modified semantic content. Furthermore, on the order of 10% of all modifications corresponded to a complete change of the linking phrase.

CONCEPT TEXT MODIFICATION	Initial Cmap (n=56)	Final Cmap (n=95)
No change at all[12]; changes in text format (e.g., font size, upper and lower case)	21%	18%
Add or remove article	5%	17%
Spelling changes	16%	10%
Gender and/or number changes; changes between infinitive and conjugated form of verbs.	11%	6%
Concept rewording	5%	4%
Increase in concept specificity	9%	18%
Improve concept definition	18%	9%
Complete change in concept	11%	14%
Other (less specificity, worse definition, etc.)	4%	5%

Table 2. Nature of concept text modifications in initial and final Cmaps.

LINKING PHRASE TEXT MODIFICATION	Initial Cmap (n=33)	Final Cmap (n=41)
No change at all; changes in text format (e.g., font size, upper and lower case)	6%	12%
Improved reading of proposition	6%	12%
Spelling changes	12%	2%
Articles; gender and/or number changes	15%	10%
Linking phrase rewording	9%	7%
Removing concepts from linking phrase; introducing verbs	3%	10%
Add greater detail to linking phrase	26%	22%
Complete change in linking phrase	9%	12%
Other (linking phrase does not improve or worsens)	15%	12%

Table 3. Nature of linking phrase text modifications in initial and final Cmaps.

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[10] Those cases in which original text was modified more than once, the variation between the original and final form of the text determined the category into which the sequence was placed.

[11] It might be argued that changes of format can impinge upon the intended meaning of a concept or linking phrase, as when italics or bold face or colors are used for emphasis. For this study, however, meaning has been considered as disjoint from format, since the meaning that could be implied by a given format has no objective reference for interpretation.

[12] Text is rewritten exactly as it was originally.

4.1.4 Concept permanence

An interesting question that emerged from analyzing text modifications of concepts is the following: How likely is it for a concept to remain in a map after being created? We will refer to this notion as "concept permanence." In order to calculate this probability, we considered the complementary event, "concept removal." Once a concept has been placed in a map, there are two mutually exclusive events that result in a concept being permanently removed: 1) the concept box is deleted, and a new concept box with that same concept or its equivalent is never created again; and 2) the concept is modified so that its meaning is completely transformed, and a new concept box with the old concept or its equivalent is never created. The sum of the probabilities of these two events yields the probability that a concept is permanently removed; the probability of a concept remaining in a Cmap is 1 minus this probability.

The likelihood of permanence was calculated for all concepts on each of the 25 initial and 25 final Cmaps of our sub-sample, and averaged to find the *mean concept permanence per Cmap*. Computations yielded values of 88% (83%, 93%) on the first Cmap, and of 95% (93%, 97%) in the final Cmap. The unequivocal conclusion is that once a concept is put down in the concept map, as far as meaning is concerned, it becomes fixed. These results provide further evidence for what we already noted above, namely, an unwillingness to change ideas once they have been put down in writing.

5 Discussion

Two things stand out from our results. First, during Cmap construction, subjects tended to emphasize form over content. At a purely mechanical level, this assertion is supported by the types of actions carried out. In the final Cmap, for instance, form-related actions accounted for 50% of all actions; in contrast, actions related to content constituted only 29%. Moreover, considering that about a third of concept and linking phrase boxes were added and deleted without ever writing any text in them, the percentage of actions ultimately associated with content ends up closer to 23%. At the semantic level, our claim is supported by results concerning the nature of text modifications. For example, of the 10% of concepts in the final Cmap whose text was modified once or more and not deleted, 55% of all modifications were changes in format which had no bearing on the concepts' intended meaning. A similar analysis for the 7% of linking phrases whose text was rewritten once or more and not subsequently deleted, revealed that 43% of changes altered form without affecting meaning.

Second, our data suggests that during Cmap construction there is little rethinking of concepts and linking phrases, and hence propositions, being put forth. This assertion is based on the fact that writing and rewriting of text constituted a minimal fraction of the total actions performed – between concepts and linking phrases, text writing took up on average around 10% of actions – and that much of the rewriting involved relatively unsubstantial changes to content. It would seem that inexperienced users might be more reluctant than experienced users to modify text, owing to lack of ease with the machine, typing difficulties, emotional factors, or any combination of these; however, mean percentages turned out to be similar for the two groups. Hence, technological difficulties and/or issues involving affect would not appear to be responsible for the low percentages of text modification. Of course, it is possible that much of the thinking took place before Cmap construction and hence there was no need for rewriting. However, the fact that the average semantic quality of the final maps was low (Miller, 2008) does not support this argument. We believe something else is at work here, namely, an inclination towards rote learning on the part of our subjects. Further evidence of this comes from the fact that approximately half the time text rewriting involved trivial modifications; along with the high concept permanence, 88% and 95%, on the first and final Cmaps, respectively.

6 Conclusions

Computer-based learning environments give us the opportunity to examine, in addition to "finished" products, the individual steps taken to produce them. In the case at hand, the CmapTools Recorder proved an invaluable instrument, allowing us to examine specific actions performed by teachers in the course of constructing their Cmaps. For the population of schoolteachers considered, the results presented in this paper indicate that beginning mappers dedicate most of their effort to form-related actions, with little revising of propositions. This is consistent with what might be expected from subjects accustomed to learning by rote. This kind of detailed information is valuable to programs such as Conéctate since it provides feedback that can help redirect training efforts towards strategies that can indeed engage teachers in the rethinking of the meanings being expressed (or omitted) from their concept maps.

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