Students Interacting through a Cognitive Apprenticeship Learning Environment

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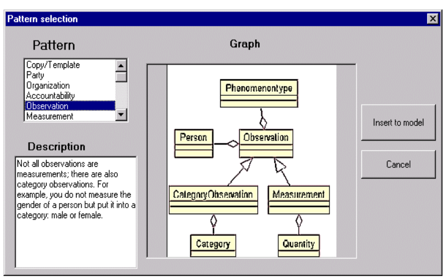
Abstract: *This paper reports on a study in which computer science students interacted in a learning environment for object-oriented (oo) modeling. The learning environment used in this study support aspects such as reflection and authentic use of expert language and tools. The analysis focuses on students' activities, the results of their activities, and on their interaction with each other and with the tools in the learning environment. The analysis indicate taht the students' reasoning is changed when using the learning environment. Students start to focus on different aspects in the modeling process compared to students who do not use the learning environment.*

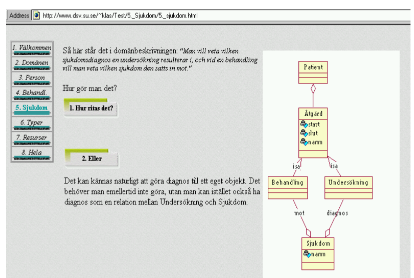
Introduction

OO-modeling is open-ended in nature and solutions to problems depend upon the particular context, goals, and enterprise and is a method for describing the information enterprises need for design and construction of supporting communication and information systems. A learning environment was designed based on cognitive apprenticeship learning ideas (Collins, Brown, & Newman, 1989) and with the intention of supporting learners to engage in a kind of reasoning that is similar to that of experienced oo-modelers. In cognitive apprenticeship and situated cognition has argued for designers of learning environments to see learning as the collaborative construction of understanding in social contexts (Wilson & Myers, 2000). (Pea, 1992) uses the term 'learning discourse' to denote learners' ability to participate in relevant conversations and using the concepts they are learning. The learning environment in this study focuses on aspects related to the notion of learning discourse such as reflection and authentic use of expert language and tools.

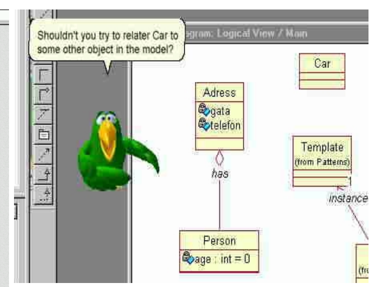
The learning environment consists of three tools supporting different aspects of cognitive apprenticeship and of oo-reasoning. For more detailed descriptions of the design of these tools see (Karlgren, Tholander, Dahlqvist, & Ramberg, 1998), (Tholander, Karlgren, Rutz, & Ramberg, 1999). The tools are a pedagogical assistant, a library of modeling patterns, and problem-solving tracks illustrating reasoning of experienced modeler and are integrated with a commercial modeling tool for designing oo-models.



Picture 1: The Pattern library



Picture 2: Expert track



Picture 3: The assistant

The pedagogical assistant

The pedagogical assistant has the form of an animated character and is placed on the side of the modeling tool. It poses remarks in text and speech to the students' concerning their modeling. The remarks mostly concern if the students can represent different aspects of the problem domain in their solution, e.g., "Are you sure you have modeled that airplanes might be redirected from their original destination". When the assistant has a remark it indicates this to the students and they can attend to the remark if they want to. The design intentions behind the assistant is to support learners' metacognition by making them reflect and think critically about the solution they are creating and about their reasoning (Tholander et al., 1999).

The pattern library

The library of modeling patterns is a resource to help students solving tasks in the modeling tool. Modeling patterns are prototypical solutions to problems that have shown to occur frequently in oo-modeling, design, and programming (Fowler, 1997) (Gamma, Helm, Johnson, & Vlissides, 1995). They are presented graphically, with textual descriptions, and a video recording with examples of how each pattern is used. The patterns can be automatically inserted into the students' model and can be accessed both through the assistant and separately through the interface of the modeling tool. The intention of the design of the pattern library is that students should practice solving problems with the tools and terminology that experienced modelers use, and further to support students in actively using and creating abstractions in their solutions. We see modeling patterns as an important aspect of the language that experienced modelers use to reason and construct models with. The pattern library is a way to support students to include important aspects of the domain they are learning in their learning discourse.

Expert Problem Solving Tracks

The expert tracks are extracts from solutions to problems (similar to the ones the students were given) solved by experienced modelers. The intention of the design of the tracks is to illustrate the problem solving process the experience modelers goes through in solving their problems. The focus is on giving an authentic account of their reasoning in order to support students to get insights to the reasoning of experienced oo-modelers. This includes reasoning that is later rejected as well as reasoning that takes them closer to the final solution, in order to make the tracks as 'authentic' as possible. The format of this is detailed accounts of their talk and drawings they make during their modeling.

Method

55 second and third year computer science and electro-technology students aged 22-40 at the Royal Institute of Technology in Stockholm participated in the study. They were offered to take part in the study as an extra credit exercise at the course "Information Systems Design". The exercise was given at about two-thirds of the course when they were expected to have completed 50-75 percent of a group project.

Students were given a modeling exercise to solve and were video recorded while working on the exercise. We had made the exercise too extensive for the students to complete during the session, to make sure that it would be challenging to all of them. The students were divided into a tool and a control group where the tool group had access to the learning environment tools during their modeling and the control group only used the modeling tool. All students were given the same exercise, which was to construct an object oriented model for a fictitious terrorist organization that needed to build an information system to manage the planning and execution of airplane hijacking operations. The students worked in pairs, except four that worked alone, and two groups of three. Altogether 30 sessions were conducted with students modeling for 45 minutes, however only 27 sessions are reported here since we used the first three as a pilot study. All students started solving the exercise by only using the modeling tool without access to the learning environment. After fifteen minutes the tool groups were asked to go through the expert tracks during fifteen minutes and then continue modeling for thirty minutes while using the learning environment tools. The other groups continued to model without any support during the whole session.

Method of analysis

When new models of learning are brought into the design process, what students should be learning is often redefined. In the case of cognitive apprenticeship this involves a shift from focusing on concepts and procedures to a focus on students' ability to participate in social practices (Greeno, 1997). Interaction analysis as described in (Jordan & Henderson, 1995) focuses on studying learning and understanding as socially and culturally situated activities and can focus on different aspects of human action, from activities of individuals to the social organization of the activities.

In rich video material of the kind collected here the possible aspects to analyze is numerous and varying. It is therefore important to find a focus that matches the goals of the study (Goodwin & Duranti 1992). The tools studied here are designed to achieve a particular way of reasoning as a means to support students' learning. The goal has therefore been to reach an understanding of the reasoning that students engage rather than if any learning is occurring. This is done by analyzing three aspects of the students' interaction and the results of that interaction to achieve methodological triangulation (Reeves, 1997).

The first focus analyses the character of the students' models with respect to two different dimensions in the modeling process. We took snapshots of the character of the models during the modeling sessions. The first dimension concerns the amount of detail in the model, e.g.*,* how many attributes or relation names have been included in the model. The second dimension concerns how much, what we call, component-likeness a model has. A component like model has a character of building blocks which can be removed, modified, and combined with other building blocks and is closely related to the idea of modeling patterns. However, a component like model does not have to include any of the modeling patterns from the pattern library or from textbooks. The characterizations were done at two stages in the modeling process, after 15 minutes of modeling and at the end of the session. This allowed us to see how the models of the students using the tools changed compared to the control group. We also analyzed other aspects related to these issues such as how they were organized, what constructs the students used, and how complete the final models were.

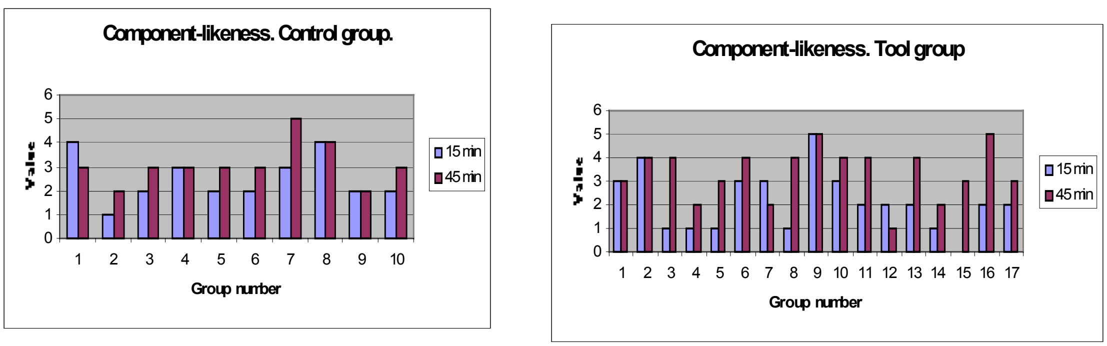
The second focus of analysis concerns the character of the modelers' activities during the modeling sessions with respect to the two dimensions of component-likeness and detailedness. The purpose of this was to see if the students worked with larger pieces of the information in the enterprise being modeled or with singular concepts only. Further, we wanted to see that the students not just proceeded linearly from concept to concept but rather that they were able to meaningfully connect different parts of a model.

An important aspect of the cognitive apprenticeship learning model is the development of efficient problem solving strategies (Collins et al., 1989). We therefore analyzed how the initial time period in the modeling sessions affected the rest of the session, and particularly how it affected the component-likeness and the detailedness of their models. What we call strategic classes was central for the progress of their modeling.

The third focus is on the conversations between the subjects. It analyses the character of their talk with each other with and their interaction with the tools. Similarly the reasoning of the students not using the tools was analyzed and comparisons were made concerning the differences of their activities. Their use of language and concepts of modeling practice in their argumentation and constructions was also identified.

Results: Focusing on Students' models

We hypothesized that the change with respect to the detailedness and component-likeness of the models would be greater for the tool group. We expected that the models of the tool groups would shift focus to include more aspects of component-likeness which would also give the their models a less detailed character.



Component-likeness and detailedness

Figure 1 shows the level of component-likeness for each of the groups. The graphs indicate that the tool group more often than the control group changed their modeling style after the first 15 minutes. Especially

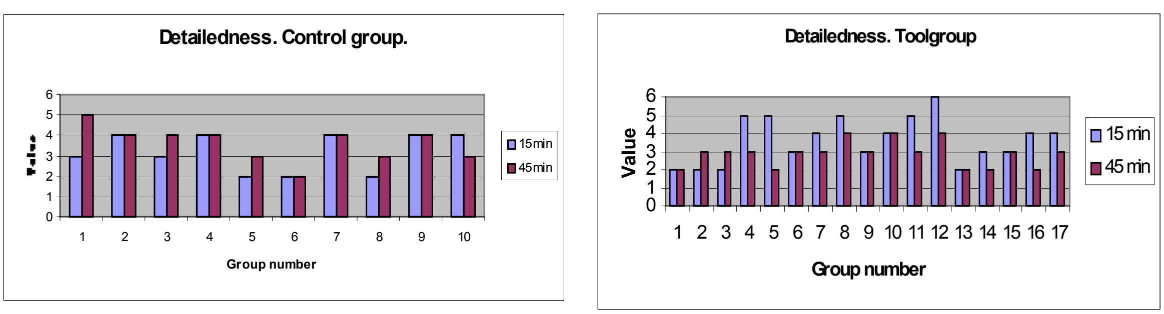
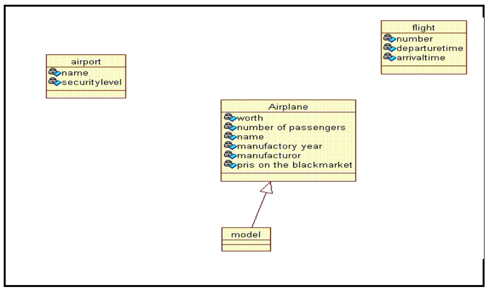
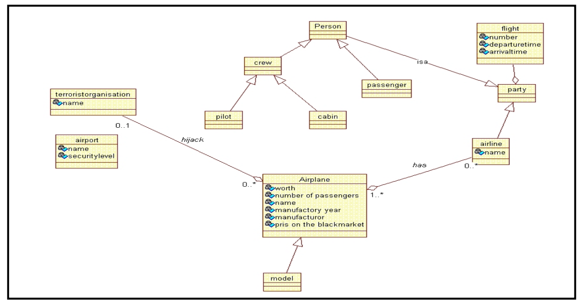


Figure 2: The detailedness of the models

interesting is that some groups, for instance, 3, 8, and 16 have changed their modeling style with respect to this dimension quite radically. In the control group several groups also changed their modeling style throughout the session but not to same as extent as some of the tool groups.

In Figure 2 the detailedness of the models are shown. For the control group one can see that this dimension was mostly unaffected throughout the session as none of the groups show any significant changes in their modeling style. For the tool group several of the groups have significantly lower values at the end of the session compared to after 15 minutes. The two models in Figure 3 show a group's model after 15 minutes and at the end of the session. Here it is evident that the focus has shifted from a few classes with a lot of attributes at the beginning to a higher level of classes and relations at the end.





The graphs for component-likeness and detailedness both seem to indicate that the tool groups change their modeling towards a stronger focus on higher level aspects of modeling such as use of patterns and that more detailed aspects such as attributes and mapping are given a lower priority. This is inline with our hypothesis that the tool groups reasoning would be more component-like and is further investigated below.

Organization and structure of models

Most groups organized around the concept of a flight which was made the central class from which most other classes were derived and developed. Flight was indeed central to the task but for several groups an overemphasis on expanding this class has caused them to neglect other concepts of equal importance. Concepts such as hijacking operation, resources, and planing were often not as elaborated as needed, although they were also central for the task. An obvious reason for this was that one of the first concepts discussed in the exercise were flights and concepts related to that and this made the students focus on that. However, we believe the main reason that flight was given a central place was that throughout the task the students elaborated concepts that they were previously familiar with, such as flights, airplanes, and airlines rather than concepts they were unfamiliar with. Less familiar concepts such as hijackings and planning and scheduling required more effort to complete and were therefore not as elaborated as the familiar concepts.

Many groups have structured their models around two constructions that had been emphasized during the course, so called inheritance hierarchies and copy-template structures. However, in several cases they used the constructions in atypical ways and in unusual situations. Most of the models created contained elements from these two kinds of constructions. One mistake often made among the students was that they mixed up different constructs in their models. Several groups used copy-template constructions together with inheritance hierarchies. Generally these two constructions should not be mixed together as they are different ways to model similar problems. One could also see an extensive use of inheritance hierarchies. Almost all groups used an inheritance structure to model person, crew, passenger, etc, even though this would have been as efficiently modeled with a copy-template construction. We hypothesize that this is because people are used to such way of structuring things in the world, from for instance natural science and everyday language, and therefore prefer representations they can relate too easier (see also section Strategic concepts).

This kind of behavior matches the description of learning as legitimate peripheral participation by (Lave & Wenger, 1991). The students practice using the constructions that they have observed experienced modelers use during the course and from the learning tools. Lave & Wenger describe this as an enculturation process where students carry out the same kind of activities with the same tools and concepts as experienced modelers use. The students practice using the kind of constructs used in the oo-modeling community even though they do not have the ability to fully understand the usage of the concepts in these activities. Of course, in the situation studied here the experienced modelers are not physically present but the students can still have access to aspects of their reasoning. Further, we saw that the tool groups used such constructs to a larger extent than the control groups even for constructs that both the test groups and the control groups knew. This indicates that the tools provide scaffolding in the enculturation process of using the language and tools of experienced modelers. By giving students access to more such constructs to use *during their modeling* we can bring their learning discourse closer to what we strive for.

Completeness of models

A natural expectation in a study like this would be that the groups using the tools would solve the problems quicker and better, but this was not the case. Rather the groups using the tools often got into deep and reflective discussions concerning different aspects of their models and therefor proceeded slower. Groups working without the tools instead were focused on coming up with quick solutions. Further, the students' working on their own often felt that they completed the task in a shorter time period than the other groups. (Bell & Davis, 2000) call the reflection prompts that they face learners with for "learning speed bumps" to illustrate how their learning support aim at slowing down the problem solving process to support learners' meta-cognition. Our learning environment seem to play a similar role.

Results: Focusing on students' modeling processes

We identified two dominant ways of starting out to solve the problem, a general and a specific. In the general way of starting out the students laid out classes that they thought would be useful for solving the exercise, usually those were flight, airline, airplane, person, pilot and then created relations between these. In the specific way of starting the students laid out only one or two classes and instead focused on adding attributes to those classes, *e.g*., number of passengers, engine type, manufacturing year, to the class airplane.

The general approach to starting out modeling turned out to be more effective with respect to the component- and detailedness of the models. We believe that this is because this approach provided a set of strategic classes to expand the model from. Several of the groups created single classes with five to ten attributes. In some cases the attributes that students had created initially turned out to be more complex than many of the subjects had realized for both types of starting to model. The process of turning these attributes into classes turned out to be difficult for the subjects that had started to model specifically compared to the subjects that had used the general starting approach. The tool groups often broke out of a their detailed modeling strategy as they got access to the tools, see Figure 3.

Strategic classes – finding the concepts

One aspect related to the component-likeness of the models is what we choose to call strategic classes. In many cases, complicated aspects of a problem were solved when one central and strategic class for what was currently being modeled was found. The idea of strategic classes can be seen in several of the patterns in the pattern library and in the expert tracks. In the detailed video analysis we also found that several of the groups that used those two tools had a greater variety of such classes to reason around which made their modeling more efficient (see section below on the students conversations).

For instance, two groups used the concept hijacking-strategy as a class to specify the different kinds of hijackings that would be used. From this concept one could see that several of the related concepts were much easier to model and the students did not have to rely on specific properties or attributes of a class but instead kept the model at the more general level of classes and relations.

Almost every group started modeling concepts that related to airports, flights, and airplanes, and these were also the most elaborated classes in many of the final models, even though some of these did not even have to be represented as classes at all. The obvious reason for this is that these concepts were mentioned early in the exercise description and were indeed central to the task, although from a strict modeling perspective these were no more important than other aspects of the exercise.

However, we believe there are other reasons for this that can help understand students' learning and how we can support their learning. In studies on people's understanding of scientific concepts it is known that everyday experiences might interfere with the understanding of theoretical concepts (McCloskey, 1983), (diSessa, 1988). Similarly, the concepts that the students started with are all everyday concepts that people use regularly and have well-developed pre-conceptions about. For most people today concepts such as airplanes, flights, and airports are familiar whereas concepts that they did not start modeling and that were less elaborated in the final models do not belong to such everyday concepts. Indications of this could also be seen in how several groups returned to parts of the model containing familiar concepts when they encountered something difficult to solve, such as adding attributes to concepts such as airplanes or airlines.

Results: Focusing on students' conversations and use of learning tools

Socio-cultural studies of learning and understanding have shown and argued for how our reasoning is mediated through artifacts such as technological tools, as well as mental artifacts such as language (Säljö, 1996), (Wertsch, 1998). Here we illustrate how both the virtual (computer based) constructions as well as internalized (mental) modeling constructions are treated as artifacts. This includes analysis of how students without access to any of the computer tools still 'interacted' with concepts learnt during the course. Their conversations are greatly influenced by the artifacts they are given to work with and of the artifacts they have learnt. In the transcripts Italics are used to emphasize aspects of their conversations.

The four cases illustrate the reasoning of the students' with as well as without the learning tools. *The first case* shows how one student use modeling concepts he knows of to strengthen the arguments of his solution to his friend. *In the second case* a pair of students use concepts from the expert tracks and treat them as superior to their own knowledge of modeling concepts. *The third case* shows how a group uses a pattern to build a structure in order to handle the concept flight and seeks to find a mapping between their own solution and the pattern they have chosen. *The fourth case* shows how the three tools complement each other and support the students to represent information about resources and planning of hijackings.

Case 1: Arguing with modeling concepts

Here, two students reason around how to represent that different kind of flights require different resources. Subject O is hesitant (line10 and 15) towards the solution that T is suggesting but O is repeatedly persuaded by T's use of modeling concepts (12, 14, 16) in their discussion. This illustrates how they in their reasoning can provide motivation and status to their ideas by using the language of modeling practice.

(10) T: Does one want it as a separate object or do you think it is enough as an attribute on flights?

(11) O: no, it's probably its own, did you intend to call it resource or resources*?*

(12) T: Mmm, or, I thought of writing an *isa-relation*, if it is a transatlantic or a non-transatlantic flight and make it an *isa relation* to flights. One could do that, I think. And then one can store *specific d*ata there.

(13) T [Creates classes "transatlantic flight" and then "non transatlantic flight"]

(14) T: What do you think about that? And then we *isa relate* to flight, it really is a flight. Data that is *general* for flight is also valid for these, actually *general data*, while you want to create *unique objects* too store how many people is needed for such a flight compared to such a flight.

(15) O: so it's always the same for all non transatlantic? Or? … (inaudible)

(16) T: noo, but since they only discuss that in the text I thought. Of course one could come up with something smarter but it is the basic idea I am after. Some flights, a flight always has start and an end time. Something which is *general* for flights only while these two here really have something unique for flights that are transatlantic and those within europe. Then if there are *unique* ones for such going to other countries and stuff then one can *specify* that then.

At a later point O again tries to contradict (lines 29, 31, 33) the solution created by T by suggesting to use a *reification* (line 31) but T convinces O about his solution by referring to modeling concepts such as *generalization and copy-template* structures in his argumentation (lines 37 and 40). From an experienced modelers point of view the solution suggested by O would probably have been the most appropriate in this case but T's argumentation made O accept his solution.

(29) O: But the question is now, are these the only resources that will, that they want to store

(30) T: No, I think there are loads of other one want to store, eh, but all flights have fuel, but this have more fuel, then there are for instance …

(31) O But isn't it better to create one called resource and then *reification* between these

(32) : T Yeah, but what object do you want in that *reification*

(33) O: If one draws, if one creates one called resource and draws from there, a flight has many [points at screen]

(34) T : Mmm

(35) T: And a bunch is *isa* from that [points again]

(36) O But why, what is the benefit of that

(37) T: Really, this is kind of a *copy-template* structure. We store some information that is *general* for all flights here while we store *unique* information for the different *types* of flights here then there are certain stuff that is here like food and fuel. That goes *generally* for all flights, don't you think?

Case 2: Collaborating through the expert tracks

Here, two students are triggered to use the expert tracks to solve a problem concerning how resources for a hijacking operation are booked. One can see how they refer to the solution in the tracks in their reasoning. By comparing and trying to find analogies to their own problem they quickly proceed toward solving the problem (line 118-121) they compare the concept of activity in the expert tracks to their concept hijacking and the attributes related to those concepts. Further in lines 126-128 they again map their model to the one in the expert tracks when discussing hijackings and resources.

(115) O: ”reserve certain pieces of equipment”
(116) T: Is that that they have a certain amount of equipment and they can book it for a certain …
(117) T: Book it for a certain …
(118) T: Ahh, okay, let's look at that [switches to expert tracks]
(119) T: Shall we look at her, we want to look at this with *time reservations*, right?
(120) T: An *activity* has a *start* and an *end time* [switches back to their own model]
(121) T: A *hijacking* has a *start* and an *end time*, should we enter that? [Adds start and end time and returns to tracks]
(122) O: Should we create one of those [points at the screen]
(123) T: mmm [goes back to their model and creates a new class reserve]
(124) T: Ehh, mmm, no, let's take reserved, reserved
(125) O: *Reservation* maybe
(126) T: Let's go [adds start and end time as attributes on reservation and returns to expert tracks]
(127) T: From *hijacking* to *resources* [goes back to their model and draws relation from reservation to hijacking and reservation to equipment]
(128) T: From *hijacking* to *resources* [goes back to expert tracks and then back to their model and changes the direction of the relation between hijacking and reservation]

Case 3: Using patterns to create ideas

This case shows how a group realizes that they the need to build a whole structure to represent a particular requirement. They use a pattern to achieve this and use it as a tool to reason with and test ideas around. Even though the pattern they choose is not especially tailored to fit this requirement the possibility to have *some thing* to reason *with* helps them to generate and test new ideas. They use the accountability pattern to refer to their own solution (lines 4 - 6) by trying to see analogies and even when they doubt the usefulness of some parts of the pattern (lines 7 - 8) they try to see how it fits their own solution. In line 12 they further seek to find a connection to their own model by mapping the concept organization to airlines.

(1) K: Should we create a class called Flight?
(2) T: Ehh, ahh, it feels like one have to build a whole *structure* with that. Because then they also want to know what airline is responsible for the it
(3) K: yes, then we can make one like flight that is included in the …
(4) K: yeah, they had a picture here that was pretty good. Here in a way. If you have *flight* here and then you have kind of who like who like takes *part* (points at *accountability pattern* and the class *party*)
(5) T: ahh, like *person* and the *pilots*
(6) K: yes, exactly
(7) T: yeah, that's how we should do it, but then this class *party* we might not need
(8) K: oh, yes, parts you now being a part of. I mean if you remember it's one of those *recursive* things

The pattern they use and the concepts in the pattern are used as something to construct their solution with much more than giving them ready made solution.

Case 4: The three tools as resources for problem solving

This case shows how the three tools support complementary aspects of the problem solving process. The assistant (A) makes the student stop and think about their solution and they realize that they need to adjust the pattern they have inserted into their model (lines 3-12). The comment of the assistant is interpreted as central to their problem and slows down their progression, as they articulate their solution to themselves.

(1) A: “Do you really need all those classes”
(2) B: Well, do we really? Well, let's see!
(3) B: *Implement*, ehh, *resource allocation*, yes we want that
(4) C: We want *resource allocation*, *quantity* is good, we want *resource type*, and then we can make *isa* from that to all people and then maybe
(5) B: Yes
(6) C: And even, we could *need two of this pattern*, one that goes to *hijacking* and one to flights. *Proposed and implemented action*, what is that anyway?
(10) B: The question is if we need it. *He asked that. If we really needed all those classes*
(11) C: An *action* could be like controlling the airplane and that is good.
(12) B: But that's not really the *resource allocation* we wanted. Were there any more of those?

A couple of turns later they are still not sure how to continue and make use of the way the two experienced modelers, Paul and Maria, solved a problem in the expert tracks to better understand how to use the pattern to solve their own problem. By referring to the tracks (line 4) they articulate aspects of their solution.

(1) C: But, we can check this with how *Paul* did it
(2) B: Yes, but *his one* wasn't really good
(3) C: How about the way *Maria* did it?
(4) B: I think there should be a resource object or instantiation that a specific allocation uses, if one uses this particular nurse Eva. then that is different from any nurse at all. *Paul* had not included that, at least not the way I wanted
(5) C: Yes, right because *he* did a really general one

Conclusions

The three focus of analysis all indicate that the tools in the study help students to shift focus in their reasoning towards aspects that we believe give them a more productive learning discourse. However, the students still in many cases are heavily influenced by pre-conceptions that they bring with them from other situations. The students seem still not to be aware of that modeling practice is very much an activity where they are giving local meaning to concepts that are used in other ways in our everyday discourse. This kind of meta-cognitive awareness is something that students would benefit greatly from. We could also see that by giving learning support to students the results of learning activities did not change dramatically. However, when data is analyzed from different perspectives indications are often found that show interesting changes in students' reasoning. One of the purposes of the learning tools used in this study was that students should be supported to actively use tools and concepts in their problem solving. The results in this study indicate that students do this even without the tools. However, from the patterns and the expert tracks they get a greater diversity in the artifacts they can use to reason with compared to only using the tools that they have mental access to. The tools support the students' activities in a direction where the kind of concepts used can be increased and more varying This helps students to expand their engagement and the possible activities they can participate in. Another important aspect to notice is that the learning support used here did not help students to always produce 'better' models or produce them quicker. The opposite was often the case, the tool group often got in to long and reflective discussions concerning their modeling where as the control group proceeded more quickly proceeded towards solving the problem they were given. These are both meaningful learning activities and shows how we must value different kinds of activities when understanding students learning.

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