Interacting representations: How students discuss, construct and use representations within a System Dynamics framework

Maria Larsson
LUCS
Lund University
Kungshuset
222 00 LUND, Sweden
+46 (0)46 222 4045
maria.larsson@lucs.lu.se

Mats Svensson
LUCSUS
Lund University
Sölvegatan 10
222 00, LUND, Sweden
+46 (0)46 222 8081
mats.svensson@lucsus.lu.se

When students learn to master system dynamics methodology they are introduced to tools and conventions for representing systems and the dynamics in them. This study explores how students collaboratively construct models of dynamic systems in the form of Causal Loop Diagrams (CLDs). Our focus is on the role of the graphic representation in the students' interaction and communication. The work process, comprising both the students' discussions and physical actions, reveal their process of making meaning. The results show that the evolving graphical representation serves as a major resource in students' meaning making. It is also shown that preconceptions are influential, but sometimes hard to incorporate in a new representational format. Different representational formats interact. For example a phase graph, showing static optimums, influences the process of developing CLDs. Our study also reveals how students recurrently check and validate their CLD by using counterfactual conditional statements.

We base much of our understanding of the world in terms of causal relations; you could even say that the whole modern scientific community builds upon the notion of causal relationships. As laymen we also perceive many phenomena in the world as causal and we need to make sense of them in order to make decisions in every day life. But if the phenomena involves causality with many parameters, sometimes only indirectly connected, and if they work on different timescales, we have a hard time grasping them (Sloman 2005; Jensen and Brehmer 2003).

A widely used method for problem understanding is to make a graphic representation of it. Various tools, both psychological and material (Kozulin 2003), scaffold the problem solving process in different, more or less cognitive demanding ways when it comes to learning and talking about real-world, dynamic problems.

In this paper we address the question of what physical and cognitive resources university students use to collaboratively construct shared meanings in a modeling task. The study aims to explore how students construct models of dynamic systems in a formal learning context. The situation in which students engage is seen as both social and cognitive. Students who construct a model do so in a relationship to physical tools and a relationship to peer students and teachers.

Mediated action theory (Wertsch 1991) views cultural tools as carriers of culture with affordances and constraints (Wertsch, Del Rio, and Alvarez 1995). Not only the physical tools, like the models on paper are of interest, but also the language used in the process of solving problems. The role of the tool that the students learn to use in their activities, the Causal Loop Diagram, is of special interest in our study. In the dialogical approach (Linell 1998) taken here, the tool does not stand by itself. In the hands of any person it is something that he or she needs to make sense of – a sense making that takes place in a dialogue where the person(s) and the tool mutually interact and influence one another. Although tools regulate and shape activities in allowing for certain actions and making other actions impossible or less likely to occur, they can be interpreted in multiple ways and therefore do not embed unambiguous meanings (Roth 2001).

A Causal Loop Diagram can be considered as a tool for exploring causal relations, comprising both physical and conceptual aspects. It aims for an understanding of how variables in a system might influence one another (more of x leads to less of y; less of y leads to less of z; less of z leads to more of x, for example). It is a representational method to visualize the interconnectedness and possible feedback loops of a system by drawing and writing, but it also comes with a set of concepts and a way of reasoning closely linked to the work of constructing the diagram.

The working order of the diagram construction process has clearly stated elements of activity, described in the following paragraph. This working order may seem like a straight-forward process, both for those people working with it and those looking at the situation from the outside, i.e. teachers. But that is not always the case. As we will show, students take different actions to make sense of the tool and of the problem they have to solve using this tool. We aim to give an example of a situation where the tool makes students problematize taken-for-granted assumptions or makes visible the need for a decision on an issue they did not anticipate. The meanings negotiated and co-constructed in this face-to-face interaction does not attempt to draw conclusion of any generality. Instead, the results of the analyses will be used to illuminate the particular task-related interaction from which they are derived.

The normative working steps for the students

The elements of activity that the students in this study are taught to make a Causal Loop Diagram are:

Defining the relevant variables

Sorting the variables into different categories

- Actors
- Factors
- Conditions

Structuring

- Defining causal links by drawing arrows
- Defining if the causes are positive or negative
- Defining causal loops by drawing arrows
- Defining if the loops are balancing or reinforcing

The central problem that the students address when constructing a causal loop diagram, as implied by the name, is the issue of causality. But first the students must select relevant facts in the case and translate them into terms that are appropriate to use with the tool at hand (Greeno and Goldman 1998; Devi et al. 1996). The reformulation step is important since students must take descriptions of the case and translate them into terms that are appropriate to use in a Causal Loop Diagram.

The first thing that the tool demands when starting on the CLD is that the students write down a word. This word generally names a variable which the students see as a central part of the problem. They typically decide on either the *first* thing or the *most important* thing; the first thing being the beginning of a chain of events following a chronological order in the story, and the most important thing being what they perceive is the central variable in the problem.

The next step that the students take, guided by the normative working order, is to decide the causal relations between the variables. The way to show this in a CLD is to draw an arrow from the word that has an effect to the word that is being affected. This shows the causal direction of influences. A plus sign (+) or a minus sign (-) adjacent to the arrow defines if the change in the variable at the tail of the arrow will cause a change in the variable at the head of the arrow in the same (+) or opposite (-) direction.

A feedback loop is accomplished if there is a mutual circular causation between variables, i.e links coming back to the original variable. In a causal loop diagram there can be either reinforcing (R) or balancing (B) loops. Using those concepts can help the students explore if the connection has a stabilizing effect (B) or an effect that will just make the variable increase indefinitely (meltdown in a nuclear power plant) or decrease until there is nothing left (cooling effect), (R) (Richardson and Pugh III 1981).

Case study

This case study focuses on the work students undertake when constructing a CLD for the case of Merchant Wang. The linguistic representation in the form of a written story handed out by the teacher is re-presented in a CLD by the students. A particular issue for the students is that a pre-conceived understanding of a Supply-Demand model in the well known form of an phase diagram gets in the way of representing the case in a CLD.

Setting and data collection

We observed students at a trans-disciplinary Master's program (LUMES, Lund University International Master's in Environmental Studies and Sustainable Science) attending a five-week academic course in System Dynamics. The course consists of introductory lectures followed by project work where the students work in groups. There are a total of four projects/cases to be completed in the course. For each assignment students were given a written case story for which they should derive a model and use it to simulate various outcomes.

Eight groups with two students in each group were videotaped during the first two hours when constructing CLD:s with pen and paper. The models on paper were also collected to support the analysis. In this paper we show results from one pair of students.

The verbal protocols of the students' discourse were transcribed and analyzed with a coding scheme inspired by the Rainbow analysis method (Baker et al. 2007). The categories in the coding scheme will not be used here, but served only as a first step in analyzing the discussions in order to find sections in the dialogue where we could find issues related to the research question.

This case study is based on the work of one of the eight groups that were videotaped, Marcus and Helen, starting to work on their CLD for the second project in the course.

Short description of the students' task: The case of Merchant Wang
The Merchant Wang case deals with how to manage food supply to avoid famine and starvation in a small community. The case is described in an old Chinese story about a province experiencing food shortage. None of the farmers considered are taking care of the surplus of grain during the years with good harvest. Merchant Wang buys it at a low price and stores it. As the people become more and more hungry during years with bad harvests, the merchant sells at raising prices and makes a profit. The purpose of the modeling exercise is to analyze the situation and the dynamics of the system and to draw a CLD for it. This will serve as a blueprint for making a quantitative computer model.

Students are supposed to build a model of a food supply system influenced by stochastic weather factors. They shall then add a "buffering system" where excess food supply are bought up and sold when the food supply is scarce. No numbers are given in the case.

Our study: Helen and Marcus creating a Causal Loop Diagram for the case of Merchant Wang
Step 1 in the working order: Defining the relevant variables: Conceptualizing and reformulating the case story to fit into the representational format of a causal loop diagram.

Helen and Marcus meet after reading the story of Merchant Wang on their own. They start by discussing the case in detail, going through the story together. As they speak, Helen uses a blue marker to highlight key words or sentences in the case story.

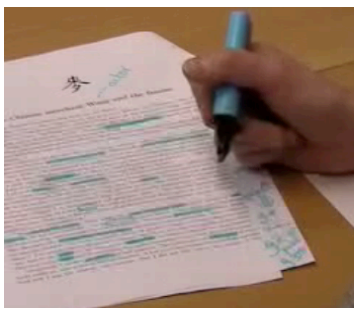
Figure 1. Marking key words in the case story.

Helen and Marcus use the empty sheet of paper after 14 minutes. They start by making a list in the top left corner. Helen suggests:

*HELEN: I start a brainstorm thing here okey ?
we just write down stuff that we have to come back later to
okey ?

She picks out four variables that she thinks are important to consider, based on the ongoing discussion:

*HELEN: so we have to distinguish between
profits
prices
supply
demand

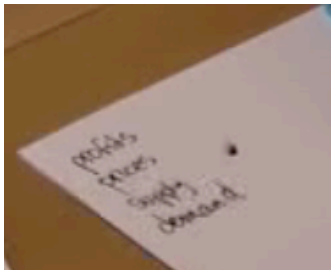

Figure 2. Making a list as the first modeling step.

The four variables stated first are variables that they keep throughout the CLD work that lasts for two hours. They continue to decide which words to put on the list and end up with seven variables in total before starting on the CLD after 29 minutes.

The first thing that the tool demands when starting on the CLD, is that there has to be a word written down on the paper. Marcus writes the word “Supply” and then the word “Demand”, two of the words from the list.

*MARCUS: supply and demand
this is the first thing
that we connect together

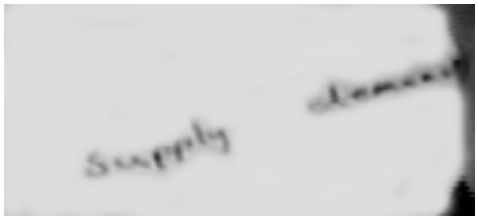

Figure 3: The first two variables in the CLD.

Combining step 2, 3 and 4 in the working order: Defining links, loops and deciding a positive or a negative influence.
As soon as there are two words or more on the paper the next step in the working process is to draw an arrow from one word to another to define a causal relation. This is called a link. If another link can be drawn back to the original word, it is called a loop. Students commonly use the term “connect” when talking about causal relations and drawing arrows from one variable to another.

The rules on how to use the tool make it possible to draw arrows to and arrows from each word on the paper. There are decisions to be made regarding which arrows to draw, but also which arrows *not* to draw. This possibility gives rise to discussions of issues that were first conceived of as unproblematic by the students.

With just two words on the paper our assumption is that the words are selected with the notion that it is possible to draw an arrow from (at least) one of the words to the other. Marcus draws an arrow from supply to demand and Helen simultaneously says:

```
*HELEN:    so (.) the higher the supply
```

Helen indicates that she agrees to define a causal relation between supply and demand. As Marcus is drawing the arrow, she wants to state whether it is a positive or a negative influence. She is signaling this by using a counterfactual conditional mood in the opening of the sentence (typically the continuing part of the phrase would be "… the lower/higher demand"). The use of conditional sentences is to discuss hypothetical situations and their consequences. Conditional sentences refer to a hypothetical state of affairs, or an uncertain event that is contingent on another set of circumstances. A conditional (or "if-then") statement indicates what would be the case if its antecedent were true.

But then she stops without ending the sentence:

```
*HELEN:    but (.) can we connect those logically
           aren't they both (.) independent of each other ?
```

The words dependent and independent are used to talk about causality. Saying "independent of each other", suggests that Helen thinks that there should not be a link between supply and demand. But Marcus argues for a link:

```
*MARCUS:   supply (.) in the end (.) more supply means less dema:nd
```

Marcus puts his pen on the head of the arrow but does not write anything. He hesitates and shows uncertainty.

Neither agreeing nor refuting but trying to find a resolution to this uncertainty, Helen takes the focus off the two words on the paper and introduces another form of representation. She draws a phase diagram at the top corner of the sheet.

```
*HELEN:    the typical economic (.) thing is this one right
           this is the
           supply
           this is demand (.) and here we have the price
```

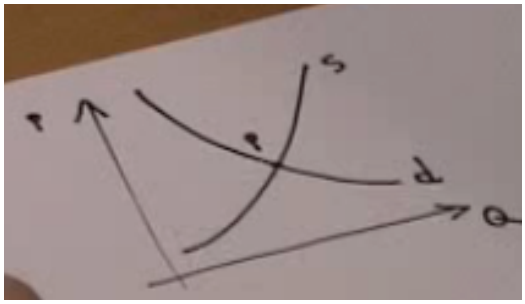

Figure 4: A phase diagram of how supply and demand determine price. It shows that price is determined as a balance between supply and demand, but does not show a causal relation between the two.

When talking on the basis of the phase diagram of supply and demand, the word Price is introduced. Marcus argues that Price should be a variable and tries to find a place for it in their CLD. This indicates that he thinks that the two representational formats (the CLD and the phase diagram) are compatible in some sense.

```
*MARCUS:    okey
            we should put price here
            [points to an empty space to the left of demand]
            or
            shall we have
```

Helen ignores Marcus' suggestion and Price does not go into the CLD at this point. Instead she tries to reason about causal relations on basis of the phase diagram, but is still in doubt.

```
*HELEN:     so the higher
            the supply (.) but how can we do that ?
            complicated
```

It seems like Helen and Marcus use the phase diagram for different purposes at this time. Marcus is focused on identifying a new variable to put in the CLD, whereas Helen is concerned with finding the causal relation between the two present variables; Supply and Demand.

The pre-conceived model of the market mechanism that the students quickly draw on when deciding what variables to use, works through the interaction between supply and demand. In Economics, this interaction is commonly taught through comparative static analysis which does not really capture the dynamics involved in the market (Wheat 2007). Thus, the two representational formats (the CLD and the phase diagram) are not compatible. Models that represent the dynamics of market interactions are known to be hard for students to create (Wheat, 2007). The comparative static analysis represented in the phase diagram shows some correlation, not to be confused with a causal relation that could be stated as a linear regression where something (x, the independent variable) is causing something else to change (y, the dependent variable).

The pre-conceived model of supply and demand gets in the way of thinking of the case as a dynamic situation based on causal relations. Two major problems surface. One problem is that the phase diagram may give the impression that there is a given corresponding value for Supply for a given Demand, thereby implying a (false)

causality between these two entities. It is often possible to mechanically plot a phase diagram of two entities, even though there is no causality involved between the two.

The other problem the students face is the concept of Demand per se. When using Demand as a variable, the students find it difficult to define what effect it has on the Supply. Is *demand* the same as *need* or does it mean *consumption*? Or is it more like a *wish* and, in that case, how can a wish be operational?

Marcus tries to convince Helen that there should be a causal link from demand to supply and reasons by using a concrete example and referring to something that he regards as common knowledge:

```
*MARCUS:   well we could say demand
           when you
           if something you need
           if the supply
           is one (.) grain
           demand is very high
           everybody wants it
```

Helen agrees and tries to reason again, but her uncertainty remains:

```
*HELEN:    that's true
           so the smaller the supply
           basically
           the [writes a plus, erases the plus and writes a minus]
           bigger the demand
*MARCUS:   yeah .
*HELEN:    and the bigger the demand [draws an arrow from demand to
           supply]
           the bigger the supply has to be [keeps the tip of the pen
           close to the arrow head]
           that's strange
```

Helen agrees on the link from Supply to Demand and shows this by adding a plus or a minus sign besides the arrow head. She then draws a link from Demand to Supply. Trying to justify this action and in order to be able to put a value sign by the arrow head she says “The bigger the supply has to be”, which is not a causal relation. Helen talks of Supply as a kind of prerequisite for the Demand to rise, which is an issue that cannot be taken into consideration when defining causal relations. Rather, the causality should define what effect one variable has on the other. After drawing the arrow from Demand to Supply, Helen keeps the tip of the pen by the arrow head as preparing to draw a + or - sign, but she does not write anything. Instead she says “that’s strange”, signaling that she is not sure of this line of reasoning.

Marcus changes the focus somewhat and looks for something that could affect (increase or decrease) Supply if they choose not to keep the arrow from Supply to Demand. He suggests to add a new variable, Harvest, but takes it back:

```
*MARCUS:   supply is what [points to supply]
           because then we have
           could have
           you know the harvest coming in here [points to supply]
```

or have it all in the same thing
cause if we do it like this [makes a circle in the air around Supply and Demand]
then it works
I mean
demand [points to Demand]
finish the supply [points to Supply]

Helen signals that she is listening by saying "mhm", but is not really engaged in Marcus' argumentation. It seems like she is already on to a new topic. To resolve the situation and to avoid the perceived problematic situation, Helen suggests adding a variable to put "in between" supply and demand.

*HELEN: mhm
or maybe if we put the price somewhere in between [writes Price]
and say
the higher the supply [draws an arrow from Supply to Price and writes a minus (-) at the head]
but if we have
if we have a high demand [draws an arrow from Demand to Price and writes a plus (+) at the head]
then the price goes up

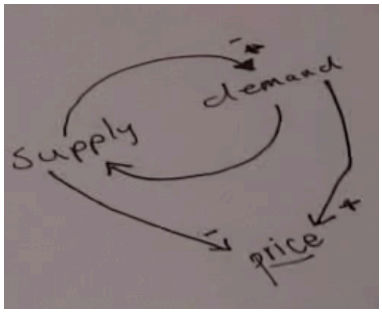

Figure 5. Variables with both indirect and direct links.

The spatial word "in between" is used in order to argue for the place of the new variable in the system. She writes Price below the words Supply and Demand. By putting something "in between" she can break the direct relation between two variables.

*HELEN: maybe we connect it like this
because I'm not sure how to connect those two directly [makes a circle in the air around supply and demand]

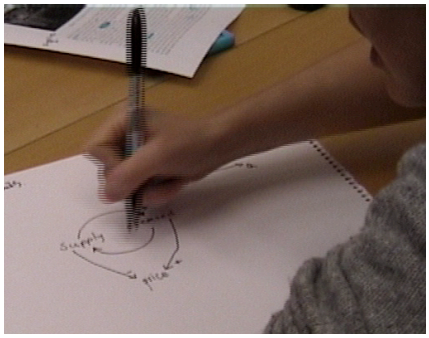
Figure 6. "I'm not sure how to connect those two directly". Helen makes a circle in the air around Supply and Demand.

Again, when talking about making or not making causal links she uses the word "connect". She then justifies the addition of the new variable and continues her reasoning by using a conditional mood:

```
*HELEN:    because this is definitely the case
           if we have a lot a lot a lot
           the price is low [points to the arrow between supply and
           price]
           if we have lots of grain
           then
           as
           as we have in the first year
           this case
           lots of supply
           very small price [underlines Price]
           second time
           lots of demand [draws a circle in the air around Demand]
*MARCUS:   yeah
           that's right
*HELEN:    so maybe we connect the two like this
           even though it's not a loop then
           but
           because those two [supply and demand] I don't know
           if we can connect them so directly
```

Saying "even though it's not a loop then", Helen evaluates her suggestion and signals that she thinks they have a problem: there are supposed to be loops in a causal loop diagram and her addition to the diagram does not result in a loop. This is the first time that the concept "loop" is used when referring to their own work.

Marcus agrees to Helen's suggestion of adding the variable Price, but they also keep the previous links. They end up with two kinds on relations; one direct and one indirect (see Figure 5). Not having a loop with the new variable included does not seem to be a big issue for the students at this moment.

Helen is still not satisfied with the direct link between supply and demand and adheres to the problem with the first loop they made. She suggests adding a new variable that influences the supply, coming back to the issue raised before by Marcus:

```
*HELEN:    because basically the supply
           is also
           influenced by
           natural [draws an arrow to supply from outside the diagram]
           ahm
*MARCUS:   productivity
           or
*HELEN:    yeah
           by the environment
           by the weather and however the harvest is you know
```

Marcus agrees and adds the variable Harvest.

```
*MARCUS:   yeah yeah
           but then we can have
```

just harvest here
it's easy [writes Harvest by the arrow going to supply]

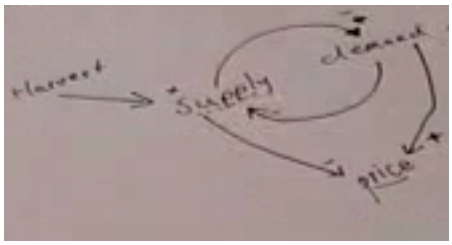

Figure 7. Marcus adds the variable Harvest

The reference to the phase diagram is no longer explicit. Helen suggests finding a new variable that affects demand and draws an arrow from an empty space on the paper to the word Demand.

*HELEN: mhm
okey
and then we can
the demand is influenced by
[draws an arrow from outside the diagram to demand]
the hunger of the people
basically

Figure 8: Helen draws an arrow from outside the diagram to Demand.

*MARCUS: yeah
that's the supply

Marcus sees the Hunger of the people as influencing Supply in the same way as Demand does, thereby making the Hunger of the people redundant in their model. Helen does not accept this and looks for a definition and distinction between the variables, but Marcus persists:

*HELEN: the hungrier they are
*MARCUS: but that's the supply
*HELEN: the supply is the grain that ahm
is thrown on the market
right ?
*MARCUS: yeah
*HELEN: and the demand is what people really want
to take from the market
*MARCUS: yeah
and that's I mean
it's the same
effect

```
          the hunger and supply
          I mean
          very little supply means hunger
*HELEN:   that's true
          also
*MARCUS:  I think it's all right
          it just
          have it like this
```

Marcus says “it’s the same effect, the hunger and supply” referring to the effect that supply and hunger has on demand in the model in front of them. A smaller supply of grain makes the demand go up, and hunger also makes the demand go up. Marcus signals that he thinks that is no use adding the variable Hunger since they already have Supply that affects Demand. In an everyday situation we would supposedly not talk about hunger and supply as the same thing, but given this way of representing it could be feasible. Helen agrees with this line of reasoning and they keep the model as it is.

The later CLD-session, where student groups working with the same problem share and discuss their first models with each other, leads to a major revision of Marcus and Helen’s model. The joint discussion together with teachers’ comments and questions make all the groups converge towards quite similar models where the original supply and demand structure is dismissed.

Prior to the discussion in the CLD session, the Supply and the Demand variables were used in more or less the same way by all four dyads that were videotaped. This structure emerge from interactions within the dyad groups, but meeting other groups leads to a new negotiated common set of variables and suggestions of a structure. Consequently, this development of shared ways of talking emanated from distributed rather than individual achievements. This means that the unfolding activity allowed the development of a shared view and a common structure despite that none of the groups originally had this structure. At the bigger-group level, a new structure emerged and Demand was taken out of the model.

Conclusion

When conceptualizing and solving the task students use a multitude of resources, both of cognitive and physical kinds. This case aim to show how topics of discussion can be introduced because of the structured way that students work with this representational tool and what resources students draw on when engaging in the activity of constructing a dynamic model.

There are two major issues that the students address in this excerpt:

Issue 1: Is there a loop? Discussing an interrelationship between two variables

Is there a causal relation between Supply and Demand? And is there a feedback link from Demand to Supply?

Issue 2: Expanding the model: Introducing a third variable

How a new variable (Price) fits into the existing model and how it can resolve a perceived problematic causal relation between Supply and Demand.

The analysis shows:

- *The evolving graphical representation plays a central role in the discourse and serves as a major resource for students' meaning making.*

The CLD has an important function in maintaining and sequencing conversations. It provides means to a kind of task-regulation during the work process where the evolving graphical representation gives the students feedback on their ongoing work and discussion.
For example, having put a value sign at an arrow head means that it should be possible to say ”more of x leads to more of y”. If what they say does not sound logical, the students stop and go over the possible relationship again. In a way, the students create a kind of external aid themselves whilst creating their model, which helps them determine if they are going in the right direction.

Some causal relations seems unproblematic for the students (for example that a bad harvest causes hunger to increase), but there are also quite a number of seemingly straight-forward causalities that are problematic as a decision needs to be made whether an arrow should be drawn or not. Marcus and Helen quickly draw a link from Supply to Demand and a link back from Demand to Supply to indicate a interrelationship between the two. But in the next step when the students are faced with putting a plus or a minus sign by the links, the interrelationship becomes problematic and the link itself is questioned.

- *The students follow the normative working order to a high extent*

The rules for making a causal loop diagram that the students have been taught strongly influence their working order. In all groups in our study we can identify the elements of activity defined in the list of working steps. The structured working order helps students deciding on what to do next.

Some students, like Marcus and Helen, start by making a list of things and people they find important in the story before drawing the CLD. Others start with the diagram at once. The step of sorting the variables (the second step in the normative working order) is often omitted by the students.

There is a tendency of wanting to have causal relations defined between two variables at a time before proceeding to expand the model. Usually the variables are then added one by one immediately followed by the definition of the causal relations, building the model in small iterating steps. An alternative would be to write all variables down first, and after that define the causal relations and feedbacks.

- *Reasoning based on counterfactual conditional statements is widely used to check and validate the CLD*

The introduction of a new variable opens up for a new discussion on how this fits with the current model. This is done by using counterfactual conditional statements. Also, when students review what they have done so far and look at their model in a global manner, counterfactual statements are used. It can be in the form of explicitly saying “if-then …”, but it can also be implicitly stated in the form of “more of x, less of y”. They check if the chain of causality seems reasonable, often by pointing at a word on the paper and following the arrow to another word using counterfactual conditional statements simultaneously. In this manner they can actually hear if the line of reasoning

holds or not. This seems like a helpful strategy since it is frequently used by the students.

- *Pre-conceptions are influential in the meaning making process*

The first choice on variables hinders the work for quite a long time for three of the four groups in the study. The choice of variables were never questioned by Marcus and Helen, but were almost treated like given. One reason for this could be that they spent about thirty minutes discussing the case and deciding the variables before starting on the CLD. It is likely that they felt confident in their choice and that this was a working step that they had completed. Another reason could be that the phase diagram of supply and demand is such a pervasive model that the fundamental variables are taken for granted. Supply and Demand are parts of a word-pair that seems to be well known by the students. In other cases that the students work with, there are not pairs of words that are so strongly connected as in this business case. Relying strongly on the pre-conceived model could also be the reason why there seem to be an implicit assumption that there is a direct causal relation between supply and demand.

- *The students use the concepts of System dynamics to make sense of their actions and discussion, especially when accounting for and evaluating their own work.*

For every new variable there are possibilities to draw an arrow between variables written down on paper. Drawing or not drawing these arrows calls for a decision, which elicits different forms of discussions. Having to put pluses (+) or minuses (-) on the arrows helps students in the process of telling the story when going through the model step-by-step, moving from one variable to the other. When Helen says “even though it’s not a loop then” after changing the structure of their evolving graph, she uses the term “loop” to evaluate her suggestion.

The work process, comprising both the students’ discussions and physical actions, reveal how different representational formats interact. It also reveals what role the representational tools play in the students’ activity when learning to construct models of dynamic systems.

References

Baker, Michael, Jerry Andriessen, Kristine Lund, Marie von Amelsvoort, and Matthieu Quignard. 2007. Rainbow: A framework for analysing computer mediated pedagogical debates. *International Journal of Computer-Supported Collaborative Learning* 2:315-357.

Devi, Roshni, Andrée Tiberghien, Michael Baker, and Paul Brna. 1996. Modelling students' construction of energy models in physics. *Instructional Science* 24 (4):259-293.

Greeno, James G., and Shelley V. Goldman. 1998. *Thinking practices in mathematics and science learning*. Mahwah, N.J.: Lawrence Erlbaum Associates.

Jensen, Eva, and Berndt Brehmer. 2003. Understanding and control of a simple dynamic system. *System Dynamics Review* 19 (2):119-137.

Kozulin, Alex. 2003. *Psychological tools: A sociocultural approach to education*. Cambridge, Mass.: Harvard University Press.

Linell, Per. 1998. *Approaching dialogue : Talk, interaction and contexts in dialogical perspectives*, *Impact, studies in language and society, 3*. Philadelphia ; Amsterdam: John Benjamins Publishing.

Richardson, Gorge P. , and Alexander L. Pugh III. 1981. *Introduction to System Dynamics Modeling*. Portland, OR: Productivity Press.

Roth, Wolff-Michael. 2001. Situating cognition. *The Journal of the Learning Sciences* 10 (1/2):27-61.

Sloman, Steven A. 2005. *Causal models: How people think about the world and its alternatives*. New York: Oxford University Press.

Wertsch, James V. 1991. *Voices of the mind: A sociocultural approach to mediated action*. Cambridge, Mass.: Harvard University Press.

Wertsch, James V., P. Del Rio, and Amelia Alvarez. 1995. Sociocultural studies: History, action and mediation. In *Sociocultural studies of mind*, edited by J. V. Wertsch, P. Del Rio and A. Alvarez. New York: Cambridge University Press.