Learning objectives for successive development stages of system dynamics competency

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Abstract

The system dynamics field has a need for defining what one needs to know and capable of doing to ne a *system dynamicist*. This paper builds on previous steps taken in order to elaborate a shared definition; it adopts the methodological orientation of stage-wise competency development from beginner to competent. It also uses Bloom's taxonomy – a widely accepted reference framework – to articulate an organized set of learning objectives. A Delphi process has been designed to exploit the knowledge and experience of a set of system dynamics experts use their contribution to obtain a clear statement concerning the learning objectives for beginners, advanced beginners, competent and proficient (practitioner). The resulting ordered and classified set of learning objectives is a necessary, though not sufficient, step towards a shared standard for system dynamics instruction and training. Building on it, standard activities and materials, as well as certification devices can be designed and developed.

Keywords: competency, learning objectives, Bloom's taxonomy

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1 Introduction

Despite the fact that system dynamics is increasingly taught and practiced, there is no explicit statement concerning what an individual ought to know and to be able to do in order to be a system dynamicist. Implicitly the information can be inferred from the few widely used textbooks or from the itinerary of learning helps like roadmaps. However, such sources do not distinguish between the successive levels of competence development; therefore designers of courses and learning activities do not have a reference frame to refer to, and what different institutions certify is hard to compare. Last not least, this makes it harder for newcomers or outsiders to inform themselves what system dynamics means in terms of knowledge and skill.

There have been previous contributions, though. An internal report prepared for the Policy Council of the International System Dynamics Society gave brief indications to self-learning individuals (Ignacio). A research project was conducted on best practices (Martínez-Moyano & Richardson, 2001), thus oriented towards practitioners. Some authors have proposed a competency profile for *systems thinking* (Stave & Hopper, 2007; 2008). The first reported attempt at defining an explicit representation of the *system dynamics* competence was based on Bloom's taxonomy of learning objectives, a widely used reference frame in education (Schaffernicht & Madariaga, 2010). While this was a step forward, a necessary next step is to work towards a widely accepted agreement concerning this representation of system dynamics learning objectives by the field. As a contribution towards this goal, the work reported here consists in conducting a Delphi study with recognized system dynamic experts in order to establish the learning goals for several stages of development.

The paper is organized as follows: the next section briefly defines competency and learning objectives and recapitulates Bloom's taxonomy. The following section describes the work process. Section 4 presents the resulting sets of learning objectives. The concluding discussion gives an outlook at the steps to follow.

2 Concepts and terms

Even though there is no universally used definition of competency, usual definitions have a shared pattern:

a) "a complex 'know act' that encompasses the ongoing development of an integrated set of knowledge, skills, attitudes, and judgments enabling one to effectively perform the activities required in a given occupation or function to the standards expected in knowing how to be in various and complex environments and situations" (Roegiers, 2007, cited in Cihcc, 2010).
b) a "complex *knowing to act* supported by the effective mobilization and use of a variety of resources" (Tardif, 2004; emphasis in original).

Knowing to act is not know-how, because it involves the capability to diagnose a situation ("what is the case"), to know what to do and to be able to do it. In this, we see the presence of skills as well as explicit knowledge, and it is no surprise that competency is learned by maturing through successive stages of development. Kubanek (2002) used the four stages proposed by Dreyfus & Dreyfus (1980), and since there is no more accurate information concerning the development stages of system dynamics competency, the same stages are used here and reproduce Kubanek's descriptions:

1) *Beginner*: "Sees the need for a quantitative policy methodology to deal with a complex, dynamic problem; however is stuck in a simple linear thinking view of cause and effect. Curious"
2) *Advanced beginner*: "Knows when SD is the right method for the job and is able to view problems as non linear complex systems with feedback, delays and causal flow."
3) *Competent*: "Has mastered basic tools and adept at drawing causal loop diagrams on the spot and able to build stock and flow models with 3 to 10 stocks that are dimensionally consistent and have feedback loops that describe real behaviour."
4) *Proficient*: "Has applied SD to real problems for several years. [under the guidance of a mentor]"
5) *Expert*: "SD modeller and trainer/teacher/consultant for many years who has earned the respect of people inside and outside the field."

Of course, the descriptions from 2002 are not sufficiently specific to serve as a reference framework for the design of courses or for certification. However, diverse studies into the nature of implicit learning and "Könnerschaft" (Neuweg, 1999) have shown that indeed, the novice or beginner has to start learning following abstract rules (for a lack of personal experience and judgment) and progressively acquire a personal standpoint allowing to act on situational clues. However, instruction will usually accompany a learner up to the "competent" stage – except maybe individuals in a dedicated PhD program.

Therefore, the present study strives to establish the knowledge and skills for the first four stages:

1) *Beginner*: in order to act, beginners need abstract descriptions of the situational attributes to attend to and general rules describing what to do (example: deciding if a variable is a stock or a flow).
2) *Advanced beginner*: the learner slowly elaborates a repertoire of known situations, starts recognizing patterns and distinguishing relevant cues in his reasoning.
3) *Competent*: the learner has sufficient personal experience to be able to define priorities and make finer distinctions. He develops a personal perspective and own objectives and experience-based heuristic rules. He is able to judge which situational attributes are relevant, but it still takes conscious cognitive effort. The learner also develops a sense of intuition.
4) *Proficient*: the individual has further developed the capability to judge the needs of increasingly complex situations and to deploy adequate modelling.

Above all, this study aims at establishing the abovementioned *resources* - knowledge, skills, attitudes, and judgments – to be mobilized and used with an increasing degree of autonomy. In order to organize all these *resources* in a way which is compatible with the progression from *beginner* to *competent*, they are presented following Bloom's taxonomy (as discussed in Schaffernicht & Madariaga, 2010), which organizes learning objectives according to their dregree of complexity:

Knowing	***Understanding***	***Applying***	***Analyzing***	***Creating***	***Evaluating***
- define	*- predict*	*- apply*	*- separate*	*-decide*	*- combine*
- list	*- associate*	*- complete*	*- order*	*- grade*	*- integrate*
- label	*- estimate*	*- illustrate*	*- explain*	*- test*	*- reorder*
- name	*- distinguish*	*- show*	*- connect*	*- measure*	*- plan*
- identify	*- recapitulate*	*- examine*	*- divide*	*- judge*	*- invent*
- repeat	*- describe*	*- modify*	*- compare*	*- explain*	*- What if?*
- who?	*- interpret*	*- relate*	*- select*	*- Value*	*- prepare*
- what?	*- discuss*	*- classify*	*- explain*	*- criticize*	*- generalize*
- wneh?	*- contrast*	*- experiment*	*- infer*	*- justify*	*- compose*
- where?	*- explain*	*- descover*	*- lay out*	*- support*	*- modifiy*
- count	*- paraphrase*	*- use*	*- classify*	*- convince*	*- design*
- describe	*- illustrate*	*- compute*	*- analyze*	*- conclude*	*- hipothesize*
- examine	*- compare*	*- resolve*	*- categorize*	*- select*	*- invent*
- cite		*- construct*	*- contrast*	*- predict*	*- develop*
		- calculate		*- argument*	*- re-write*

Figure 1: Bloom's taxonomy. Complexity (maturation) augments from left to right (Own elaboration based upon Andersen and Krathwol, 2001.).

In this taxonomy *knowing* refers to declarative knowledge being remembered. *Understanding* reveals a successful appropriation of the concepts and methods, and *applying* demonstrates a know-how level of skill. *Analyzing*, *creating* and *evaluating* are higher order skills which develop with practice. The set of learning objective elaborated in this study uses the verbs from this taxonomy and organizes them according to the mentioned levels.

3 The work process

We have selected a set of system dynamics *experts* who have the knowledge and the experience to articulate (*create*), *analyze* and *evaluate* statements concerning relevant learning objectives. Each of contributes to a Delphi process over several rounds, as shown in the following figure:

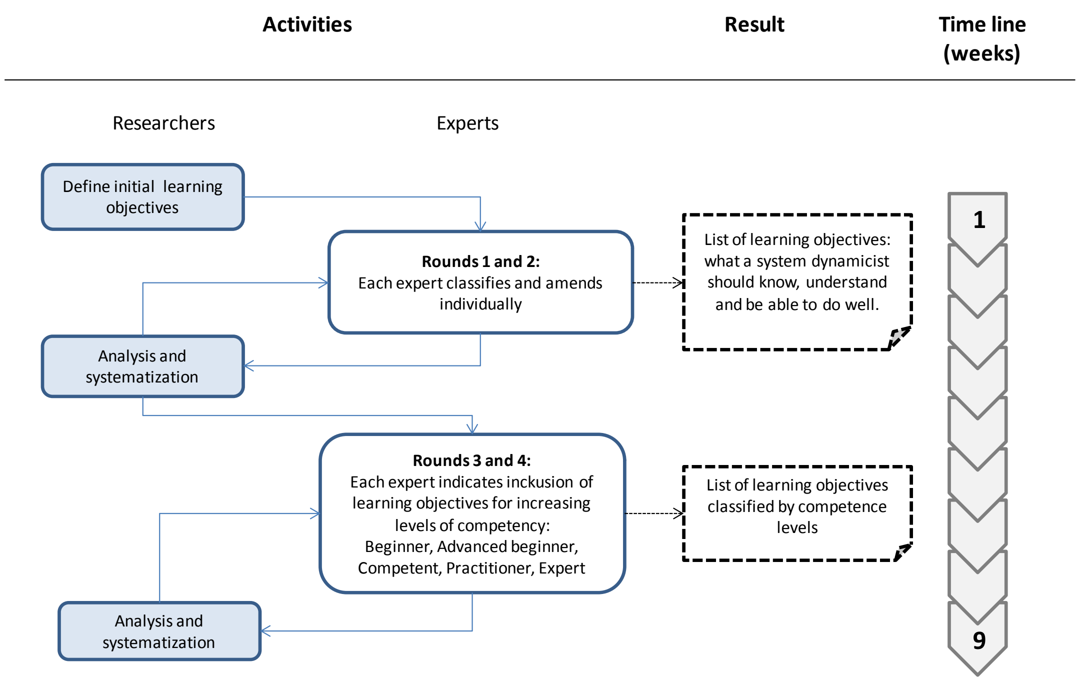

Figure 2: the work process

In a first step, the researchers developed an initial list of learning objectives, which is a revised version of the list discussed by Schaffernicht & Madariaga (2010) and is provided in the appendix. Then the experts can analyze these learning objectives, evaluate their relevance and also make changes to the list adding new learning objectives. The researchers analyze and systematize the resulting list, which is then submitted to the experts asking them to judge the pertinence of each learning objective to the different stages of competency development. The overall process requires nine weeks to be realized.

4 System dynamics learning goals

(To be developed during May and June 2013)

5 Conclusion

(To be developed during by the end of June 2013)

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Appendix: the initial list of learning objectives

Level 1: ***KNOWS*** **system dynamics modelling**
Defines the objectives of SD
Lists the phases of the **modeling process**
Defines the function of each step in the **modeling process**
Defines the **activities** of each phase of the **modeling process**
Defines the **methods applied** in each phase of the **modeling process**
Defines **dynamic complexity**
Defines the conditions for applying SD

Level 1: ***KNOWS*** **the concepts of SD**
Defines the **types of variables**
Defines **causality**
Defines **time horizon**
Defines **delay**
Defines **model boundaty**
Defines **polarity**
Defines **accumulation**
Defines **flow**
Defines **units of measure**
Defines **policy**
Describes the difference and the relationship between **accumulation** and **flow**
Defines the rules of **graphic integration**
Defines the rules of **graphic derivation**
Defines the method of **loop detection**
Defines the method for **detecting loop polarity**
Identifies generic **behavior modes**
Describes generic **behavior modes**
Identifies generic **structures (formulations)**
Describes generic **structures**

Level 2: *UNDERSTANDS* the concepts of SD

- *Explains* the **types of variables**
- *Explains* **causality**
- *Explains* **time horizon**
- *Explains* **model boundaty**
- *Explains* **polarity**
- *Explains* **delay**
- *Explains* **accumulation**
- *Explains* **flow**
- *Explains* **policy**
- *Associates* generic **behavior modes** to generic **structures**
- *Associates* generic **structures** to generic **behavior modes**
- *Interprets* **BOT graphs**
- *Describes* a stock's **accumulation** behavior given the flows
- *Describes* a flow's behavior given the stock's **accumulation** behavior

Level 3: *APPLIES* the steps of the modeling process

- *Discovers* the **model boundary**
- *Discovers* the **time horizon**
- *Discovers* the **variables** implied by a discourse
- *Classifies* the **variables** by **type**
- *Classifies* the **variables' units of measure**
- *Discovers* **causal links** implied by a discourse
- *Classifies the* **links' polarities**
- *Discovers* **delays**
- *Computes* **flows** from data about stock **accumulation** behavior
- *Discovers* the **polarity of the causal relation** between two **variables**.
- *Discovers* the **shape of nonlinear causal relations** between two **variables**.
- *Constructs* a **CLD** based upon a **S&F diagram**
- *Constructs* a **S&F diagram** based upon a **CLD**
- *Uses* **simulation to reproduce historical behavior**.
- *Uses* **simulation to formulate hypotheses**.
- *Experiments* with **simulation models** to *assess* proposed **hypotheses**.
- *Modifies* **simulation models** to *assess* proposed **hypotheses**.
- *Modifies* **simulation models** to *incorporate policies* .
- *Experiments* with **simulation models** to *evaluate* proposed **policies**.
- *Resolves* **problems** using **simulation models**.

Level 4: *ANALYZES* models

- *Infers* feedback loops in **CLDs** and **S&F diagrams**
- *Classifies* the **loops' polarities**
- *Analyzes* **CLDs** (structure and possible behavior)
  - *Interprets* the **CLD** structure
  - *Infers* limits of reasonable **behavior patters**
  - *Decides* which **behavioral implications** require simulation
- *Explains* **CLDs** (structure and possible behavior)
- *Analyzes* **S&F models**
  - *Infers* a stock's **accumulation** behavior given the flows
  - *Infers* a flow's behavior given the stock's **accumulation** behavior
  - *Interprets* the **S&F structure** using **diagram** and **equations**
  - *Formulates* **hypotheses** relating parts of the **structure** to certain **behaviors**
  - *Experiments* with **simulation models** to *assess* proposed **hypotheses**.
- *Explains* **S&F models** (structure and behavior)
- *Compares* a **model** with similar **models**.

Level 5: *EVALUATES* situations in modeling terms

- *Prepares* a **modelling project**
  - *Establishes* the **project's clients**
  - *Establishes* the **symptoms** that give rise to the project
  - *Establishes* the **reference modes**
  - *Establishes* **if SD is an appropriate methodology**
- *Establishes* a problem (with logical and temporal scope)
  - *Establishes* **desirable** and **feared futures**
  - *Establishes* the **time horizon**
  - *Establishes* a **logical boundary**
  - *Engages* **stakeholders**
  - *Formulates* a concetual model (**dynamic hypothesis)**
- *Establishes* the **purpose** of the **modeling project**

Level 5: *VALIDATES* the validity of a simulation model

- *Tests* model's **structural validity**
  - *Tests* **dimensional consistency**
  - *Tests* each variable's **correspondence** to a real entity
  - *Judges* a model's **membership** of a **model family**
- *Tests* models' **behavioral validity**
  - *Measures* the **historic fit**
  - *Tests* **extreme condition behavior**
  - *Tests* the **sensitivity** of the model with respect to uncertain **parameters**

Level 5: *EVALUATES policies and problems*

- *Evaluates* model' **structural validity**
  - *Evaluates* **dimensional consistency**
  - *Evaluates* each variable's **correspondence** to a real entity
  - *Evaluates* a model's **membership** of a **model family**
- *Evaluates* models' **behavioral validity**
  - *Measures* the **historic fit**
  - *Evaluates* **extreme condition behavior**
  - *Evaluates* the **sensitivity** of the model with respect to uncertain **parameters**
- *Explains* the **causal structure** of a **problem** or **situation**
- *Explains* how the **problem** is created by this **structure**
- *Explains* why one **policy** has high impact while others fail to do so.
- *Explains* how established and defended **policies** are the underlying cause of the problematic behavior.
- *Argues* in favor of better **policies**.

Level 6: *SYNTHESIZES (CREATES) models*

- *Proposes* **hypotheses** in the context of a **problem** (based upon a **S&F model**)
- *Proposes* **hypotheses** concerning the **behavior** of **variables** in generic **formulations**
- *Designs* a **qualitative model** (**CLD** or **S&F**)
- Uses key **agents' mental models**
- Starts from key **accumulations**
- *Infers* key **variables**
- *Connects* variables to **reference modes**
- Assures **endogenous orientation**
- Takes care of the **measurement** of variables
- Documents the **process**
- *Designs* a quantitative S+F model (Quantifies the variables)
- Starts with simple **fragments**
- Takes care of **validity** during the process
- Simulates early on
- *Distinguishes* the **perceived** from the **actual conditions**
- *Modifies* the **S&F model** to achieve **validity** (*Validates* the **S&F model**)
- *Modifies* the **model** to test **scenarios** or candidate **policies** (*Exploits* the **S&F model**)
- *Communicates adequately with a client*