A guide to defining learning objectives.

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Abstract

This report is intended to provide impetus and guidance for the goal-oriented definition of learning objectives. The definition of learning objectives and their transparent communication to the learners is the elementary basis for successfully conducting a learning event and, in particular, for making the transition from teaching to learning. This applies not only to lectures, but also to seminars, presentations, workshops, courses or, simply put, all conceivable events with the goal of learning. "Successful" in this context means that all participants are enabled to achieve the learning objectives to a sufficient degree. The target group should therefore always be the majority of participants, i.e. average students, rather than the "most talented 5%".

1 Motivation

Teaching at German universities, especially in mathematics and engineering, is still largely conducted in the form of frontal lectures and monologues, see e.g. [1]. This also means that most learning events are based on learning theories of behaviorism or at best cognitivism, cf. [2, 3]. However, the urgent recommendations have been going in a clearly different direction for quite some time (see e.g. [4]): Learning environments based on constructivist learning theories (see e.g. [5, 6, 2]) significantly facilitate learning, see e.g. [7, 8], and are fundamentally to be classified as having no alternative in view of the increasing heterogeneity of students, see e.g. [9, 10, 11]. Learning events should therefore be designed in such a way that they achieve the transition from teaching to learning in a student-centered as well as competence- and action-oriented way, see e.g. [12]. This also includes promoting self-organization and thus taking responsibility for the individual learning process and success, see e.g. [13].

The clear definition of learning objectives is the first and very important step. The aim of this report is therefore to provide impulses and start-up aids for this. Section 2 lists elementary points that should always be kept in mind when formulating learning objectives. These points are also intended to stimulate critical reflection on one's own courses. In Section 3, we review taxonomy levels as useful tools in the concrete formulation of learning goals. Section 4 begins with quite typical examples of formulations of learning goals that can be found in module descriptions in particular, but which are neither purposeful nor helpful. Thereby we deal with an example from mathematics as well as mechanics. These formulations are then improved step by step, listing in each case the advantages achieved but also the inadequacies that still exist, until a didactically sophisticated form of the respective description is available.

2 Guide

In general, you should keep the following points in mind regarding didactics and related concepts:

- The primary goal is not to simplify exams and to get as many students as possible through them.
- Quite the contrary: the primary goal is to achieve meaningful, because up-to-date and urgently needed, knowledge, skills and competencies. In our experience, at least, this tends to go hand in hand with an increase in level.
- Modern didactics is, among other things, urgently needed so that the majority of students can achieve the learning objectives at all. In addition, this should enable sustainable learning and avoid "bulimia learning".
- We teachers are probably the worst yardstick for this: what we particularly liked about the courses during our studies and what was helpful for us to pass the exams or to achieve satisfactory grades is very probably not representative for the majority of students.

You should consider the following basic points when defining learning objectives:

- A listing of the topics and teaching content covered is not a definition of learning objectives. This should be made clear by the examples in section 4.
- When designing a learning event, we must constantly ask ourselves what knowledge, skills and competencies the participants should have acquired after successful completion. This must also always be communicated transparently to the participants.
- Furthermore, we have to define in more detail on which competence levels (see section 3) the learning objectives should be located in each case. For example, learning a proof/derivation by heart and being able to recite it is on a different level than having a deep understanding of all steps of the proof or even the competence to be able to conduct independent proofs for still unsolved problems.
- There is no right or wrong in this context: a learning objective at a lower competence level is not necessarily worse than one at a higher level. Keep in mind that objectives at higher levels always build on those below them.
- However, education at universities should definitely address the higher and also highest competence levels. This can, for example, also be made dependent on the type of higher education institution (university of applied sciences, university) and the course of study (bachelor's, master's).

- We should regularly ask ourselves whether the learning objectives are still up-to-date and relevant with regard to professional reality. In what way do learning objectives prepare learners for the profession — also and especially in science?
- The relevance of certain learning objectives can change significantly over time. For example, while it was advantageous for a long time to know a lot by heart, this is becoming increasingly less important in times of rapid Internet research and programs such as ChatGPT. The available tools can and should therefore also be consistently taken into account in achieving certain learning objectives and, on the other hand, used to expand the range of learning objectives. This means that learning objectives that are no longer up-to-date should be covered by these tools and the capacities thus saved should be filled with modern learning objectives.
- Always remember the motto: "students learn from what they do!". The learning objectives, especially at higher taxonomy levels, can only be achieved with sustainability if the learners actively achieve these objectives themselves. As an example: The learning goal to be able to perform proofs/derivations by oneself cannot be achieved by teachers demonstrating proofs and learners only watching. It is therefore necessary to describe through which independent activities learners can achieve the learning objectives.
- The learning objectives should always be closely related to the subject of study, i.e. tasks in the context of an engineering course should always have a concrete reference to typical problems from engineering, for example. Also a distinction e.g. between civil engineering and mechanical engineering can be very helpful. Looking ahead to the following sections, it should already be mentioned here: The achievement of the highest competence levels is also and in particular based on applying, the closeness to reality ensures a far better motivation than (as far as possible) abstract examples.
- The learning objectives must always be auditable and ultimately also be audited by us. Learning objectives that are not part of the examination will not be achieved by the majority of students. On the contrary, we must make use of the examination in order to guarantee the achievement of the desired learning objectives through it. If the form of examination stands in the way of achieving meaningful and important learning goals, we must think critically about the usefulness of the form of examination used.

3 Taxonomy levels

The hierarchical structure and classification of learning objectives goes back to works such as [14, 15] and has been continuously developed. The approach taken here is fundamentally based on [16] and in particular on the extensions described in [17]. In the latter work, the so-called performance dimension is defined in terms of certain verbs. More precisely, these keywords define the respective taxonomy level as important tools for formulating learning goals, see Table 1.

Table 1: Overview of different taxonomy levels and associated terms as well as usable verbs to define learning objectives according to [17]

level	Cognitive process	Suitable verbs
1. Remember: Access relevant knowledge in long-term memory	recognize, remember	write, reproduce, list, describe, indicate, enumerate, name, draw, sketch, repeat, ...
2. Understand: Assign meaning to information from the learning unit	interpret, illustrate, classify, summarize, infer, compare, explain.	present, describe, discuss, explain, summarize, explain, repeat, ...
3. Apply: Perform or use a course of action (a scheme, a method) in a given situation.	Execute, Implement	perform, calculate, use, apply, solve, edit, ...
4. Analyze: Decompose learning content into its constructed elements and determine how they are interconnected to form an overarching structure or purpose	Differentiate, organize, assign	test, compare, select, distinguish, contrast, analyze, determine, examine, categorize., ...
5. Evaluate: Make judgments based on criteria or standards	Review, Evaluate	judge, argue, predict, choose, evaluate, justify, test, decide, criticize, assess, evaluate, conclude, ...
6. Create: Put elements together to form a coherent or functioning whole; Assemble elements into a new pattern or structure	Generate, plan, develop	construct, design, conceive, derive, develop, ...

4 Specific examples of implementation

In this section, two specific examples are given — one from mathematics and one from mechanics. In each case, several steps of an evolution from an inadequate to a satisfactory formulation are considered. The starting points are common and still widely used descriptions of the topics covered in the modules.

- Starting Point

  Mathematics:

  > *In this module, we cover Green's theorem.*

  Mechanics:

  > *In this module we cover basic principles of rigid body dynamics.*

  + There is nothing positive about these formulations in terms of didactics.
  − As already indicated above, only the main topics are listed, but no learning objectives. We teachers can intuitively deduce which knowledge, skills and competences could be connected with it or which we associate with it from a subjective point of view. However, this is impossible for learners, even if technical terms are already known. On the other hand, such subjective assessments of learning goals on the part of teachers are also never unambiguous. In this context, imagine that a course is passed on to another person: Is it then clear to this person what exactly the learning objectives of the course are and what the focus should be? Is this always only clear from the documents and teaching material used? At the end of this section, please ask yourself whether you would have linked the learning objectives listed there directly and explicitly to the topics mentioned here. However, we would like to point out that this form of describing learning objectives is neither helpful for learners nor for teachers.

- Step 1

  The first step is in the direction of learning activities, which could be achieved by the following formulation.

  Mathematics:

  > *This module teaches the derivation of Green's theorem as a special case of Stokes' theorem. The students also learn to apply Green's theorem independently to problems.*

Mechanics:

> *This module teaches the importance of the fundamental principles of dynamics such as the force theorem and twist theorem. The students also learn to apply these principles independently to problems.*

+ On the positive side, it is at least somewhat clearer what learners can expect and what they should "do" with the content/topics addressed.

− It is still formulated far too vaguely what exactly the application entails. In addition, it is not addressed what purpose this application serves. Related skills and competencies are not specified, so the description of the learning objectives is still inadequate.

  In general, it can still be noted that formulations such as "will be taught" or "The students learn" should be avoided at all costs. Learning is a complex process that teachers can only influence indirectly. So to claim here that we teach these aspects and students learn them is too daring. Our task as teachers is to enable, facilitate and promote learning processes and their initiation.

- Step 2

  In the next step, skills and competencies are specifically addressed and the above claims ("is taught", "students learn") are also weakened.

  Mathematics:

> *After successful participation in this module, students will be able to reproduce Stokes' theorem and Green's theorem by heart. Furthermore, the students are able to derive Green's theorem as a special case of Stokes' theorem. Furthermore, students will be able to calculate the zero-, first-, and second-order moments of given areas both as a surface integral and using Green's theorem as a boundary integral. This includes, in preparation for integration, the skill of choosing appropriate variables and parameterization for each boundary as a function of those variables. Finally, the students are able to compare the different solution methods, to find out advantages and disadvantages and to judge independently which of the methods is to be preferred in different application cases.*

Mechanics:

> *After successful participation in this module, students will be able to name the basic principles of dynamics and explain their importance for solving engineering problems. By applying these principles, students will be able to independently derive equations of motion for systems and solve them to understand the motion of these systems. In addition, students will be able to calculate the reaction forces that occur in the system, and evaluate them in terms of ultimate limit states. Finally, based on these analyses, students are able to draw conclusions regarding possible and possibly necessary adjustments to the underlying systems and to optimize them.*

+ In this formulation, it is clear what students are capable of doing. This is done by using the keywords "reproduce", "derive", "calculate", "use", "choose", "compare", "find out", "judge", "name", "explain", "apply", "solve", "understand", "evaluate", "draw conclusions" and "optimize" also clear at which level of competence this is done in each case, compare Table 1. In addition, at least in the example for mechanics, the big picture of the entire module can be found, namely the design and optimization of systems.

As a text for module descriptions, this form of describing learning objectives seems to be sufficient in principle. If necessary, the description should be kept shorter and the learning objectives should be filtered.

– The mixed formulations used should be avoided because, for example, deriving equations, solving them, and tracing the resulting motion fundamentally describe learning objectives at different levels. The same applies to the following sentence ("calculate reaction forces" and "assess them"). This makes it difficult to clearly decide whether the learning objective has been achieved.

  It also remains open through which specific activities students acquire the skills and competencies.

  If you are bothered by the repeated use of the phrase "are able to", you are of course welcome to use alternative but equivalent phrases or a listing of the points after the introductory phrase "After successful participation in this module, students are able to,".

- Step 3

  In the next step, the learning objectives are expanded to include the respective learning activities. This usually leads to rather long formulations, which may be too long for overviews in module descriptions. As a basis for your own learning event, however, the learning objectives should be prepared in this form and also communicated transparently to the students.

  Mathematics:

  Upon successful completion of this module, students will be able to ...

  – *reproduce Stokes' theorem and Green's theorem by heart, applying them independently (as described below) to various problems.*
  – *reproduce the derivation of Green's theorem as a special case of Stokes' theorem by reproducing and explaining given and detailed derivations step by step.*
  – *select suitable variables in the context of the application of Green's theorem and, on this basis, carry out the parameterization of the boundary of given areas. To do this, students implement the appropriate equations in the program* MATHEMATICA *and create a drawing of the area's edge.*
  – *calculate the zero-, first-, and second-order moments of the given areas both as a surface integral and using Green's theorem as a boundary integral. To do this, students make hand calculations of the surface and equivalent boundary integrals.*
  – *find out the advantages and disadvantages of calculating the moments of area using surface or boundary integrals. To do this, students implement the calculation of*

boundary integrals in addition to hand calculations using MATHEMATICA. *Through comparisons, students are then able to choose one of the approaches based on the context.*

Mechanics:

Upon successful completion of this module, students will be able to ...

- *independently derive equations of motion for systems by applying the balance of linear and angular momentum to given systems and thus derive the respective differential equation of motion.*
- *determine the functions of the degrees of freedom depending on time for different systems by comparing them with the given general solution.*
- *visually trace the motion of these systems. To do this, students make diagrams of the previously determined functions using the Python programming language and also independently create programs, also in Python, to animate the motion of various systems.*
- *calculate the reaction forces occurring in the system by independently defining subsystems using the principle of intersection and applying the balance of linear and angular momentum to them.*
- *assess the load-bearing capacity of the systems. To do this, students calculate the mechanical stresses in the various or relevant elements of the system on the basis of the previously determined reaction forces and compare these with the specified maximum admissible stresses.*
- *Optimally design systems with regard to common criteria in engineering. For this purpose, the students first define the respective objective function and, if necessary, associated restrictions. Subsequently, the students independently calculate analytical solutions for selected system parameters in terms of mathematical optimization.*

+ These are sophisticated and goal-oriented formulations of learning objectives.

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Below are some additional examples that we have taken from current module descriptions. The aim here is that you, as a reader, recognize independently the extent to which these descriptions may be inadequate and that you can judge them on this basis. We ask for your understanding that we do not name the sources here.

- “Students learn the central concepts of linear algebra as well as the basics of sequences and series.”
- “After successful participation in this module, students are able to systematically approach and analyze technical problems.”
- “Students will be able to work with a 3D system.”
- “Students will learn the fundamentals of linear algebra.”
- “Students will gain insight into the fundamentals of the finite element method.”

5 Conclusion and outlook

The demands on mathematicians and engineers in the profession are monotonously increasing, novel methods have long since found their way into everyday and professional life. A current and particularly representative example of this are data-based methods and advances in the field of artificial intelligence (AI), e.g. using neural networks. The study program must meet these new requirements with a contemporary education. The first step in this process is the didactically sophisticated definition of learning objectives, for which this report is intended to provide impetus and a guideline. Learning objectives form the foundation of a learning event: Without the clear definition of learning objectives, we teachers are in principle unable to give our event a common thread and a big picture. Accordingly, the learners do not recognize this red thread and the big picture either, and urgently needed learning objectives cannot be achieved by the majority of the students.

Beyond the definition of learning objectives, further concepts must be taken into account and applied in order to ensure up-to-date and competence-oriented education. These include, in particular, “Constructive Alignment”, which, in addition to the reasonably defined learning objectives, also explicitly takes into account the implementation of the teaching and learning activities necessary to achieve these learning objectives, as well as the implementation of continuous learning assessments. Within the framework of this concept, further questions arise quasi automatically, e.g. regarding didactically appropriate and competence-oriented forms of examination. These are the next steps in the conception of a didactically sophisticated learning event, which we will examine and discuss in more detail in the further course of our activities.

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