What is competence in a technical perception and how can we develop it?

TECHNISCHE UNIVERSITÄT DARMSTADT

The question of what competence is, is, of course, debatable. In fact, so far there is no binding definition, no generally accepted concept, no theoretical construct. In educational sciences, we have agreed upon the fact that in terms of theory, competence is a relative term. In other words, competence is what one defines as competence in a particular case. However, it is understood that competence has something to do with the capacity to act. A person is competent when he or she acts in a meaningful way.

Within the frame of this convention, there are diverse but equally legitimate approaches to the concept of competence. This is because the reasons for meaningful acting can be diverse. For instance, someone who has been trained in a particular course of action is competent. Or someone who is able to control a complex course of action independently is competent. Or someone who is able to act effectively in complex, problematic situations is competent. Or someone who is able to further develop their capacity to act independently is competent.

If we compare the Anglo-American concept of competence with the German one, we can make out a significant difference: While Anglo-American approaches to competence focus on the outcome of action, German approaches rather focus on controlling action, they focus on the cognitive processes involved. However, in the end both is equally important, since good outcomes can only result from being able to control the action properly.

At present, the relation of outcome on the one hand and action control on the other hand, is the real scientific challenge. In contrast to machines and systems, we have neither been able to find an analytical, nor an empirical explanation. In this context, we speak of emergence. This means that there is a meaningful relation of one's disposition and the outcome of action. However, so far we have failed to explain this phenomenon in detail in either direction. To give an example, similar dispositions of two people can result in highly distinct outcomes of action. Then again, two relatively similar outcomes of action can result from highly distinct dispositional arrangements.

Regardless of this uncertainty, empirical findings show that there are certifiable connections between outcome and action control. Case 1: If activities are mainly characterized by dexterity and routine, they demand psychomotoric rather than cognitive dispositions. Here, one learns through simple imitation and practice. Case 2: If activities are characterized by both dexterity and internal decision-making processes, they demand psychomotoric as well as simple cognitive dispositions. Here, one learns through imitation and

Fachbereich Humanwissenschaften
Arbeitsbereich Technikdidaktik

Technikdidaktik

Prof. Dr. Ralf Tenberg

Alexanderstraße 6
64283 Darmstadt

Tel. +49 6151 16 - 6832
Fax +49 6151 16 – 6844
www.td.tu-darmstadt.de
tenberg@td.tu-darmstadt.de

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practice. Case 3: If activities are mainly characterized by complex processes of analysis and decision-making, they demand complex cognitive dispositions. Here, one learns through reflected problem-solving.

In Germany at the beginning of the twentieth century, there was a wide gap between these activities. Academics were nearly completely to be found in field number 3, non-academics almost exclusively in field number 1, the reason being a general low level of education in society and taylorized mass production. Until the end of the twentieth century, this changed quickly among non-academics. Responsible for this change were education offensives and higher flexibility in the production sector. Due to the outsourcing of mass production in low-wage countries and the rising dominance of robotics, activities according to case 1 have decreased significantly in Germany. Predictably, they will soon die out in the German industry. In contrast, activities according to case 3, or rather, mixed forms of case 2 and 3 are on the increase, due to the so-called computerization and informatization. Because of the spread of fast and easily accessible information systems, professions and activities that were formerly characterized by manual work have slowly been enriched with knowledge work.

An aircraft mechanic for example spends more time on information acquisition, analysis and integration than on the operational implementation in the aircraft. In addition, the current spread of cyber-physical systems, both inside and outside of production, needs to be considered. Activities remaining there have high demands with regard to approaching and understanding these semi-autonomous systems and their momentum.

It is therefore obvious that now and in the near future there are important activities that, on the one hand, require immediate, concrete action in technical systems and that, on the other hand, require enormous cognitive abilities.

Let us again turn to the example of the service mechanic. In the United States, people who aim at this profession need to go to college. In Germany, people have to undergo a vocational training. In both cases, it is essential that students learn very similar competences on an extremely high level. They need to be successful, because what is at stake here is nothing less than the passengers' safety.

In both cases – as elaborated earlier – students need to acquire both knowledge and the capacity to act. In the following I would like to further elaborate on this against the background of competence theory:

The starting point of whatever kind of expertise is always breaking new ground. At the beginning, we have to learn theory that we are unable to assign, and we practice things whose background and context we can hardly understand. And yet, these very first steps are highly important, because they prepare us for the development of competences that has started and that will accompany us throughout our career. Continuous reflection is the motor of technical competence development in both theory and practice, and especially with regard to their dynamics. I do something differently if I understand it, or rather, I can better understand those things that I have already done. The further developed the competences, the more demanding the action and, therewith, its understanding. Errors occur either when somebody acts according to the principle of trial and error, or when someone gets information that he or she cannot turn into action (so-called "inert knowledge").

Whether or not competence development stops at this point or continues, depends on the person's reflection processes. At the starting point, learners might still be able to establish certain connections. Later on, however, learners cannot make these connections so easily anymore. Then, they rely on learning support. For instance, professionally correcting an interference within a technical system, requires the system's comprehensive understanding right from the start. One needs to know its individual components, functions, working processes, regulation processes, and intervention processes in case of error. Furthermore, varied experience in dealing with such systems and its components is required, that is, how to orient oneself; how to act within the system; what to consider; what could go wrong …

If one thing or another is missing, the defect cannot be recognized; or it will be falsely interpreted; or its actual cause cannot be understood; or the correction of the defect is based on inappropriate measures. We have to consider that – sooner or later – our learners make such mistakes. Consequently, avoiding the mistake would mean that the error is corrected. However, in such a case of avoidance we must assume that leaners could not really learn how to solve the problem. This is why demanding learning environments for competence development have to allow for such errors. In fact, they must trigger them, because they are the lynchpin for demanding competence development. Learners must have the chance to realize their mistakes and to resolve them in concrete contexts, thereby working on their knowledge gaps and their deficits in understanding. Moreover, learners must understand the principle of one case being representative of others; they must understand that one situation is exemplary of others and that problem-solving can work across similar situations. This way, learners are prepared for knowledge transfer in the future. Subsequently, learners should have the chance to test different solution options without running the risk of causing damage. When learners attempt to test new solutions in technical learning environments, they might have to face difficulties that only show in the actual process. This way, learning loops between theory and practice as well as understanding and applying are created.

Adequate learning environments not only provide the necessary scope of action and approaches to theory. More than that, they give constant feedback to learners, and they assist them whenever they can no longer progress.

The learning factory is such an adequate learning environment. This by now well-established concept of the learning factory facilitates technology-oriented and demanding competence development. It clearly has its strengths when it comes to creating a shielded room for development wherein working realities are authentically represented. Also, it allows for alternating between theory and practice in the learning process. If attempting to further enhance these learning environments, the aforementioned 5 key aspects of competence development prove helpful:

1. The higher the authenticity of learning factories, the higher the level of competences learners can develop.
2. The better the access to technology, the lower the risk of causing damage and the more self-dependent the learning.
3. The more encompassing, immediate, and understandable the system's feedback, the better can learners coordinate their learning actions.
4. The more relevant, up-to-date, encompassing, and accessible the theoretical information, the more productively can the learners alternate between understanding and applying.
5. The better the teaching staff in learning factories understand the processes of competence development, the better can they support the learners within the learning formats and come up with new formats.