



Use of concept maps in university education in the field of control technology

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Abstract

In the context of this study $n = 16$ students in the diploma program in mechanical engineering created concept maps on the content of the lecture previously given in the module "Control of Production Machines and Systems". The concept maps were then evaluated according to three criteria described in more detail here. As a basis for the evaluation of the individual concept maps, they were compared with a reference map prepared by three experts in the field of mechatronics within the scope of this study. Immediately after the creation of the maps, the students answered a questionnaire that included demographic data as well as a self-assessment survey on concept mapping. The 10 items of this sheet are assigned to the subject characteristics interestingness, usefulness and manageability. The subject characteristics and evaluation criteria were examined for initial dependencies. The tendency showed that the students generally evaluate the method of concept mapping as positive, despite first-time application and shortened introduction.

Im Rahmen dieser Studie erstellten $n = 16$ Studierende, im Diplomstudiengang Maschinenbau, Concept Maps (Cmaps) zum Inhalt der zuvor gehaltenen Vorlesung im Modul "Steuerung von Produktionsmaschinen und Anlagen". Die Cmaps wurden anschließend nach drei hier näher beschriebenen Kriterien bewertet. Als Grundlage für die Bewertung der einzelnen Cmaps, wurden diese mit einer Referenzmap verglichen, die von drei Experten auf dem Gebiet der Mechatronik im Rahmen dieser Studie angefertigt wurde. Unmittelbar nach der Erstellung der Cmaps beantworteten die Studierenden einen Fragenkatalog, der neben demografischen Daten auch einen Selbsteinschätzungsbogen zum Concept Mapping umfasst. Die 10 Items dieses Bogens werden den Probandenmerkmalen Interessantheit, Nützlichkeit und Handhabbarkeit zugeordnet. Die Probandenmerkmale und Bewertungskriterien wurden auf erste Abhängigkeiten untersucht. In der Tendenz zeigte sich, dass die Studierenden die Methode des Concept Mapping, trotz erstmaliger Anwendung und verkürzter Einführung, generell als positiv bewerten.

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1. Introduction and problem definition

During the ongoing digital transformation in manufacturing companies towards "Industry 4.0", engineers in the field of mechatronics are faced with the challenge of dealing with increasingly complex technical machines and systems in their professional work [1]. In addition to working on the devices themselves, the focus is on the physical and virtual networking of the individual technical components and stations. This makes it necessary not to view the systems in isolation, but rather to understand them as an interconnected overall system [2]. The authors Spöttl et al. interviewed personnel in companies in the metal and electrical industry and found that "skilled workers [...] think and optimize systems and their function from the point of view of processes and software. This requires a completely different understanding than was necessary for mechanically and electrically operated systems" [3].

The technical focus of this study is on *the digital twin*, which is becoming increasingly important as an enabler in the construction and design process, in the commissioning of cyber-physical production systems and in their operation. [4]. It serves as a digital image of reality, usually with bidirectional data exchange between the real and digital systems, and can be created and used for processes, products, plant components or entire factories [5]. However, the term itself is not clearly defined, which is why there are always misunderstandings in interdisciplinary collaboration when dealing with the term, as well as associated terms such as "model", "simulation" and others.

Within the university education of prospective engineers in the field of control technology at the Technical University of Dresden, the necessary specialist content and skills are taught in lectures, followed by in-depth study in seminars and assessment at the end of the semester by means of written examinations. As a result, both the lecturers and the students themselves receive little information about the current level of knowledge during the semester, for example to enable the lecturers to adapt the course sequences/content of the

courses and the students to adapt their individual learning focus.

This study examines the potential of concept mapping for deepening and reflecting on the content of lectures using the example of the "digital twin". In contrast to many other methods for capturing knowledge, the use of concept maps offers the advantage that not only isolated factual knowledge but also conceptual overview knowledge can be captured [6].

2. Technical background to the digital twin

The digital twin (DT) is one of the technologies that have found their way into the manufacturing industry with digitalization and is counted among the Industry 4.0 technologies. It belongs to the field of modeling technical systems and describes a digital model of a system that is in a bidirectional, automatic data exchange with its physical counterpart (production system, plant, product, process). In contrast to this, the digital shadow (DS) only has an automatic data flow from the physical to the digital object, making the DT an extension of the DS. Depending on the use case and the need for information processing that the DT is to perform, it can contain a functional, behavioral or structural model or a combination of the aforementioned model types.

In general, the DT is used to solve problems or to investigate the effect of operations that are not appropriate, not possible, or too dangerous on the original. In these cases, one speaks of a simulation.

The ability to carry out tests (simulations) on the DT without the need for hardware and very quickly makes it ideal for feasibility analyses, variant investigations, and studies, analyzing interactions between machine and process and pre-commissioning production systems, which is also known as virtual commissioning (VIBN). In the operating phase, the DT can be used for the "virtual measurement" of non-measurable physical variables or production-parallel optimization of the process.

3. Theoretical background and state of research on concept mapping

Concept maps are two-dimensional networks of terms that are usually used to answer a focus question or problem. The task when creating the maps is to link different terms, referred to below as "concepts", with each other in such a way that as many correct statements as possible are created [7]. For this purpose, the concepts can be arranged arbitrarily on the map and connected to each other with arrows if the two terms are related according to the creator's idea. These arrows are then labeled with "relations" to specify the contextual connection between the concepts. Each directed arrow and the labeling then result in a statement known as a "preposition" in the form of a group of words or a sentence. For the example in Figure 1, the following three prepositions result:

- "Simulation enables virtual commissioning",
- "Simulation works with functional model" and
- "Simulation works with behavioral model".

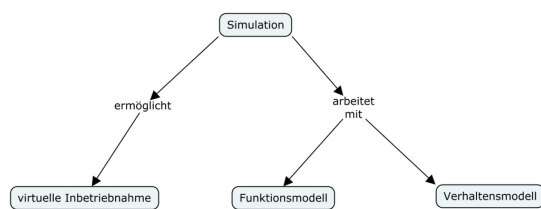


Fig. 1: A section of the reference map created as part of this study is shown.

The origins of this method were first published by Stewart, Van Kirk and Rowell [8], who created a concept network for the article in the journal *The American Biology Teacher* and presented it to the scientific community as a "concept map". Initially, these networks only consisted of terms connected by dashes without arrow connections. As a result, it was impossible to form prepositions and closer analyses of individual concept maps were only possible to a limited extent. One article that significantly advanced concept mapping in relation to the present day was by Joseph D. Novak [9], the then Professor of Education and Biological Sci-

ences at Cornell University, who has always been one of the most important researchers in this field. In the aforementioned article, the concept maps contained directed and labeled arrows for the first time, making it possible to read out meaningful groups of words or sentences. According to his own statement, Novak developed concept mapping as early as 1972 together with students when they were looking for a way to analyze Ausubel's [10, 11] "assimilation theory". Looking for a way to better represent "what the learner already knows" better [12]. The *Novakian concept maps* spread across the entire planet from this point onwards, with *Learning how to learn* [13] considered one of the most important early contributions to the field. Since then, the method has become increasingly popular and has been used in many studies, examined in more detail and constantly expanded. For in-depth literature on changes over time in the creation of concept maps, please refer to the article *Varieties of concept mapping* by Mauri Åhlberg [14], who was able to identify ten elements for improving the method compared to the original article by Novak and Gowin [13] in his literature research.

Since the late 1970s and early 1980s, the concept mapping method has been used in a wide variety of research and teaching applications. The main areas of application are:

- as a means of knowledge diagnostics in scientific studies,
- as a teaching method in the teaching-learning process,
- as a feedback method for teachers and learners and
- as an assessment tool.

The meta-analysis conducted by Schröder, Nesbit, Anguiano and Adesope [15], in which experimental studies on concept mapping from 1972 to 2014 were examined in more detail regarding learning success, the mean effect size for concept mapping showed a mean positive effect ($g = 0.58$) in favor of learning activities with concept maps. Additional results that are particularly relevant for use in university education are that the effect is greater if the students create the concept maps themselves ($g = 0.72$) instead of working with ready-made maps ($g = 0.43$ for students

and pupils in grades 4 to 12 and $g = 0.32$ especially for students), if the method is used regularly ($g = 0.36$ before and $g = 0.68$ after a week) and that the effect is independent of whether the topic of the concept map is STEM or non-STEM [16].

The use of concept mapping as a feedback method in university education has also been evaluated positively in various studies. For example, the studies by Daley and Torre [17] in the field of medicine, Becker et al. medicine, Becker et al [18] in biology, Joseph et al [19] in physiotherapy, Lachner et al [20] in the field of educational science and Vodovozov and Raud [21] in the field of power electronics.

For use as a diagnostic tool, feedback method and assessment instrument, it must be possible to evaluate the concept maps according to previously defined criteria. In his article, Graf distinguishes between the following evaluation methods [22]:

- global evaluation strategy according to Novak,
- Differential diagnosis of individual terms,
- Aspects of graph theory and
- Comparison with a reference map.

The following table shows which parameters of a concept map are considered in the respective evaluation method used.

These are: *hierarchical organization* (1); *interconnectedness* (2); *structuredness* (3); *degree of interconnectedness* (4); *scope/richness* (5); *linkage density* (6); *fissuredness* (7) and *correspondence coefficients* (8).

Table 1: Comparison of the different concept mapping methods according to Graf

	1	2	3	4	5	6	7	8
Novak	X	X	X					
Differential diagnosis				X	X			
Graph-theor. aspects					X	X	X	
Expert map								X

Graf deduces from this that although the evaluation according to Novak, the examination according to graph-theoretical aspects and the comparison with a reference map created by experts examine different parameters in detail, the focus is on the overall assessment of the concept map, whereby the content of statements made is not considered. In the differential diagnosis of individual terms, on the other hand, the focus is exclusively on analyzing the statements made, which result from the concepts, the direction of the arrow and the preposition and can be technically correct or incorrect. It becomes clear that the methods must be combined to ensure a holistic evaluation of the concept maps, taking into account as many of the parameters as possible.

Important factors to consider when creating a concept map are general guidelines for the structure. Firstly, the maximum number of concepts and secondly, the individual design of the structure of the concept network should be defined. Research results show that a maximum number of 15 to 25 concepts per concept network should not be exceeded in order to ensure clarity in the concept map [23]. In the area of Industry 4.0 and cyber-physical production systems, there have not yet been any experimental studies on the use of concept mapping in engineering education. This justifies the need for studies to be carried out in this area.

4. Research questions

Derived from the previous chapters, the following research questions arise, which are to be answered in the context of the article be answered in this article:

- (1) How do students rate the concept mapping method regarding the test subject characteristics of *interest*, *usefulness*, and *manageability*?
- (2) In which courses do students consider the concept mapping method to be useful?
- (3) What differences are there between the reference map created by experts as part of the study and the novice concept maps created by the students?

5. Research design

The data was collected as part of the second lecture in the module "Control of production machines and systems" on the topic of "Information processing and digital twin".

The study involved $n = 16$ students on the mechanical engineering degree course. Within the first 65 minutes of the 90 minutes course, subject-specific content was taught in a content was taught in a more traditional teaching-learning format. This was followed by a short five-minute introduction based on the *concept mapping training program* by Sumfleth et al [24] to familiarize the students with the method. In the remaining 20 minutes, the students created the concept map with pen on paper and answered the self-assessment questionnaire.

Due to the limited time span of 90 minutes, the training program had to be shortened so that all the subject content relevant to the creation of the concept map could be taught and the students still had enough time to create the concept map and complete the questionnaire. Ten concepts were specified for the concept map about the focus question "How do the following terms relate to the topic of digital twins?". The number of concepts was set at ten to reduce complexity. This was intended to avoid potentially overwhelming the students due to an excessively high number of given terms was to be minimized. In order not to inhibit the participants' creativity and since no special structuring options are presented in the concept mapping training program, it was decided that the concepts could be arranged in any order and related to each other with arbitrary relationships. arbitrary relations to each other.

The following ten terms were jointly selected by the three experts in line with the lecture content:

Model, system, digital model, structural model, behavioral model, functional model, digital twin, digital shadow, virtual commissioning, simulation.

As part of the study, an evaluation procedure was used in which each concept map was analyzed and concept map is analyzed and evalu-

ated according to three criteria. Each evaluation criterion can have a value of 0 to 1 whereby the higher the respective values, the better the result. Based on the findings of McClure et al [25] regarding the reliability of the evaluation of concept maps, a reference map was created and used for the evaluation. To this end, three experts in the field of mechatronics, two university lecturers and one vocational schoolteacher, initially each created a concept map independently of one another. The guidelines were identical to those that the students had to follow. The concept maps were then presented to the other experts one after the other and they then jointly created the concept map shown in Figure 2 using the freely available program *CmapTools*. The advantages of this software tool are described in explained in more detail in the work of Cañas et al [26].

The individual evaluation criteria are listed in more detail below:

(1) *Scope/interconnectedness* x_{UV} :

This value indicates the degree of cross-linking of the concept map in relation to the reference map. For this purpose, the total number of arrow connections $n_{\bar{U}}$ that match those of the reference map is compared to the total number

$$x_{UV} = \frac{n_{\bar{U}}}{n_{Ref}} \quad (1)$$

of connections of the reference map n_{Ref} is set.

(2) *Degree of compliance* x_{UG} :

The next step is to examine how many of the total number of arrow connections in the concept map created by the test subjects match those in the reference map. To do this, the matching connections are compared

$$x_{UG} = \frac{n_{\bar{U}}}{n_V} \quad (2)$$

to the total number n_V of connections made.

The criteria scope/interconnectedness and degree of conformity are independent of the selected relations and therefore do not consider the content-related connections between the concepts. As the two values are directly related, they are also multiplied together, resulting in x_{Str} a measure of the general *structuredness* of the concept map:

$$x_{Str} = x_{UV} \cdot x_{UG} \quad (3)$$

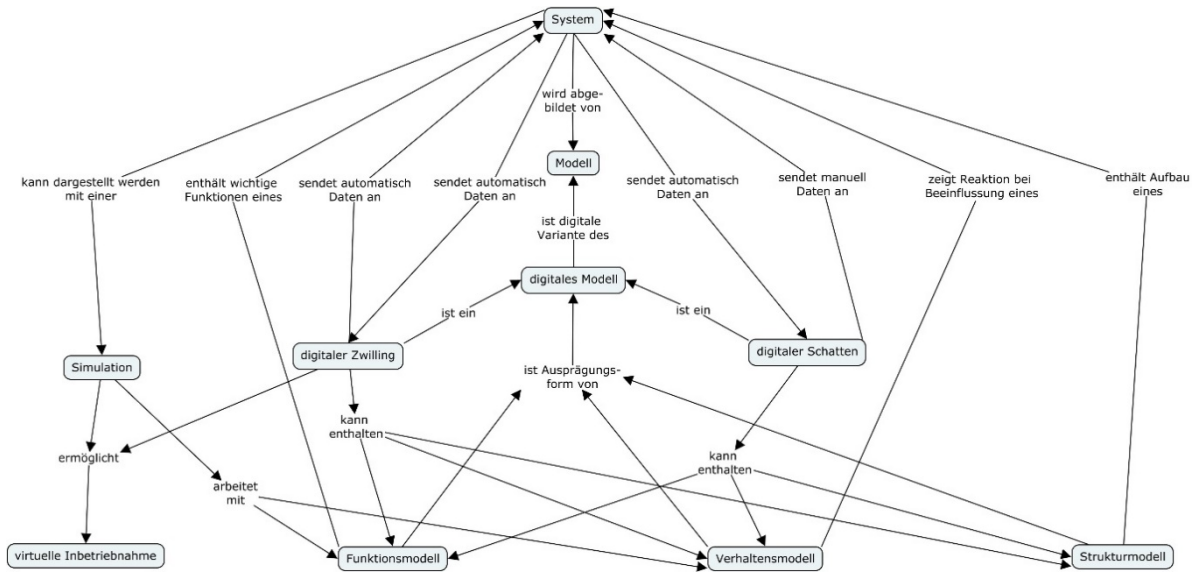


Fig. 2: The illustration shows the concept map on the topic of the "digital twin", which was created by three experts and serves as a reference map for the study. The CmapTools program was used to create the map.

(3) Consistency of content $x_{IÜ}$:

The relations of the matching arrow connections are then checked for professional correctness by matching them with the reference map. The value for $x_{IÜ}$ results from the ratio

$$x_{IÜ} = \frac{n_{IÜ}}{n_{Ü}} \quad (4)$$

of the total number of technically correct cross-connections $n_{IÜ}$ to $n_{Ü}$.

The use of these three evaluation criteria is intended to ensure that as many of Graf's parameters as possible are considered in the evaluation.

For the self-assessment questionnaire, the sub-questionnaire for assessing concept mapping was used, based on the study by Ryssel [27]. The possible answers to the 10 items are coded with numbers ("strongly disagree" = 1 "strongly disagree" = 2, "somewhat true = 3" and "strongly agree" = 4), assigned to the respondent characteristics *interestingness*, *manageability* and *usefulness* and then transferred to the SPSS program. The negatively polarized answers are converted beforehand. Assuming an ordinal scale, the mode and median for the individual respondent characteristics can be calculated from the data set.

The questionnaire also included the age, gender, and previous knowledge of concept mapping were also recorded in the questionnaire, as well as possible areas of application for the

concept mapping method in university engineering education.

6. Evaluation

The socio-demographic attributes of age and gender recorded in the questionnaire, as well as the proportion of students who have already worked with the concept mapping method, are shown in Table 2. It should be emphasized that the proportion of female students with 18.8 % is very low and only 12.5 % of the students had previous experience with concept mapping.

Table 2: Descriptive description of the participants

Attribute	Students
Quantity	16
Age	24.4 a
Participants	18.8 %
Experienced in concept mapping	12.5 %

The first research question was investigated by means of a self-assessment questionnaire, which had to be completed immediately after the creation of the concept map. From the available data, the mode and median were determined for the subject characteristics from the available data (Table 3). The characteristics *usefulness* and *interestingness*, with values > 2.5 as positive ("rather true") and *manageability*

The results of the evaluation are shown in Figure 5 for the individual evaluation criteria in the form of a box plot.

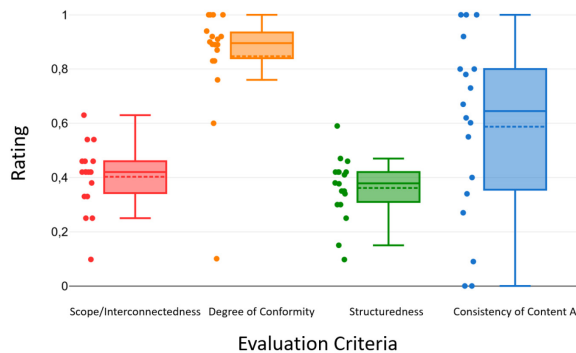


Fig. 5: The evaluation results for the respective criteria are shown in the form of a box plot.

For the criterion *scope/interconnectedness*, the mean value was 0.42 with a standard deviation of 0.1. The students thus made an average of 10.1 ± 2.3 arrow connections, which correspond to those chosen by the experts.

The *degree of conformity* resulted in a mean value of 0.89 also with a standard deviation of 0.1. From this it can be deduced that on average only 11 % of the arrow connections made by the students do not match those from the expert map.

In order to exclude extremes such as for example, to connect all terms with arrows ($x_{UV} = 1.0$) or only making an obvious arrow connection ($x_{UG} = 1.0$) are rated as positive, both criteria should always be set in relation to each other in order to be able to evaluate the structure of the concept map as a whole. For the combined criterion of *structuredness*, a mean value of 0.38 with $s = 0.1$.

Due to the high scatter ($n = 3$ subjects with the value 1 and $n = 3$ subjects with values < 0.1) and a large standard deviation of 0.34 for the criterion of *consistency of content A*, the value of *consistency of content B* was also determined (Figure 6). This was done under the assumption that students from whose concept maps no preposition formation was possible for less than 33% of the of the arrow connections made, because they either had no arrow direction and/or no relations were present, had comprehension problems when implementing the concept mapping method or linguistic problems when formulating the prepositions.

For *consistency of content B*, the four students in question were not considered. Under this assumption, the standard deviation could be reduced by 47 % to $s = 0,18$ could be reduced by this assumption.

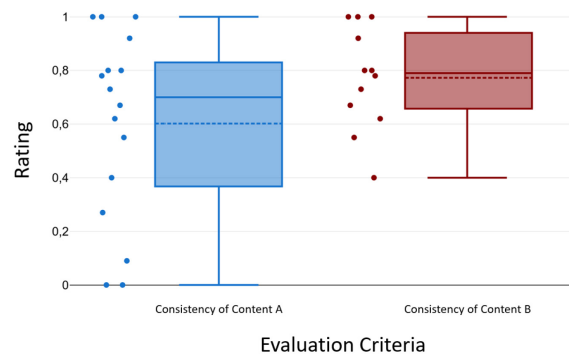


Fig. 6: The evaluation criterion Content match B results from the reduced sample.

For the criterion of *consistency of content A*, the mean value was 0.60. Considering the results of the criterion *scope/interconnectedness*, the students thus formed an average of 6.1 correct relations per concept map. For the reduced sample, the value for *consistency of content B* was 0.77. Based on the assumption made above, it can be that students who were able to internalize the method formed an average of 7.8 correct relations.

7. Discussion/Limitation/Outlook

This study has shown that the use of concept maps in the field of control technology has great potential. To this end, 16 students each created a concept map on the complex topic of digital twins, which were then evaluated by comparing each map with a reference map created by experts according to the three evaluation criteria described here: *scope/interconnectedness*, *degree of conformity* and *consistency of content*.

The evaluation showed that an average concept map of the students has 11.3 arrow connections, of which 10.1 match the reference map and per map 6.1 (7.8 with a reduced sample for the *content match* criterion) can form technically correct prepositions.

In addition, a questionnaire on the assessment of concept mapping, which had to be completed directly to be completed directly after

the concept map was created, showed that students find the method interesting and useful. More than half of the students were able to name specific areas of application for university engineering education. The manageability of the method was rated below average, which could be improved, for example, by a more intensive introduction and/or regular use.

In the following, further studies in this area, due to the small sample of students $n = 16$ students will be necessary to verify or falsify the results of the study. Only then will it be possible to derive concrete recommendations for action regarding the use of concept mapping in the university education of engineers in the field of control technology. Initial results are also promising results on the use of concept maps by prospective mechatronics engineers as part of vocational school lessons are also promising [28]. Increased work with digital tools (e.g. *CmapTools*) is also very well suited, for example, to develop an automated evaluation procedure that can be use of automatic image recognition.

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