Development of Multidisciplinary Digital Competencies to Prepare Technical Vocational Students for Industry 4.0

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Abstract

In Industry 4.0 (so named in reference to the three preceding industrial revolutions), real-time data transmission connects the stakeholders of industrial production chains not only horizontally, but also vertically. Due to this networking, one no longer speaks of mere production chains that tie the suppliers with the final production, but of so-called value-added networks. These networks enable the production of goods in “batch size one”, i.e. individual items at the price of mass-produced ones, through intelligent control systems. While the term “Industry 4.0” originated in Germany, the flexibility it refers to has also become an important element for business and science beyond German-speaking countries. The increasing interconnectedness offers customers an individualization of their desired product with a high quality and at an affordable price.

However, the smoothly interconnected processes required for this also increase the complexity of production. This complexity also affects jobs and job-related tasks. These will undergo change, because numerous tasks, depending on the profession, will be eliminated and new ones added. One consequence of this will be that the job-related competencies of employees will also have to change, depending on the substitutability of the respective job-related tasks. At present, the transformation of production chains into Industry 4.0 value-added networks is still mostly of a conceptual nature. Nevertheless, it can be assumed that the manufacturing and technical professions in production will be the first affected by the changing requirements.

As a result of increasing interconnectedness, the demand for multidisciplinary competencies is increasing, especially for technical tasks. Furthermore, many of the classic work tasks are shifting to the digital context, which means that digital competencies are increasingly needed in addition to job-specific and technical competencies. The first research question was addressed in this thesis is therefore which multidisciplinary digital competencies technical vocational students should possess in the future in order to be adequately prepared for the requirements of Industry 4.0. In order to promote the necessary competence development of technical vocational students, so-called Learning Factories 4.0 were implemented in vocational schools in Baden-Wuerttemberg. These are model-like, interconnected industrial production facilities and can represent batch size one production with all the consequences and necessary interfaces. This led to the second research question, namely whether Learning Factories 4.0 can support the desired development of competencies among technical vocational students.

To provide a valid answer to these research questions, an explorative mixed-method research design was chosen for this dissertation. Based on theoretical assumptions, two qualitative studies were conducted in which both corporate instructors (study 1) and technical vocational teachers (study 2) were asked which multidisciplinary digital competencies, in addition to their technical competencies, will be important for technical vocational students in the future. The following central competence dimensions were formed from the respective responses: *attitude towards digitization*, *handling of digital devices*, *Information Literacy*, *application of digital security*, *usage of copyright*, *collaboration*, *problem solving* and *self-reflection* in a digital context. These competency dimensions and their interrelationships were then empirically tested and modified through a quantitative study using a structural equation model (study 3), confirming attitudes towards digitization as a predictor of the conceptual model of multidisciplinary digital competencies. Finally, the development of competencies through the support of Learning Factories 4.0 in vocational schools was investigated (study 4). The results indicate that subject-related technical competencies develop significantly better through the support of Learning Factories 4.0 than without the use of these learning environments.

The model of multidisciplinary digital competencies should be understood as a conceptual model in the context of German technical dual education and training that complements the models of digital competencies and 21st century skills. Therefore, this dissertation provides a complementary contribution to a hitherto insufficiently researched field of digital competence research and the integration of Learning Factory 4.0 in technical vocational training. Practical implications for technical training can be derived from the results of the conducted studies. By systematically integrating multidisciplinary digital competencies into the respective vocational training, technical vocational students could be better prepared for the requirements of interconnected working in Industry 4.0. In this matter, and in the research area of Learning Factories 4.0 at vocational schools, this dissertation offers further research ideas for future studies in order to expand the scientific evidence of these technology-based instructional systems and thus to promote the development of competencies. Due to the different limitations of the individual studies, suggestions for possible avenues of further research are provided. The findings are discussed and practical implications are derived from them in this dissertation.

Zusammenfassung

In der Industrie 4.0 werden durch die Datenübertragung in Echtzeit die Stakeholder von industriellen Produktionsketten nicht nur horizontal, sondern auch vertikal miteinander verbunden. Aufgrund dieser Vernetzung spricht man nicht mehr von bloßen Produktionsketten, die die Zulieferer mit der Endproduktion verbinden, sondern von sogenannten Produktionsnetzwerken. Diese ermöglichen es durch entsprechend intelligente Steuerungssysteme Güter in Losgröße 1, also Einzelstücke, zu den Kosten einer Massenproduktion, zu produzieren. Diese Flexibilität nennt man in Anlehnung an die vorangegangenen drei industriellen Revolutionen auch „Industrie 4.0“ und ist mittlerweile auch außerhalb des deutschsprachigen Raums ein wichtiger Bestandteil für Wirtschaft und Wissenschaft. Die zunehmende Vernetzung bringt dem Kunden eine entsprechende Individualisierung seines gewünschten Produktes bei hoher Qualität und zu einem bezahlbaren Preis. Allerdings steigert sich durch die dafür benötigten, reibungslos miteinander vernetzten, Abläufe auch die Komplexität der Produktion. Diese Komplexität wirkt sich auch auf die Arbeitsplätze und -aufgaben aus, weil, je nach Beruf unterschiedliche Aufgaben wegfallen und neue hinzukommen. Eine Konsequenz hieraus wird es sein, dass sich die berufsbedingten Kompetenzen der Arbeitnehmer, je nach Substituierbarkeit der jeweiligen berufsfeldbezogenen Arbeitsaufgaben, ebenfalls ändern werden müssen. Momentan ist die Transformation der Produktionsketten zu Wertschöpfungsnetzwerken der Industrie 4.0 meist noch eher konzeptioneller Natur. Dennoch lässt sich erahnen, dass gerade die produzierenden Berufe in der Produktion von den sich verändernden Anforderungen zuerst betroffen sein werden. Durch die zunehmende Vernetzung wird der Ruf nach überfachlichen, also multidisziplinären Kompetenzen, gerade bei technischen Arbeitsaufgaben, lauter. Des Weiteren verschieben sich viele der klassischen Arbeitsaufgaben in den digitalen Kontext, womit neben den berufsspezifischen und fachlichen Kompetenzen auch vermehrt digitale Kompetenzen benötigt werden. Hierbei tat sich eine erste Forschungsfrage auf, inwiefern technische Auszubildende zukünftig über welche multidisziplinären digitalen Kompetenzen verfügen sollten, um adäquat für die Anforderungen der Industrie 4.0 vorbereitet zu sein. Um die notwendige Kompetenzentwicklung von technischen Auszubildenden für die Industrie 4.0 zu fördern, wurden in gewerblichen Berufsschulen in Baden-Württemberg sogenannte Lernfabriken 4.0 implementiert. Diese sind modellhafte, vernetzte industrielle Fertigungsstätten und können eine Losgröße 1 Produktion mit all den Konsequenzen und notwendigen Schnittstellen darstellen. Daraus resultierte die zweite Forschungsfrage, ob Lernfabriken 4.0 die gewünschten Kompetenzentwicklungen bei technischen Auszubildenden unterstützen können.

Für eine valide Beantwortung dieser Forschungsfragen wurde in dieser Dissertation ein exploratives Mixed-Method-Forschungsdesign gewählt. Basierend auf theoretischen Annahmen wurden in zwei qualitativen Studien sowohl Ausbildungsverantwortliche (Studie 1), als auch gewerbliche Berufsschullehrer (Studie 2) befragt, welche multidisziplinären digitalen Kompetenzen neben den fachlichen Kompetenzen für technische Auszubildende zukünftig wichtig werden. Aus den jeweiligen Antworten wurden die folgenden zentralen Kompetenzdimensionen herausgebildet: *Einstellung gegenüber Digitalisierung*, *Handhabung von digitaler Hard- und Software*, *Information Literacy*, die *Anwendung von digitalen Sicherheitsmaßnahmen*, das Nutzen von *Copyright*, adäquates *kollaboratives Handeln*, *Problemlösefähigkeiten*, sowie das *Selbstreflektieren* im digitalen Kontext. Diese Kompetenzdimensionen und ihre Zusammenhänge wurden dann durch eine quantitative Studie mithilfe eines Strukturgleichungsmodells (Studie 3) empirisch überprüft und modifiziert, wobei die Einstellung gegenüber Digitalisierung als Prädikator für das konzeptuelle Modell der multidisziplinären digitalen Kompetenzen bestätigt wurde. Abschließend wurde der Kompetenzerwerb durch Unterstützung der Lernfabriken 4.0 in gewerblichen Berufsschulen untersucht (Studie 4). Die Resultate deuten darauf hin, dass sich bestimmte Kompetenzen durch die Unterstützung von Lernfabriken 4.0 signifikant besser entwickeln, als ohne die Nutzung dieser Lernumgebungen.

Das Modell multidisziplinärer digitaler Kompetenzen ist als konzeptionelles Modell im Kontext der deutschen gewerblichen dualen Ausbildung zu verstehen, dass die Modelle der digitalen Kompetenzen und der 21st century skills ergänzt. Diese Dissertation leistet somit einen ergänzenden Beitrag in einem bislang unzureichend erforschten Feld der digitalen Kompetenzforschung und der Lernfabrik 4.0 Integration in den gewerblichen Berufsschulunterricht. Aus den Resultaten der durchgeführten Studien lassen sich praktische Implikationen für die technische Ausbildung ableiten. Durch systematische Integration der multidisziplinären digitalen Kompetenzen in die jeweilige Ausbildung, könnten die technische Auszubildenden besser auf die Anforderungen einer vernetzten Arbeitswelt in der Industrie 4.0 vorbereitet werden. In diesem und im Forschungsbereich der Lernfabriken 4.0 an beruflichen Schulen, bietet diese Dissertation für zukünftige Studien weitere Forschungsideen an, um die wissenschaftliche Evidenz dieser technologiebasierten instruktionalen Systeme weiter auszubauen und somit die Entwicklung entsprechender Kompetenzen weiterhin zu fördern. Aufgrund der unterschiedlichen Limitationen der einzelnen Studien werden Vorschläge zu möglichen Methoden weiterführender Forschungen unterbreitet. Alle gewonnenen Erkenntnisse werden in dieser Dissertation in einen praktischen Bezug gesetzt und diskutiert

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Who would have thought this possible 10 years ago?

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1. Introduction

In this introduction, first the general motivation behind this thesis is described: why it is worthwhile to address this topic (section 1.1)? Subsequently, the research questions of this thesis are presented (section 1.2) and then discussed more specifically (section 1.3). Then the structure of the thesis is described (section 1.4).

1.1 Motivation

Previous industrial revolutions not only involved revolutionary technological developments but also changed the workplaces of their respective times. Their revolutionary growth of efficiency relied on the comprehensive implementation of new technologies in industrial production. The transition from new and larger quantities to also significantly better quality of the products marks the systematic industrial transformation (Popkova et al., 2019). Industrialization started at the end of the 18th century in England (Crafts, 1977) through industrial usage of water and steam power and other technologies, which enabled the broad implementation of mechanical production systems (Bruland & Smith, 2013). The first industrial revolution changed the demands on the workers' competencies. But due to the lack of data, it has not been conclusively proven whether the general literacy rate dropped, rose or stagnated during the first industrial revolution (Nicholas & Nicholas, 1992). De Pleijt et al. (2020) argue that the more an English county was industrialized, the lower the literacy was, but the more working skills were developed over time. Comprehensive technological changes had effects on the competence development of apprentices, as they needed to operate and maintain new production machinery (Feldman & van der Beek, 2016). Toward the end of this first industrial revolution, the education and the skills and abilities of workers in the factories improved (Nicholas & Nicholas, 1992).

The second industrial revolution took place in the late 19th and early 20th centuries (Popkova et al., 2019). A key element for this second revolutionary reduction of production costs was the rise in the use of electric power for industrial purposes (Rosenberg, 1998), and the division of labour through the transition from stationary factory production to continuous manufacturing processes (Goldin & Katz, 1998), which enabled mass production. The data situation for the second industrial revolution is only slightly better than for the first, and again only limited statements can be made about competence development during this period. But it is known that the role of formal education was becoming more important (Becker et al., 2011), since the new industrial technologies increased the demand for basic education (Galor, 2005; Galor & Moav, 2006). Innovation during this period occurred on the basis of this broader general education, but technical competencies were mainly developed by learning within production (Sutthiphisal, 2006). Therefore, technologies and needed competencies were in a complementary relationship (Goldin & Katz, 1998).

The third industrial revolution was based on the emergence of usable computers, programmable automation (Helfgott, 1986) and the introduction of robotics into mass production since the second half of the 20th century (Popkova et al., 2019). This also brought about a shift in competencies (Liu & Grusky, 2013) and a change in work activities, since machines can work more precisely and do not vary in their performance (Helfgott, 1986). Because for the third industrial revolution a much better data basis is available for all kinds of research purposes, the discourse in the scientific literature regarding competence development through industrial revolutions now integrates not only basic schooling or technical competencies, but also the cognitive, creative and social competencies of individuals (Liu & Grusky, 2013).

Now, in 2020, the fourth industrial revolution is said to be in progress (Belinski et al., 2020). The term “Industry 4.0” reflects the idea that the vertical and horizontal interconnectedness in value-added networks represents a fourth industrial revolution (Kagermann et al., 2013; Mazak et al., 2017; Sommer, 2015). In reality, calling the actual shift to real-time-interconnectedness (Yin et al., 2018) a fourth industrial revolution is more a political strategy of the German government (Kagermann et al., 2013) than it is an end of a transition process from quantitative implementation to qualitative production in high quantities (Popkova et al., 2019). Consequently, it must be considered that Industry 4.0 is evolving from already existing technology for connecting digital opportunities with physical production (Hoppe, 2017; ZEW, 2015). But even if the technology has been implemented in industry for years or decades, the (r)evolutionary aspect here is the deep and comprehensive rollout of technological infrastructure, which enables horizontal and vertical interconnection of any related stakeholders within value-added networks (Gebhardt et al., 2015; Kagermann et al., 2013). When comprehensive interconnectedness is implemented, the quantity-to-quality transition process may be completed (Popkova et al., 2019), but right now it is not yet (Tenberg & Pittich, 2017). Finishing this transition will lead to a striking market advantage, because the “batch size one” production enables mass-individualization at the prize of mass customization (Koren et al., 2015) of the third industrial revolution (Da Silveira et al., 2001). A further advantage is the real-time data transfer from physical production via cyber-physical systems. A cyber-physical system (CPS) is defined as the integration of computational systems with any physical processes (Lee, 2008; Sánchez et al., 2016). Through the interaction of these CPSs with each other and through sensors with their environment, networks are created. These networks lead to relevant stakeholders being able to see the consequences of physical actions by the CPSs in real time (Yin et al., 2018) and, if necessary, even feed in changes in the running processes (Longo et al., 2017; Popkova et al., 2019). This implies an enormous increase in complexity when applied to production with CPS (Belinski et al., 2020; Kagermann et al., 2013) and will affect everyone who works with it (Gebhardt et al., 2015; Hecklau et al., 2016).

The scientific literature therefore largely agrees that due to the changing work environment, the tasks and competencies of shop-floor workers will also have to change in the wake of Industry 4.0 (Belinski et al., 2020). The fact that most industrial shop-floor workers in Germany are trained in the dual vocational education and training system results in particularly urgent adjustments in order to prepare future workers as well as possible for the complex challenges of Industry 4.0 (Gebhardt et al., 2015; Schad-Dankwart & Achtenhagen, 2020; Scheid, 2018). Zinke et al. (2017) indicate that interconnectedness will not lead to an institutional fusion of jobs or tasks. Rather, existing tasks will change and new (IT-specific) tasks will be added within the respective field of work (Stettes, 2018). Those tasks that have so far been related to machine and plant control will become fewer as a result of Industry 4.0 (Tenberg & Pittich, 2017; Zinke et al., 2017). Mechanical tasks could become less important, whereas the assessment of circuit diagrams and technical documentation as well as the handling and understanding of data and screen interfaces will become more important. Understanding of digital-related systems and associated problem solving skills will be central challenges in Industry 4.0-related education (Hecklau et al., 2016; Zinke et al., 2017). In summary, it can be said that the more routine tasks are currently involved in a profession, the more this profession will be affected by the transformation of Industry 4.0 (Gerholz & Dormann, 2017; Hirsch-Kreinsen, 2014; Pfeiffer & Suphan, 2015; Tenberg & Pittich, 2017). Future production employees should not only have technical competencies (Hecklau et al., 2016), but also several multidisciplinary and digital competencies (Chromjakova, 2019). In this way they can better master the coming challenges of increasing real-time interconnectedness in the private and working world (Hecklau et al., 2016; Longo et al., 2017).

There have been many studies on general digital competence models over the years (Ilomäki et al., 2016). However, because existing studies usually investigated a professional group, a professional level or industry-specific changes, a transferability of the existing competence models to technical vocational students is not given (Abele et al., 2019; Hecklau et al., 2016). In general, studies that deal exclusively with the corresponding competencies of the target group of technical vocational students are rare. Studies that focus on technical vocational students often discuss required technical and subject-related competencies and also mention the importance of being digitally competent, but they do not focus on specific digital skills and abilities required for Industry 4.0 (Spöttl et al., 2016; Tenberg & Pittich, 2017). Also, many explorative qualitative studies with a focus on competencies for vocational training in Industry 4.0 are based on very heterogeneous groups of experts (Abele et al., 2019). For example, in addition to responsible and experienced corporate instructors and vocational teachers, IT specialists and managers were usually also surveyed without qualifying the differences in their opinions on required competencies (Hambach et al., 2017; Spath et al., 2013; Spöttl et al., 2016; Ziegler & Tenberg, 2020). However, pure groups of experts from the dual vocational education and training system would have to make qualified statements about future competencies of the technical vocational students. This is because in the dual vocational education and training system, the training of future skilled workers takes place on the one hand through their employment and practical work in companies (Euler, 2004, 2013); on the other hand, these apprentices are simultaneously vocational students at corresponding vocational schools (Cattaneo & Aprea, 2018). While in vocational schools the vocational teachers teach fundamental theoretical knowledge, in companies the training is mainly practical. In some occupational trainings, the theoretical and practical teaching units are combined directly at vocational school, just as it is common practice in some companies to offer additional theory lessons in addition to the practical teaching units (Euler, 2013; Gessler, 2017). Even if the acquisition of competencies by the technical vocational students takes place at the micro level through the cognitive combination of the two learning locations (Gessler, 2017), the vocational teachers and corporate instructors responsible for training and education should know best which future competencies their technical vocational students need in Industry 4.0.

The aim of vocational training is the process-oriented development of professional ability (Gerholz & Dormann, 2017). In order to achieve the best possible acquisition of competence, realistic and modern production models should be integrated as far as possible into technical vocational school lessons (Abele et al., 2015; Zinn, 2014). In preparation for Industry 4.0, this should be addressed by using state-of-the-art technology and by making optimal use of decentralized learning stations (Zinke et al., 2017). The demand for state-of-the-art industrial technology for learning purposes will be met in 2021 by the so-called Learning Factories 4.0. Although such Learning Factories 4.0 are still quite rare in German vocational schools, they have been implemented in increasing numbers since 2016 due to political initiatives in the state of Baden-Wuerttemberg (Ministry for Economic Affairs, Work and Housing, 2017, 2018). But still, there is currently a lack of empirical evidence regarding the development of multidisciplinary and digital, but also technical, competencies for Industry 4.0 in Technical Vocational Schools through Learning Factories 4.0 (Scheid, 2018; Zinn, 2014). To reduce this research gaps and to respond to the demand for adapted concepts of competence in order to avoid negative employment effects on the labour market (Stettes, 2018), this thesis explores multidisciplinary digital competencies within the Technical Vocational Education and Training (TVET) system. As Figure 1.1 shows, the foci of this thesis are on (1) the educational perspective of corporate instructors and technical vocational teachers on multidisciplinary digital competencies, (2) the dimensions structure of multidisciplinary digital competencies, and (3) competence development and assessment through Learning Factories 4.0 in Technical Vocational Schools.

1.2 Research Questions of this Thesis

It will take some time before the transformation to an integrated Industry 4.0 is complete. Until then, Tenberg and Pittich (2017) recommend that the TVET should use this time to solve all relevant didactic and methodological issues in order to continue to supply the economy with well-trained young people. Since these technical vocational students will play an important role as future shop-floor workers in Industry 4.0 (Scheid, 2018), but are just at the beginning of their careers and have little experience with working with industrial manufacturing technology, it is advisable to interview the closest stakeholders in the dual vocational training to address this specific research gap (Seufert, 2020). Due to the fact that the technical vocational students are trained simultaneously by their corporate instructors and their vocational teachers, it is appropriate to develop a corresponding competence model based on the combined opinions of these two groups.

Another, resulting research gap is the lack of empirical validation of the multidisciplinary digital competencies suggested by corporate instructors and technical vocational teachers. Furthermore, the Industry 4.0-related skills and abilities for technical vocational students that are suggested in the literature often also lack empirical verification (Gebhardt et al., 2015) by, for example, a structural equation model like the one Walker et al. (2016) applied to domain-specific problem-solving competencies of electronics technicians. It is to be assumed that vocational teachers must also have the required multidisciplinary digital competencies themselves in order to be able to pass these on adequately to their students (Maderick et al., 2015). For this reason, this validation was carried out with pre-service vocational teachers.

A third research gap, resulting from the two previous, is the integration of Learning Factories 4.0, which are precisely designed to promote both technical and multidisciplinary digital competencies (Abele et al., 2019) in technical vocational schools. However, there are no empirical studies on Learning Factories 4.0 in the specific vocational school context (Scheid, 2018).

Hence, the aim of this thesis is to enhance research on multidisciplinary digital competencies from an educational stakeholders' perspective to generate first empirical evidence and promote the theoretical foundation of the model and its related competence development via Learning Factories 4.0 further by investigating:

- Perceptions of corporate instructors and vocational teachers regarding the current and future multidisciplinary digital competencies of technical vocational students, considering the place where these competencies are promoted in the dual vocational education and training system.
- Validation of multidisciplinary digital competencies of pre-service vocational teachers via structural equation modelling.
- Empirical competence development of technical vocational students while they are learning at a Learning Factory 4.0.

In summarized form, the research question of the present thesis therefore is:

Which multidisciplinary digital competencies will educational stakeholders require from technical vocational students in the future in order to compete in Industry 4.0, and what role can Learning Factories 4.0 play in the acquisition of these competencies in technical vocational schools?

In order to answer this open research question, it was divided into several specific research questions, which were then answered through different studies.

1.3 Specific Research Questions

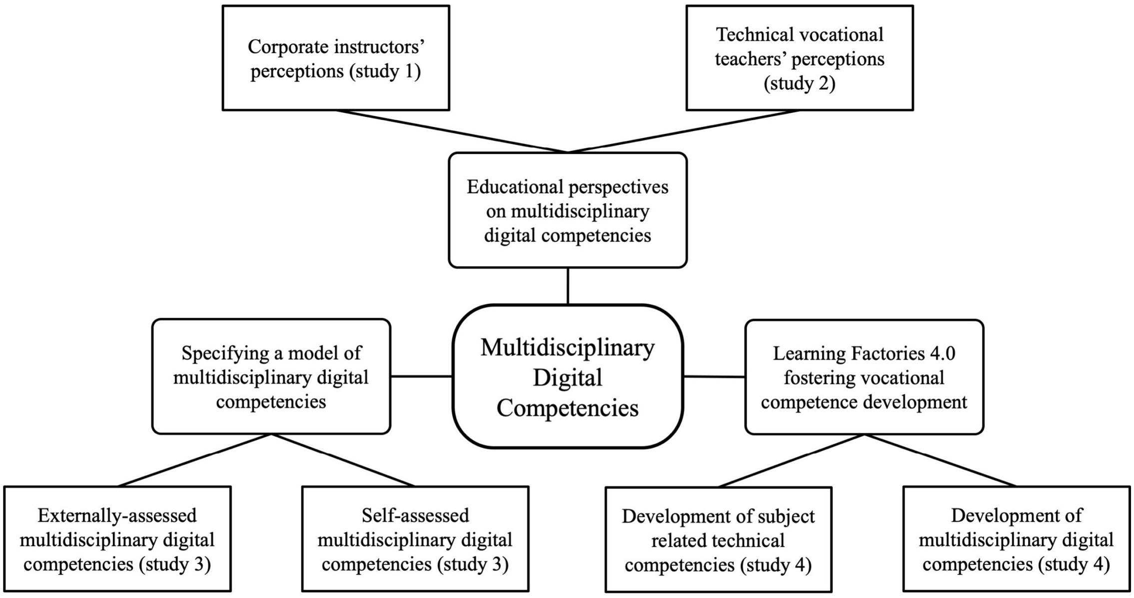
A mix of qualitative and quantitative research methods was conducted and a conceptual model of multidisciplinary digital competencies was proposed. For this reason, this thesis consists of two qualitative and two empirical studies, which are presented here in four separate chapters that build on each other. However, a scientific work on multidisciplinary digital competencies, valid in content, informative and broadening the research horizon, is explored here with these following foci, as shown in Figure 1.1:

- Perceptions of corporate instructors and vocational teachers
- Validation through pre-service vocational teachers
- Development through Learning Factories 4.0.

The thesis was designed with an explorative design that started with two qualitative studies and was then complemented by two quantitative studies (Creswell, 2008). After various adjustments to the competence model, the actual competence development in the classroom was measured using Learning Factories 4.0.

Figure 1.1

Overview of the different research foci of this thesis



A brief summary of the studies undertaken to investigate the research foci of this thesis, and of the research questions they address, can be found in the following section. At the end of the next section, Table 1.1 summarizes the research design, the type of instruments, the analysis methods selected and the respective sample sizes of the three conducted studies.

1.3.1 Corporate Instructors' Perceptions (study 1)

In the dual vocational education and training system, corporate instructors play one of the two central roles in the vocational training of future shop-floor employees. In addition, these instructors work in companies that reflect on the consequences of Industry 4.0. Consequently, the first study (chapter 3) explores the expectations of these industrial representatives in the German dual vocational education and training system with regard to non-technical, i.e. multidisciplinary and digital abilities and skills for their future technical vocational students in Industry 4.0. In particular, this exploratory study was guided by the following research questions:

- How do those responsible for training assess the current state of the dimensions of multidisciplinary digital competencies among technical vocational students?
- What influence does Industry 4.0 have on the future multidisciplinary digital competencies of technical vocational students from the perspective of those responsible for training?
- Furthermore, it was also described how cooperation between vocational schools and companies will be changed by Industry 4.0 in order to best promote multidisciplinary digital competencies?

1.3.2 Technical Vocational Teachers' Perceptions (study 2)

The complementary educational perspective in the dual vocational education and training system is that of the vocational school teachers, who are responsible for teaching theoretical knowledge. Accordingly, a survey of in-company instructors must also be supplemented by the school side. Since in the technical field the instructors themselves are increasingly using Learning Factories 4.0 to link to practice, the study surveyed the teachers who already use them. Study 2 (chapter 4) was therefore based on the following research questions:

- Which role do digitization and Industry 4.0 have for Technical Vocational Schools?
- What multidisciplinary digital competencies do the technical vocational teachers most expect for Industry 4.0?
- How do technical vocational teachers integrate Learning Factories 4.0 into their teaching?

1.3.3 Model Development of Multidisciplinary Digital Competencies (study 3)

As vocational students should also develop those competencies in vocational schools, their future vocational teachers need to develop those competencies as well. Because no significant differences in multidisciplinary digital competencies were found in the sample between the participating pre-service vocational teachers with and those without prior vocational training, this study can also be used in this context for further model examination (Instefjord & Munthe, 2017; Sloane, 2019; Tenberg, 2020). Therefore, study 3 (chapter 5) examines the structure of the dimensions of competence suggested by the previous studies to revalidate the model on pre-service vocational teachers. Because attitudes toward digitization can be a predictor of self-assessed digital literacy (Yerdelen-Damar et al., 2017), this study also inspects how these attitudes affect performance in a test for multidisciplinary digital competencies. The study also investigates whether the self-assessment of pre-service teachers can predict the results of the externally-assessed test of multidisciplinary digital competencies. The research questions guiding study 3 were:

- How do the dimensions of competence influence the multidisciplinary digital competencies?
- What influence does the attitude towards digitization have on multidisciplinary digital competencies?
- How can the self-assessed multidisciplinary digital competencies predict the results of an objective and externally assessed test of multidisciplinary digital competencies?

1.3.4 Competence Development through Learning Factories 4.0 in Technical Vocational Schools (study 4)

Following the previous studies, the competence model still needs to be evaluated in daily school practice. A major aim of Learning Factories 4.0 in Technical Vocational Schools is to foster competence development in order to prepare their learners for the challenges of Industry 4.0 (Scheid, 2018). They should therefore promote not only technical, but also multidisciplinary digital competencies. Consequently, the resulting research questions of study 4 (chapter 6) were the following:

- How do the multidisciplinary digital competencies of technical vocational students develop over time for different levels of usage of Learning Factories 4.0?
- How do different levels of Learning Factory 4.0 usage affect the development of subject-related technical competencies of technical vocational students?

In addition to the research questions mentioned in this section, Table 1.1 summarizes the research design, analysis methods and sample size for each study.

Table 1.1

Overview of studies conducted for this thesis

Study	Study 1	Study 2	Study 3	Study 4
Title	Development of Multidisciplinary Digital Competencies in Dual Vocational Education from the Instructor Perspective	The Impact of Learning Factories on Multidisciplinary Digital Competencies	Multidisciplinary Digital Competencies of Pre-Service Vocational Teachers	Learning Factories 4.0 in Technical Vocational Schools: Can They Foster Competence Development?
Research design	Qualitative research approach	Qualitative research approach	Quantitative and qualitative research approach	Quantitative and qualitative research approach
Instruments	Exploratory semi-structured interview study	Exploratory semi-structured interview study	Single choice questionnaire and open questions questionnaire	Open questions questionnaire
Analysis	Inductive content analyses	Inductive content analyses	Structural equation model	Scheirer-Ray-Hare test (repeated measures design)
Sample Size	11	19	205	63

1.4 Structure of this Thesis

The present thesis is organized into seven chapters. The first chapter is intended to give a short overview of the change in competence requirements due to industrial revolutions. Furthermore, it presents the author's motivation to contribute to the research on digital competencies, as well as on the development of competencies in Learning Factories 4.0. This chapter also contains a brief summary of the studies conducted for this thesis and their research foci. The second chapter emphasises the theoretical foundation of the concept of multidisciplinary digital competencies and places Learning Factories 4.0 in technical vocational schools in their scientific context. The following four chapters describe the four conducted studies:

- Chapter three (study 1) deals with the explorative qualitative content analysis of the opinions of corporate instructors.
- Building on study 1, chapter four (study 2) discusses the perspectives of the vocational school teachers surveyed.
- In chapter five (study 3), the empirical validation of the competence dimensions is carried out by a survey of pre-service vocational school teachers.
- The sixth chapter (study 4) examines the development of competencies through Learning Factories 4.0 at technical vocational schools.

Finally, the last chapter of this thesis contains a summary of the practical implications and limitations of each study and discusses avenues for further research based on the results. Furthermore, a general conclusion is drawn in this chapter.

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2. Conceptual Foundation of the Thesis' Constructs

This chapter focuses on clarifying the central concepts. In section 2.1, competence as the term is used here is defined. The insufficient terminological difference between the terms "interdisciplinary" and "multidisciplinary" is addressed (section 2.1.1), as are the fundamental concepts of digital competence and 21st century skills (section 2.1.2). In addition, section 2.1.3 explains in more detail the scientific foundation of multidisciplinary digital competencies. Section 2.2 presents the technology-based, complex learning environments of Learning Factories 4.0, while section 2.2.1 provides a terminological delimitation, section 2.2.2 summarizes the design of Learning Factories 4.0, which are also installed in technical vocational schools, and section 2.2.3 addresses the competencies that can be fostered there.

2.1 Multidisciplinary Digital Competencies

Competencies can be summarized as a set of skills and abilities to cope adequately, especially in unknown situations (Weinert, 2001). Internal structures of competencies are oriented towards the requirements to be addressed. Thus, the composition of subordinate dimensions of competencies is always explained by the classification of the respective concept of competence in the corresponding context (Hartig & Klieme, 2006; Rychen & Salganik, 2001). The underlying context of this thesis is the ability of technical vocational students in Industry 4.0 to act in a well thought-out and goal-oriented manner in new situations that are characterized by multidisciplinarity and include the digital context.

2.1.1 Multidisciplinarity

In Industry 4.0, vocational students need to collaborate with workers in other disciplines (Acatech, 2016a). Huba and Kozak explain this interconnectedness of Industry 4.0 like this: "Mechatronics integrates the fields of mechanical, electrical, control, and computer engineering. This multidisciplinary concentration was created because knowledge across these disciplines is essential to improve and/or optimize the functionality of modern engineering systems" (Huba & Kozak, 2016, p. 103). Although the scientific literature is in agreement on the form of collaboration that will emerge in the future, it is sometimes described as a multidisciplinary (Huba & Kozak, 2016; Wolff & Luckett, 2013) and sometimes as an interdisciplinary (Balve & Ebert, 2019; Veile et al., 2019) phenomenon. This raises the question of whether future technical vocational students would need an interdisciplinary or a multidisciplinary model of digital skills and abilities (Tenberg, 2020). The understanding of interdisciplinarity and multidisciplinarity, as well as the difference between them, is explained in the following. Nevertheless, it must be noted at this point that the literature is somewhat contradictory in its definitions of interdisciplinarity and multidisciplinarity (Besselaar & Heimeriks, 2001; Heikkinen & Räisänen, 2018; Weiß & Severing, 2018). The discourse on the terminology has not produced clear definitions that are completely distinct from each other. In the following, interdisciplinarity is understood as an institutional, or model-like, merging of different disciplines (Nissani, 1995, 1997), so that the necessary components of different disciplines are united in a new interdisciplinary relationship (Davies & Devlin, 2007; Gehring, 2013). Multidisciplinarity, on the other hand, is based on the co-existence of different disciplines that function largely autonomously, but do not exclude additional specialization in a part of another discipline (Collin, 2009; Heikkinen & Räisänen, 2018). Walker, Link and Nickolaus indicate that multidimensional competence models rely on multidisciplinary problem situations, especially in industrial training occupations (Walker, Link, & Nickolaus, 2016). Likewise, Stanford professor Stephen Jay Kline argued in 1995 that multidisciplinary discourse between experts helps solve multidisciplinary problems. This is especially true when working groups consist of shop-floor-workers from different disciplines. Kline also emphasized that through multidisciplinary discussion, "experts better understand the connection of their own field to the whole human knowledge" (Kline, 1995, p. 3). In this thesis, the two concepts of interdisciplinarity and multidisciplinarity are therefore comparable, but not congruent. While interdisciplinarity bases on institutionalized and regular collaborations, multidisciplinarity integrates different, irregular collaborations between different disciplines.

According to Tenberg and Pittich (2017), even with the increasing interconnection of Industry 4.0 (Acatech, 2016a; Vogel-Heuser et al., 2017), there is no need for any new interdisciplinary technical professions in production for the time being (Sloane, 2019). Rather, adapted training plans (Roll & Ifenthaler, 2020a) and new qualification profiles (Hall et al., 2016) will cover the linking of different disciplines required for Industry 4.0. Because of the foreseeable continuation of autonomous vocational occupations related to production and the need to further develop digital competencies, the term *multidisciplinary digital competencies* will be used in the following. However, this does not negate the need for more intensive collaboration (Acatech, 2016a; Uckelmann et al., 2018) between the disciplines, but rather includes it as a competence dimension in a model of multidisciplinary digital competencies.

2.1.2 Digital Competencies and 21^st^ Century Skills

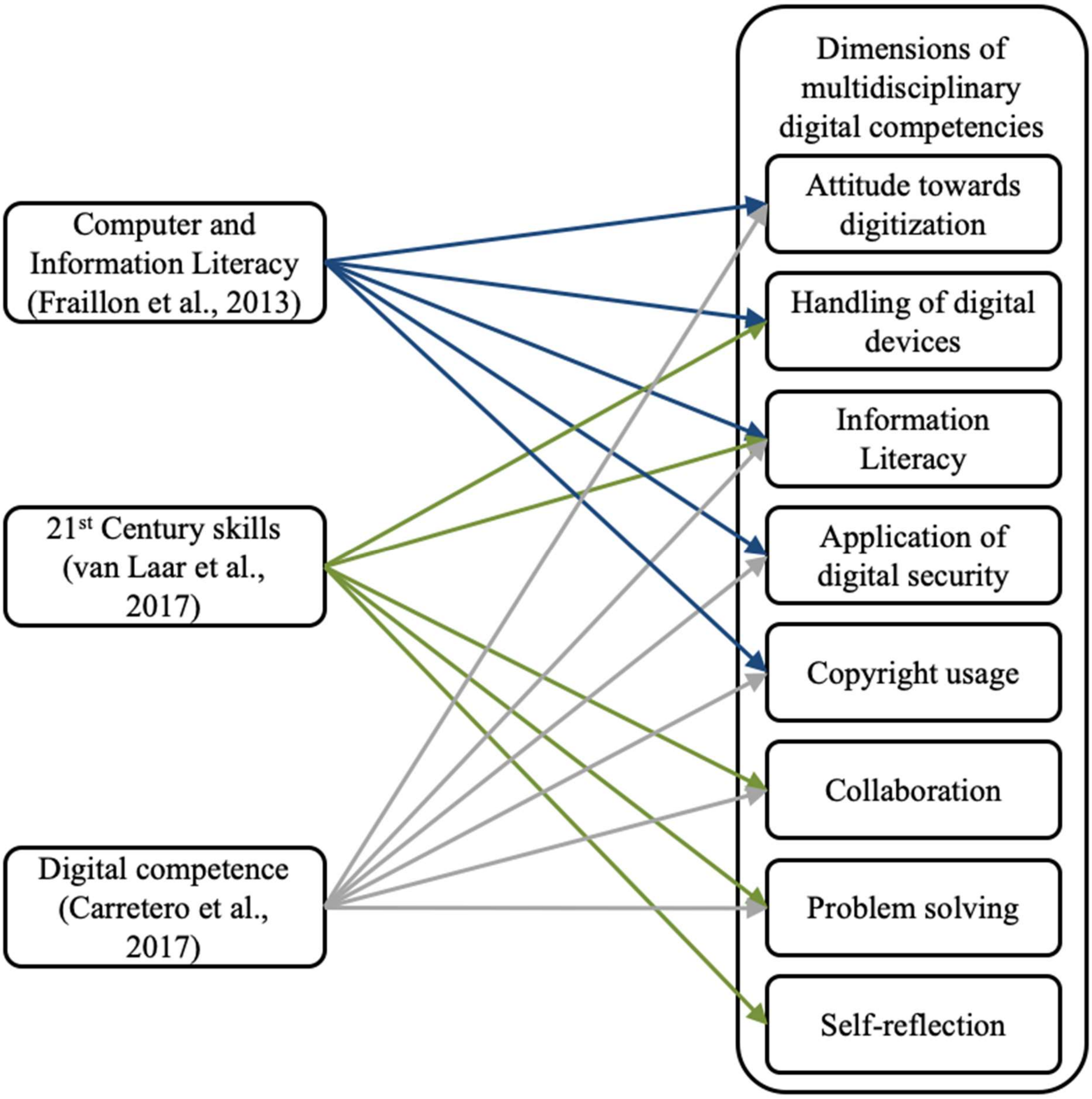
There are many and understandings of digital competencies. A good overview of the most common literature, as well as relevant conceptual distinctions, is provided by the summaries by

Ilomäki et al. (2016) and van Laar et al. (2017). Ilomäki et al. (2016) differentiated between the digital competence concepts. From an originally more technological approach, research on digital competencies has evolved and integrated a wider range of skills and abilities (Claro et al., 2012; Hatlevik et al., 2015). An example of such a broad definition is given by Hatlevik et al. (2015), who understand digital competence as: "The skills, knowledge, and attitudes that make learners able to use digital media for participation, work, and problem solving, independently and in collaboration with others in a critical, responsible, and creative manner" (Hatlevik et al., 2015, p. 124). Digital competence can now be summarized as follows: "Digital competence is an emerging, broad concept, which connects various domains in that it consists of something from each domain, and which operates as a loosely defined boundary concept (and a transdiscursive term) amongst policy-makers, practitioners and researchers" (Ilomäki et al., 2016, p. 657).

On the other hand, the understanding of 21st century skills is rather narrow. The research group of van Laar et al. (2017) tried to find a reasonable demarcation between digital competencies and 21st century skills. They list the individual skills and abilities, such as technical, information-related, collaborative, communicative, creative conceptual competence dimensions as well as critical thinking and problem solving skills (van Laar et al., 2017, 2020). These form the basis to enable the individual to participate in a modern society in the 21st century (Ananiadou & Claro, 2009). Based on Klotz's suggestion that competence models should be designed as closely as possible to reality (Klotz, 2015), it is clear that a competence model for future technical vocational students would need components from digital competence research as well as specific dimensions of 21st century skills. Therefore, the competence dimensions for multidisciplinary digital competencies used in this thesis have been adapted to the context of technical vocational students in Industry 4.0 after conducting exploratory studies. In the preparation of the semi-structured interview guidelines, however, fundamental, already existing digital competence concepts were used as a basis. It is therefore not surprising that the categories of competence dimensions that were formed as emerging categories resemble not one but several existing scientific papers on digital competencies. Therefore, the competence dimensions, shown in Figure 2.1 and in Table 2.1, have different origins in the scientific literature. Nevertheless, the respective research work often refers to pupils, students or citizens, but rarely to employees (Carretero et al., 2017; Siddiq et al., 2017; Tondeur et al., 2017; van Laar et al., 2017). But the members of the target group of this thesis are, due to the dual technical and vocational education and training system (TVET), technical vocational students who are also working at the same time as technical vocational students in companies. This also explains the multiple theoretical anchoring of the present competence dimensions from Figure 2.1.

Figure 2.1

Overview of the various competence dimensions of multidisciplinary digital competencies



From a look at Figure 2.1 it becomes evident that the competence dimensions are traceable to three scientific works (Carretero et al., 2017; Fraillon et al., 2013; van Laar et al., 2017). It is not surprising that so many competence dimensions in Figure 2.1 can be assigned to concepts of 21st century skills or the field of digital competence. Both concepts, digital competencies and 21st century skills, are usually based on multiple conceptual skills and abilities (van Laar et al., 2017). However, as Table 2.1 shows, the original sources were in fact also other publications. Hartig and Klieme (2006) consider the differentiation into individual competence dimensions to be indispensable for a differentiated adaptation of the competence to the respective chosen context.

Existing research finds that an understanding of 21st century skills is rarely focused on the integration of digital contexts and the use of Information and Communication Technologies (ICT). Digital competency models, on the other hand, often integrate digital-related skills and abilities from 21st century frameworks (van Laar et al., 2017, 2020). This thesis creates an understanding of a digital competence model that, by incorporating digital-related skills and abilities from 21st century skills, is intended to provide an appropriate competence requirement for young technical vocational students in Industry 4.0. The correlation structure of the competence dimensions of multidisciplinary digital competencies, determined in an exploratory study and based on theoretical assumptions, requires specific measurements. The empirical investigation of such expectations, e.g. with linear structural equation models, is then used as a test for the correctness of the assumed structural model (Hartig & Klieme, 2006).

2.1.3 Multidisciplinary Digital Competencies of Technical Vocational Students

It should be noted in advance that there are various studies dealing with future competencies in the context of Industry 4.0. A problem of such studies is that, in contrast to similar production-related research fields, Industry 4.0 is still a theoretical construct in itself and does not yet exist in its holistic understanding (Abele et al., 2019). Nevertheless, research must address this problem in order to support the changing dual vocational education and training system with evidence. Symptomatic of this are the proposals of competence models of the German National Academy of Science and Engineering 2016 (Acatech, 2016a), which are certainly partly transferable to technical vocational students, but in some competence dimensions are not compatible with their future work tasks in Industry 4.0. The meta-study by Prifti et al. (2017) also provides a good general overview of required competencies. Some of them can be transferred to the level of technical vocational students, but certainly not all of them. For example, studies mentioned above list the competence dimension "leadership", which should probably not play such a prominent role for technical vocational students for the time being. In 2019, the German Chamber of Industry and Commerce conducted a quantitative survey of companies where vocational students (not only technical, but commercial, social, gastronomic and constructional vocational students) need to improve their digital competencies (Deutsche Industrie- und Handelskammer (DIHK), 2019). As digital competencies can be used as a shared set of skills and abilities from different disciplines (Ilomäki et al., 2016), Table 2.1 shows the addressed competence dimensions of multidisciplinary digital competencies. In the following, these competence dimensions, which appear repeatedly in this thesis, are presented briefly and concisely:

Ilomäki et al. (2016), but also Klieme (2004) and Weinert (2001), integrate volitional aspects into the (digital) concept of competence. One can derive from this that the *attitude towards digitization* is a fundamental predictor for such a conceptual competence model. Attitudes are those dispositions which make an individual react favourably or unfavourably to something, whether it be physical objects, processes, people, or anything else (Ajzen, 1989). They are defined "as a response to an antecedent stimulus or attitude object" (Breckler, 1984, p. 1192). In this study the *attitude towards digitization* is built on the three usual responses used to infer attitudes: cognition, affect and conation (Fishbein, 1967). The verbal cognitive category expresses the beliefs, knowledge or awareness about the respective object, which could be influenced by a previous event (Pike & Ryan, 2004). While the affective category is verbally articulated by the contextual feelings about the attitude object , conation means the behavioural intentions or actions towards it (Ajzen, 1989). Attitude is essential because it is often directly related to, or a predictor of, actual behaviour towards an object (Ajzen, 1989). Another, similar approach is the MODE model. It consists of motivation and opportunity, which are the important determinants of the actual behaviour of an individual (Fazio & Olson, 2014). According to the MODE model, behaviour is influenced by the spontaneous situation (Fazio, 1990). Based on the studies carried out in this thesis and on the relevant literature, an *attitude towards digitization* is understood as the sum of respective cognitive, affective and conative aspects towards digitization. Therefore, technical vocational students should have the inner convictions to want to work and learn with new technologies (Al-Emran et al., 2016; Richter et al., 2000). This openness is an important motivational predictor of participating and working in a networked world (Fraillon et al., 2013, 2014, 2019; Senkbeil & Ihme, 2017).

Building on this, the *handling of digital devices* will continue to be of considerable importance for technical vocational students in the future (Tenberg & Pittich, 2017) and is a basis for being considered digitally competent (Sefton-Green et al., 2009). It is advisable to consider the use of digital devices not as a narrowly defined construct (Ilomäki et al., 2016), but as a conceptual idea that integrates a general handling and not just the handling of a specific software or a single type of device (van Laar et al., 2017, 2020). The definition of this competence dimension is based on Fraillon et al.'s understanding of Computer Literacy (2019) and emphasizes the procedural steps in the selection and operation of the digital devices and software that are required to use them efficiently to achieve the respective goals. The handling of digital devices is listed there in Strand 1, "Understanding computer use" (Fraillon et al., 2019, p. 18), which includes the foundational procedural knowledge of physical computer use and the use of computer conventions via software applications. Consequently, this means the physically efficient handling of CPS (Fraillon et al., 2019; Voogt & McKenney, 2017) of all kinds of devices, such as (tablet) computers, smartphones, factory machines etc., but also the skilful use of relevant software in the respective context (Fraillon et al., 2019; Tenberg, 2020). It also includes the use of social media. And naturally it also implies the correct use of specific software to work. This could refer to the software for milling machines, Manufacturing Execution Systems (MES), Enterprise Resource Planning (ERP), but also to the proficient use of Word, Excel or PowerPoint. A general understanding of handling such software and hardware is usually learned in a professional context during vocational training (Ilomäki et al., 2016).

An essential characteristic of a networked world is the amount of information that is available online (van Deursen & van Dijk, 2015). In the literature, future skilled workers are therefore sometimes referred to as "knowledge workers" (Tenberg & Pittich, 2017, p. 40), because they have to learn where to find relevant information and how to evaluate, organize and use it (van Deursen et al., 2016). The skills and abilities required are referred to as the *Information Literacy* competence dimension. The focus is especially on all kinds of digital information (Rohatgi et al., 2016). *Information Literacy* as a conceptual competence dimension is based on "aspect 2.1: Accessing and Evaluating information" and "aspect: 2.2 Managing information" of the structure of Computer and Information Literacy from the ICILS 2018 study (Fraillon et al., 2019, p. 18). On the cognitive level, the present understanding of *Information Literacy* is based on the individual cognitive process steps of Marchionini's (1996) information-seeking process, which is most suitable for application in the digital context (van Deursen & van Dijk, 2009). This process starts with the identification of the respective information demand, which then leads to the specification of the respective problem. The next step is the selection of the search engine, the search query and its execution. The delivered results are briefly analysed by the performing user; any valuable information is then extracted before it goes into the loop, and the process starts all over again with a new formulation of the search request. This loop is repeated until the user thinks that he has found and collected the necessary information (Marchionini, 1996). Therefore, the investigative process of finding information is immediately complemented by the evaluation of the usefulness, relevance and integrity of the information. The subsequent organization of information includes the orderly storage and classification of information so that it can be retrieved quickly (by oneself). This relates both to storage management on the devices as well as to the cognitive performance to cluster this information (Fraillon et al., 2019). In contrast to Erstad (2010) for example, this understanding of *Information Literacy* does not include the ability to solve problems. This will be explained in a separate section later in this chapter.

The competence dimension *application of digital security* relates to the handling and protecting of data, aspects that are currently still considered by many companies to be too poorly developed among their technical vocational students (Heiberger, 2020). A sensitive handling of security-relevant topics is a precondition for companies to successfully implement Industry 4.0 in the first place (Sommer, 2015). Therefore the aspect of digital security is integrated into many models of digital competence (Ferrari, 2012, 2013). In this thesis, the *application of digital security* includes the understanding and application of adequate security measures. More precisely, this competence dimension includes both personal responsibility with respect to privacy on the Internet and data security regarding personal identity theft, company knowledge and company processes (Carretero et al., 2017; Dodel & Mesch, 2018; Fraillon et al., 2013, 2014, 2019). Personal responsibility with respect to privacy refers to all appropriate and adequate procedures to protect one's privacy, all steps of collecting, using, processing, sharing, and editing personal information. Data security refers to all necessary steps to prevent others from gaining unauthorized access to private as well as workplace and other institutional information (Burkell et al., 2015). This competence dimension is not about designing firewalls, anti-virus programs or security guidelines by yourself, but rather about using these as standardized tools on a daily basis. It is the task of the organizations to provide the security concepts and infrastructure, but the fulfilment is primarily the task of the members (Da Veiga, 2016). In an interconnected world, it is of fundamental importance that individuals conscientiously comply with such security concepts. Inadequate or careless behaviour of organizational members is often a source of organizational vulnerabilities (Dodel & Mesch, 2018; Kemper, 2019).

The mass of information in all kinds of media requires an adequate and lawful usage of *copyright* (Heiberger, 2020; Palfrey et al., 2009). This competence dimension is not dissimilar to the two previous ones in terms of content and argumentation structure. *Copyright* is based on so-called copyright literacy, which in turn is based on Information Literacy (Todorova et al., 2014) and is defined as the demonstration of the relevant awareness, skills and techniques to create and use copyrighted material in an ethical manner (Secker & Morrison, 2016). By using the term *copyright usage* as a designation of the competence dimension, terms such as trademark, patent or intellectual property are not excluded but explicitly included (Elias & Stim, 2004). It is a mix of Fraillon et al.'s (2019) Strand 3 and 4 and includes transforming, creating and securely sharing information under legal requirements so that no privacy or corporate secrets are violated. This applies to both private and corporate life and is intended to ensure that the respective ownership rights, whether of companies, artists or private individuals, are respected so that no harmful consequences can arise for oneself or one's organization (Burkell et al., 2015). Marking the sources of external content will become increasingly important as the volume of information increases. This aspect is particularly important since it has become apparent that the increasing number of digital devices, the corresponding software apps installed on them and incorrect usage of social media has led to an increase in the number of cases of plagiarism for violations of other people's intellectual property, and that users are unaware of this issue (Hickman, 2020; Vinueza et al., 2020). Almost everything that has to do with the creation of content, whether videos, texts, presentations, pictures or music, is based on the correct application of the corresponding copyright regulations (Burkell et al., 2015; Carretero et al., 2017; Fraillon et al., 2013, 2014, 2019; Meese & Hagedorn, 2019).

The competence dimension *collaboration* means that technical vocational students can work together adequately not only within their team but also outside it, with other professional groups or with superiors (Tenberg & Pittich, 2017). Accordingly, *collaboration* in this thesis is understood as an effective interpersonal process, which aims to achieve a joint goal with all involved stakeholders (Berg-Weger & Schneider, 1998; Bronstein, 2003). The integration of the ability of collaboration as a separate dimension of competence is of particular importance for understanding the conceptual distinction between multidisciplinarity and interdisciplinarity of this model (Collin, 2009). Because collaboration connects different disciplines with each other but not institutionally. This builds on Bronstein's definition of work-related collaboration as involving interdependence, newly emerging professional activities, flexibility of all participants, collective goals and common reflection of processes (Bronstein, 2003), and adds appropriate communication to this understanding. Choosing the appropriate channel of communication and collaboration is important because there are significant differences in the ways in which young people communicate and use language when they need to communicate with each other or with supervisors or teachers (Araújo-Vila et al., 2020). This includes the choice of the communication channel, e.g. email, social media etc. (van Laar et al., 2017, 2020; Tenberg, 2020). Sometimes, despite the choice of the right channel of communication, the appropriate style or grammar is lacking. Especially in the age group targeted by this thesis, correct and formal expression through digital media is not considered to be that important (Schlobinski & Siever, 2018). In summary, in this thesis *collaboration* is the way one communicates with which counterpart and the understanding of when which form of expression is appropriate (Carretero et al., 2017; Griffin & Care, 2015).

The *problem solving* competence is certainly not a new requirement, but it is still valid for technical vocational students in Industry 4.0 (Carretero et al., 2017; Ferrari, 2012; Tenberg & Pittich, 2017). The term problem in this thesis refers to specific situations in the digital context that require an effective response in the respective environment. These situations become problematic when no effective response alternatives are immediately available or automatic approaches would not work adequately (D'Zurilla & Goldfried, 1971). This also means that considering a situation as problematic depends on the individual and his or her prior knowledge, expertise, skills and abilities in the respective context (Funke et al., 2018). It is appropriate to consider the problem solving ability as domain-specific, because the process is influenced by a combination of different domain-related knowledge types (Rausch et al., 2016). The ability to solve problematic situations in a digital context is becoming increasingly important due to the increasing amount of available information and digital devices. The adequate handling of these devices as well as a distinctive Information Literacy are important in Industry 4.0 (Jacobs & Castek, 2018). In Industry 4.0 one must identify the necessary actions, based on the possible gaps, and take steps to obtain the information or circumstances that can help to solve the problem (Rausch & Wuttke, 2016). Therefore, this competence dimension is based, on the one hand, on routine problems, whose solution requires above all independence and reliability (van Laar et al., 2017). On the other hand, it also involves the solution of more complex problems, which can be solved either by a courageous creative (Scherer & Gustafsson, 2015) or systematic approach (Wüstenberg et al., 2014). *Problem solving* is therefore not only understood as the presentation of an effective solution, but rather as techniques or processes of the solver to identify a solution to the problem (D'Zurilla & Goldfried, 1971).

The competence dimension of *self-reflection* is to be understood as a meta dimension, which plays a role in all previously mentioned competence dimensions. This concerns both the reflection on one's own usage of digital devices, on the information on finds and on how one uses it (Fraillon et al., 2019). But it involves also the reflection on one's own behaviour with regard to data protection issues (Carretero et al., 2017) and collaborative or problem solving processes (Rausch et al., 2016). *Self-reflection* is thus considered here to be a systematic approach that ensures the continuity of competence development (Lin et al., 2014). In the interconnected and digital context of Industry 4.0, this influences not only the individual competence dimensions of multidisciplinary digital competencies, but above all the *attitude towards digitization* (Ferrari, 2012). For some, *self-reflection* does not require any great investment, while for others it requires a considerable amount of effort. Insecure persons tend to reflect about themselves more structurally and according to certain schemata, whereas not so anxious persons do so automatically (Grant et al., 2002). Above all, the competence dimension of *self-reflection* includes three abilities and skills. The technical vocational students must be able to recognize where they are and what consequences their actions have by constantly comparing the actual and target situation at the workplace. Their ability to assess their skills and abilities also falls into this dimension. Finally, this dimension also includes the overview knowledge of larger processes. Such holistic thinking will become more important for technical vocational students in an interconnected world (Quieng et al., 2015; van Laar et al., 2017; Windelband, 2014).

Based on Hatlevik et al.'s (2015) understanding of digital competence, supplemented by Weinert's (2001) conceptualization that competence consists of ability, skills and attitudes, and the definition of professional action-oriented competence by the Standing Conference of the Ministers of Education and Cultural Affairs (2007), multidisciplinary digital competencies (MDC) are defined as:

A combination of willingness, abilities and individual skills, which enables the individual to act adequately and socially responsibly in the digital context of multidisciplinary professional situations, but also social and private ones.

Table 2.1

Overview and description of multidisciplinary digital competencies

Competence dimension	Description	Selected references
Attitude towards digitization	The inner convictions and motivation to work and learn with digital devices.	Al-Emran et al. (2016) Fraillon et al. (2013, 2014, 2019) Richter et al. (2000) Senkbeil and Ihme (2017)
Handling of digital devices	Adequate and effective use of required software and hardware resources depending on the situation.	Fraillon et al. (2013, 2014, 2019) van Laar et al. (2017, 2020) Voogt and McKenney (2017)
Information Literacy	Finding, evaluating and organizing information from the digital context.	van Deursen et al. (2016) Fraillon et al. (2013, 2014, 2019)
Application of digital security	Understanding and applying security measures to protect personal and company-related data in specific situations.	Carretero et al. (2017) Dodel and Mesch (2018) Fraillon et al. (2013, 2014, 2019)
Copyright usage	The legal creation of content, the labelling of copyright holders and thus also the legal handling of external materials.	Burkell et al. (2015) Carretero et al. (2017) Fraillon et al. (2013, 2014, 2019)
Collaboration	Collaboration with other disciplines through the appropriate communication channels and in the most suitable style.	Care et al. (2016) Carretero et al. (2017) van Laar et al. (2017)
Problem-solving	Solving routine problems independently and developing a creative approach to more complex problems.	Carretero et al. (2017) van Laar et al. (2017) Scherer and Gustafsson (2015)

		Wüstenberg et al. (2014)
Self-reflection	Classifying one's own actions and their consequences in the respective context.	van Laar et al. (2017) Quieng et al. (2015)

2.2 Learning Factories 4.0

Non-subject-related competencies are an integral part of what is expected in technical dual vocational training today (Tenberg, 2020; Tenberg & Pittich, 2017). And in order to promote them, a systematic literature review dealing with organizational learning in Industry 4.0 by Belinski et al. (2020) has highlighted the importance of Learning Factories 4.0 for such competence development. The term "Learning Factories 4.0" used in the thesis is intended to emphasize their Industry 4.0 orientation. The implementation of these modern learning environments in Baden-Wuerttemberg aims to prepare technical vocational students for the challenges of Industry 4.0 (Ministry for Economic Affairs, Work and Housing of Baden-Wuerttemberg 2018). When dealing with learning in a cooperative dual vocational educational context, where the focus is on linking theory with practice through the cognitive performance of the individual, there is no getting around the integrative pedagogy model (Tynjälä, 2009) and the connectivity approach (Griffiths & Guile, 2003). Both research strings have in common that the linking of what has been learned is based on authentic, action-oriented work experiences (Tynjälä et al., 2020). The integration of Learning Factories 4.0 in technical vocational schools is intended to promote these connections, as it allows theoretical learning directly to be linked with authentic work in a context relevant to Industry 4.0.

2.2.1 Terminology and Summary of Scientific Developments

The term "Learning Factory" is similar to "Teaching Factory", but the approach of Learning Factories is more learner-centred (Abele et al., 2015, 2019), whereas Teaching Factories are even closer to industrial reality and therefore have less didactic reductions (Dimitris Mavrikios et al., 2019). Teaching Factories do not have such a problem-based and experiment-promoting instructional design as Learning Factories 4.0 (Mavrikios et al., 2013, 2017; Rentzos et al., 2014; Tisch et al., 2016). The difference to the "*Lehrwerkstatt*" (training workshop) is that the *Lehrwerkstatt* is defined as a separate facility within the company for training purposes. It is physically and organizationally separate from the normal workstations and often does not represent an entire value chain. The technical vocational students can learn independently from the actual production process (Pätzold & Goerke, 2006; Schönfeld et al., 2020).

The learning of relevant industrial and practical work in appropriately equipped instructional environments dates back to the 19th century, when the first training workshops were set up in industry to enable new employees to learn without risk (von Behr, 1981). Learning Factories attracted scientific attention even before the term "fourth industrial revolution" was formulated in 2011 (Kagermann et al., 2013; Weckherlin, 2017). Since the 1980s, there have been a number of isolated technological instructional designs called Learning Factories (Tisch & Metternich, 2017). The concept of learning workshops existed even before that, but they were not yet the holistic modelling of an entire factory. Due to an increase in scientific contributions to Learning Factories, the scene became more and more institutionalized, and in 2011 the 1st Conference on Learning Factories took place. Since then, the field of research has been growing and becoming increasingly international, with the International Association of Learning Factories being founded in 2016 (Abele et al., 2019).

2.2.2 Summary of the Learning Factory 4.0 Design

Learning Factories usually contain various workstations that use transport systems to map all processes of a production plant (Abele et al., 2019). The Learning Factory becomes Learning Factory 4.0 (Windelband & Faßhauer, 2016) through the application of CPSs, sensors and interconnectivity, as well as the integration of MES (Bedolla et al., 2017; Pittich et al., 2020; Tisch et al., 2016). In Industry 4.0 the product itself can be a CPS (Block et al., 2018). Given the interconnectedness of the production line, one differentiates the assembly system from CPS by calling it Cyber Physical Production Systems (CPPS) (Block et al., 2018; Pantförder et al., 2016; Vogel-Heuser et al., 2014). The automated de-centralized decision making through communication between CPPS and CPS is the core of Industry 4.0 (Klöber-Koch et al., 2017; Schuhmacher & Hummel, 2016; Spöttl et al., 2016). A typical Learning Factory 4.0 impresses with its sometimes idealized but authentic representation of Industry 4.0 production processes (Abele et al., 2019; Tisch et al., 2016). Accordingly, this learning environment is also seen as complex from the learner's perspective (Tisch et al., 2016). Of course, this also applies to the vocational school context, but it should be noted here that the term Learning Factory 4.0 does not only refer to the holistic production plant. Because they consider the different requirement level of vocational school pupils compared to university students, Learning Factories 4.0 usually include a foundation laboratory. In this laboratory, the individual workstations (or learning modules) from the holistic production chain are set up separately, so that the learners can learn at these workstations before going to the large holistic plant (Scheid, 2018).

Above all, Ilomäki et al. (2016) state that digital competencies can best be developed in such a learning environment that is problem-oriented, technology-rich, authentic and has several different (digital) technologies constantly available. These criteria apply to Learning Factories 4.0 in technical vocational schools.

2.2.3 Competencies and Learning Factory 4.0

However, the main reason for setting up a Learning Factory 4.0 has been to promote professional and methodological skills (Abele et al., 2019). Even if the literature mostly considers the possibilities of professional and methodological competence development through Learning Factories 4.0 (Cachay et al., 2012; Kreimeier et al., 2014; Müller-Frommeyer et al., 2017), they can also promote holistic and multidisciplinary competence development. Because of the wide range of psychomotor, cognitive and also affective learning goals that can be targeted with Learning Factories 4.0, almost all skills can be promoted (Abele et al., 2019). The great advantages of Learning Factories 4.0 include the high degree of realism, learning activity, the state-of-the-art technical equipment and the possibility to test and develop processes in a low-risk (with regard to the consequences of wrong decisions) but highly contextualized learning environment (Abele et al., 2015). Learning Factories 4.0 are particularly suitable for developing problem solving skills in problem- or scenario-based learning situations (Abele et al., 2019).

It should be mentioned here how the term Learning Factory 4.0 is to be understood within this thesis in the context of technical vocational schools. For this purpose, the definition of Learning Factories is taken from the CIRP Encyclopedia of Production Engineering and is adapted to the context of technical vocational schools. Accordingly, a Learning Factory 4.0 is defined by:

- processes that are authentic, include multiple stations, and comprise technical as well as organizational aspects
- a setting that is changeable and resembles a real value chain
- a physical product being manufactured
- a didactic concept that includes formal, informal and non-formal learning, enabled by the actions of the trainees in an on-site learning approach (Abele, 2016, p. 1) and tailored to the vocational students' needs and possibilities.

This tailoring to the requirements of everyday vocational school life means that learning occurs through teaching and training and not through applied research. Accordingly, the outcome in vocational training Learning Factories 4.0 is not innovation, but rather focuses on the technical students' respective competence development (Abele, 2016).

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3. Development of Multidisciplinary Digital Competencies in Dual Vocational Education and Training from the Instructors' Perspective

This third chapter explores the perceptions of corporate instructors on which multidisciplinary digital competencies are necessary for working in Industry 4.0 as a future technical vocational student. Following an introduction, the theoretical background is explained. Then the scientific methodology and its results are presented. The results are then discussed and put into context, and avenues for further research are discussed.

3.1 Digital Competencies in the Dual Vocational Education Training System

During these times in which companies are increasingly networking vertically and horizontally (Ahrens & Spöttl, 2015) and educational facilities are concerned with the digitization of their activities (Roll & Ifenthaler, 2017), the dual vocational education and training system must also change (Spöttl et al., 2016). In the context of Industry 4.0, which connects the physical product manufacturing process with the digital possibilities of the Internet of Things (IoT), future employees must be prepared for the new demands of the job market and should have the competencies required to participate in society and in professional life. This requires efficient digital infrastructure at all learning locations, supportive framework conditions, and especially adequate didactic concepts and learning environments that support holistic teaching and learning processes across all learning locations. This applies not only to data-related training occupations (e.g. in media technology or computer science), but also to the commercial sector (e.g. industrial management assistant) and the industrial training occupations (e.g. mechatronics engineer).

In order for integrative didactic concepts to be developed for the vocational and educational training sector, an assessment of the possible shifts in competence caused by Industry 4.0 is required (Spöttl et al., 2016). Part of this research paper is aimed at examining whether technical vocational students are digitally competent, how digital competencies must change in line with the implementation of Industry 4.0, and how digital cooperation between learning locations in dual vocational training is currently advancing.

3.2 Theoretical Background

The following sections briefly describe the respective starting points for this exploratory, qualitative study.

3.2.1 Industry 4.0

The term Industry 4.0 was coined in 2011 as part of the German government's High-Tech Strategy to ensure the competitiveness of the German economy. It is a broad term that is interpreted and defined differently by different actors; as such, it lacks a common definition (Kagermann et al., 2013; Tschöpe et al., 2015; Venema, 2015). For the Federal Ministry of Education and Research, Industry 4.0 comprises the smart integration of modern information and communication technology with manufacturing (Federal Ministry of Education and Research, 2017). The German Mechanical Engineering Industry Association (*Verband Deutscher Maschinen- und Anlagenbau* – VDMA) defines Industry 4.0 with an emphasis on maintaining competitiveness, the cost cutting potential, and the process of adaption, and also highlights the issue of real-time data transmission (Anderl & Fleischer, 2015).

The term Industry 4.0 is frequently used as a synonym for digitization, which would only marginally distinguish it from the third industrial revolution, which refers to the comprehensive implementation of automation. However, the digitization of production processes is merely a fraction of what Industry 4.0 encompasses (Kagermann et al., 2013; Wilbers, 2016): its utmost novelty is the replacement of a central organization by a decentralized control and manufacturing process (Ahrens & Spöttl, 2015; Spöttl et al., 2016). Innovation and technology are advancing in bounds, increasing the performance of embedded systems and leading to so-called smart factories (Federal Ministry of Education and Research, 2017; Wank et al., 2016). The three following points are characteristic of this industry (Ahrens & Spöttl, 2015):

- The production systems of a smart factory are vertically connected from the management level to the production line
- The second integration runs horizontally across the value-added networks, thus connecting the entire supply chain and, in particular, also including the customers
- To enable horizontal and vertical integration, a consistent engineering system spanning the entire product lifecycle is required.

Industry 4.0 is based on so-called Cyber-Physical Systems (CPS). These are defined as integrated systems that use sensors to record physical data and actuators to collect and influence physical processes in real time (Lee et al., 2015; Spöttl et al., 2016). CPS are digitally connected, can use universally accessible services and data and have user interfaces for human-machine interaction (Vogel-Heuser et al., 2012; Vogel-Heuser et al., 2014). This is how a self-organized, efficient and flexible production can be created in which humans, machines and products communicate with each other and processes can be intelligently interlinked (BMWi, 2017).

3.2.2 Industry 4.0 and Companies

The majority of companies foresee a great potential for Industry 4.0 technologies within their production sites (Klammer et al., 2017). This includes for example: avoiding redundancies, reducing storage and transport costs due to horizontal integration of the value-added networks, and increasing customer satisfaction due to new digital business models (Acatech, 2016b; Huber, 2016; Koch et al., 2014; Windelband & Dworschak, 2015; Windelband & Faßhauer, 2016). The most important aspects for companies of all sizes are flexibility in production as well as an increase in revenue and production.

But despite this potential, many companies, especially small and medium-sized enterprises (SMEs), have been restrained in their enthusiasm (Sommer, 2015). The scepticism is justified, for example, by the complexity and the high expenditure required to get the systems up and running (Wank et al., 2016). Furthermore, SMEs complain that they usually employ an insufficient number of employees to handle other complex issues beyond their product range (Faller & Feldmüller, 2015; Sommer, 2015). Sommer argues that a lack of self-confidence in dealing adequately with the consequences of information security and data protection could be a reason for the reluctant implementation of Industry 4.0 in SMEs (Sommer, 2015). The accompanying challenge for human resources development will be the adequate occupational training and further education of (future) employees to prepare them for the infrastructural Industry 4.0 tasks. Thus, suitably adjusted education and training could help to counter the attitude that horizontal and vertical networking is too expensive and too complex for small and medium-sized enterprises (Hecklau et al., 2016; Sommer, 2015).

3.2.3 Industry 4.0 and Vocational Schools

The curricula of several occupations that require vocational training, such as electronics technician for automation technology or industrial mechanic, already include relevant target formulations and content for Industry 4.0. These demonstrate that the current curricula already cover many of the content and competence requirements of Industry 4.0 (Löhr-Zeidler et al., 2016). To ensure that Industry 4.0 can be successfully taught in vocational schools, modular teacher training courses are offered in Baden-Wuerttemberg, for example. These courses cover new cross-modular content in the areas of metal processing and electrical engineering and provide didactic input (Löhr-Zeidler et al., 2016). In order to ensure an appealing high qualification of dual vocational training, standardized curricula regarding Industry 4.0 are requested (Scheid, 2018). A study of the Bavarian Employers' Association for the Metal and Electrical Employers' Association (*Bayrischer Metall- und Elektro-Arbeitgeberverband* – bayme vbm) recommends that initial vocational training be made more application-oriented (Spöttl et al., 2016). To further enhance process orientation, the State Institute for School Development (*Landesinstitut für Schulentwicklung*) of Baden-Wuerttemberg has developed a corresponding Handbook 4.0 (Hörner et al., 2016). This offers technical colleges as well as vocational schools with a focus on metal and electrical engineering an adequate overview over the implementation of Industry 4.0 in the respective classes, sorted by requirements and varying scenarios.

The call for adjusting the technical equipment of schools to meet the demands of Industry 4.0 (Spöttl et al., 2016; Wilbers, 2017) is being implemented in Baden-Wuerttemberg by installing 37 Learning Factories 4.0 in technical vocational schools (Ministry for Economic Affairs, Work and Housing, 2017, 2018). The Learning Factories 4.0 represent a new approach to the implementation of Industry 4.0 in technical vocational schools. A Learning Factory 4.0 (LF 4.0) is a model-like Industry 4.0 manufacturing facility, which has been implemented at technical vocational schools in Baden-Wuerttemberg since 2017 (Ministry for Economic Affairs, Work and Housing of Baden-Wuerttemberg, 2017). The Learning Factory 4.0 consists of a modular basic laboratory in which basic content is to be learned. Singular industry-related topics can be taught on corresponding modules. Here, the students get to know individual components of the entire facility in more detail. The primary goal of the basic laboratory is to prepare the students appropriately for the demands of Industry 4.0 (Scheid, 2018). The larger and holistic Learning Factory 4.0 facility connects, as a CPS, physical production with the corresponding control software. Because in this case the whole production line is a CPS, it is also called Cyber-Physical Production System (CPPS) (Monostori, 2014; Seitz & Nyhuis, 2015). Among other things, the CPPS is used to model complex production lines and batch size one production. Furthermore, the effects of connected production are displayed realistically (Ministry for Economic Affairs, Work and Housing 2015; Scheid, 2018).

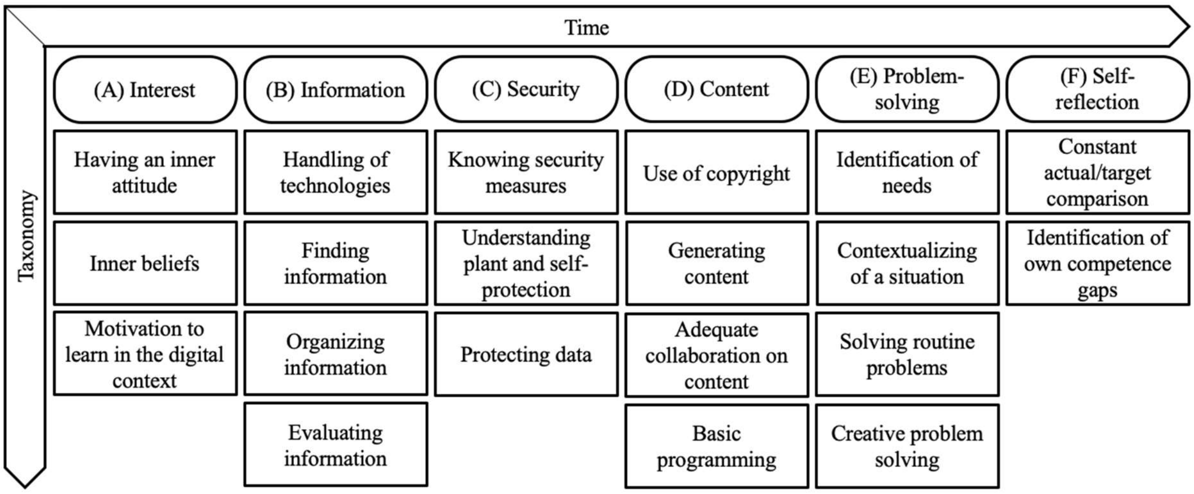
3.2.4 Multidisciplinary Digital Competencies

The background described above requires an examination of which competencies in the digital context are necessary in order to act confidently and in accordance with the situations of everyday work and social environment (Abele et al., 2015; Kagermann et al., 2013; Walker, Link, van Waveren, et al., 2016; Wesselink et al., 2009). This question of multidisciplinary digital competencies has not been conclusively answered. Thus Genner et al. (2017) discuss the necessity of a defined term, but in the end they do not provide an answer. The rapid progress of Information and Communication Technology (ICT) in recent years, increasing globalization, modification in occupational content, and changing occupational structures ensure that companies should continuously engage with transformed occupational requirements and the corresponding competencies (Genner et al., 2017; Tynjälä, 2009). Due to the thematic and occupational differences, competence diagnostics is the ideal solution in the search for a common examination level. For reasons of authenticity, an occupation-oriented competency diagnosis should be designed close to real life conditions in order to ensure "safeguarding and support of study- and work processes" alongside theory (Klotz, 2015, p. 36). This common level of examination refers to skills and abilities which cannot be allocated to a specific subject in vocational education and training and are therefore regarded as multidisciplinary digital competencies. The promotion of such multidisciplinary competencies, which affect technical vocational students of a wide range of subject areas, must be given the same standing as the respective technical skills and abilities (Hübner & Wachtveitl, 2000). In order to simulate real practical relevance, a model of multidisciplinary digital competencies should be applicable to everyday vocational tasks of technical vocational students. A listing of potential individual skills and abilities, derived from literature, is pictured in Figure 3.1. It is based on several aspects of DIGCOMP projects of Ferrari (2013) and Carretero et al. (2017), on ideas of the ICILS study (Fraillon et al., 2013, 2014), and on the main competence dimensions of the 21st century skills of van Laar et al. (2017), and has been specifically complemented by demands raised by Spöttl et al. (2016). Figure 3.1 is intended to allow a task in the context of Industry 4.0, whether industrial or commercial, to be dissected into its individual components. The dimensions of the model can be viewed from both a chronological and a taxonomic point of view. The applied taxonomy of learning objectives is based on Anderson et al. (2001). After going through the above-mentioned scientific literature, the constructs are divided into the chronological dimensions (A) *Interest*, (B) *Information*, (C) *Security*, (D) *Content*, (E) *Problem solving* and (F) *Self-reflection*. These constructs are listed alongside the associated skills and abilities in Figure 3.1. In the following, Figure 3.1 is explained in more detail; it should be pointed out that the taxonomic gradations and the chronological arrangement of the constructs serve the purpose of model development and orientation at the current point in time and should not be considered as to be set in stone. A first review of the literature-based order established in Figure 3.1 will take place in the following explorative study. A validation of the same requires a further qualitative and subsequent quantitative verification by means of a structural equation model.

Interest: According to Fraillon et al. (2014), the emotional engagement of individuals with digitality at work but also at home plays a major role. In the following, this dimension is referred to as interest in learning and working with ICT of all kinds. The inner attitude is understood as the attitude towards the use of digital devices in general (Yerdelen-Damar et al., 2017). Inner beliefs about engaging with ICT can impact the outcome and the emotional commitment to solving the task. These two abilities, in sum and supplemented by the ability to self-reflect (dimension (F)), result in the motivation of the acting person. Whether an individual develops competence depends, amongst other things, on his or her approach to solving a task successfully (Heckhausen & Heckhausen, 2010; Hecklau et al., 2016; Kreisler & Rebmann, 2014). Whilst attitudes and beliefs are intrinsic to this construct, motivation also includes extrinsic variables.

Figure 3.1

Multidisciplinary digital competencies derived from the literature



Information: The dimension of cognitive information acquisition and processing unites four skills. The basis is the handling of digital technologies (Fraillon et al., 2013, 2014; Spöttl et al., 2016). Knowing where and how to find the information you are looking for is the second skill in this competence dimension (Ferrari, 2013; Fraillon et al., 2014). As more and more information become available, it must be ordered cognitively, but also physically by using appropriate structures in order not to lose the overview. When organizing information, it is also essential to evaluate the information found and to separate unimportant from relevant information in the specific context (Fraillon et al., 2019).

Security: By means of the transparent and centralized standardization of information and digital systems as well as of the interconnectedness of the companies, every individual within the organization must be aware of how safety-relevant work is conducted (Carretero et al., 2017; Ferrari, 2013). This dimension deals with the issue of students taking certain safety standards into account at all times while working on a task (Carretero et al., 2017; Spöttl et al., 2016). This does not refer only to IT security; the physical security of the person and his or her environment are also represented within this dimension. The first point in this dimension considers whether the individual knows the security mechanisms and standards of the company.

Understanding these is the prerequisite for their successful execution, because security – not only in the context of digital technologies – is guaranteed only if the person acting takes all security measures into consideration and applies them. The three dimensions (A), (B) and (C) described so far represent the basic skills and abilities for the following dimensions and fundamentally influence the success the approach to the task.

Content: If (A), (B) and (C) are given, the information obtained is now combined with existing knowledge about the problem (Carretero et al., 2017; Ferrari, 2013). To use content or generate new content, individuals must know and be able to apply the rules of copyright (Fraillon et al., 2014). Based on this, it can be observed whether the students use the collective company knowledge and can work with the appropriate licenses (Ferrari, 2013). Meaningful and targeted generation of content is particularly important, including for the exchange of information regarding the task (Fraillon et al., 2014). The highest taxonomic level integrated in this model should represent the extent to which the student needs basic programming skills (Arntz et al., 2016; Ferrari, 2013).

Problem solving: It is expected that "Industry 4.0 will place significantly higher demands on all employees in terms of complexity, abstraction and problem solving" (Spöttl et al., 2016, p. 17). The dimensions described so far in this model are now combined in the ability to correctly identify further needs of a technological or cognitive nature, because the actual task management starts with contextualizing the task and its topic. The integrative process which combines theoretical knowledge, practical work and measures of self-reflection is part of the ability to solve problems (Tynjälä, 2009). It is therefore helpful to place the core problem into a broader context. If these are routine problems, tried and tested strategies from the intellectual property of the company can be used. Should the problem be something other than routine, the person affected must become creative and search for solution strategies on his own. The *problem solving* ability is indispensable for successfully developing competencies (Bereiter & Scardamalia, 1993). The nature of the problem determines the required taxonomy level of this dimension (Carretero et al., 2017).

Self-reflection: The integration of the ability to self-reflect as the last chronological dimension of the model represents a starting point for a renewed task management. The model is thus self-contained when the summative self-reflection changes the individual's attitude towards a thematically similar task. Therefore, this dimension includes one's ability to evaluate oneself formatively, the task itself as well as the actual or target status. The inclusion of a reflective component in the model serves to uncover one's own competence gap. This allows for a more precise self-assessment (Heckhausen & Heckhausen, 2010).

Even if the Industry 4.0-related changes in competencies and tasks cannot (yet) be predicted in detail, they require adequate qualification strategies and an organization of work which promotes learning. After all, a long-term successful implementation requires an in-depth understanding of change processes and their content (Kotter, 2007). Therefore, well-trained specialists are essential for the successful implementation of Industry 4.0 (Mansfield, 1996). Taking into consideration the fact that digital competence plays a role not only in the world of work, but also in the digital society (Fraillon et al., 2014), and based on the definition of vocational competence of the Standing Conference of the Ministers of Education and Cultural Affairs (KMK, 2007), a provisional definition of the term "multidisciplinary digital competencies" emerges:

> *Multidisciplinary digital competencies include the willingness, abilities and skills of a technical vocational student to reflect appropriately in the digital sphere of professional, social and private situations as well as act in an individual and socially responsible manner*.

Tynjälä et al. (2006) note that formally learned knowledge within the school context must be combined with informally learned knowledge from practice through self-regulating processes. The sustainability of multidisciplinary digital competencies is promoted through metacognitive and reflective competence dimensions.

3.2.5 Multidisciplinary Digital Competencies across Different Learning Contexts

It is both an educational and a policy goal to connect different places of learning (Aprea et al., 2020; Beiling et al., 2012; Cattaneo & Aprea, 2018). Looking at cooperation between learning locations on the basis of the connectivity definition of Griffiths and Guile (2003), it becomes apparent that multidisciplinary digital competencies have a supra-institutional integration function and are therefore not based on a purely organizational anchoring. The understanding of cooperation between learning locations is aligned in conformity with Griffiths and Guile (2003):

> Connectivity defines the purpose of that pedagogic approach which educators would adopt in order to take explicit account of the relationship between theoretical and everyday knowledge in their attempt to mediate the different demands arising in the contexts of education and work (Griffiths & Guile, 2003, p. 59).

The development of competencies can be optimized through close cooperation between schools and training companies (Biemans et al., 2004). This coordination of learning at school and learning at work has been the subject of relevant research for decades. Balancing the different responsibilities and services in a cross-location approach is a central component of successful competence development (Wesselink et al., 2009). Cattaneo and Aprea (2018) indicate that the conscious perception of the boundaries between the school and company learning locations allows for more effective learning in dual training. Taking into consideration the assumption that problem solving skills do not develop on their own in practice, the necessity of a didactic concept within the workplace is given (Hardy & Parent, 2003). However, to ensure that employee competencies measure up to changing job requirements, the optimization of cooperation between the learning locations is essential (Tynjälä, 2009). Competence development across learning locations is successful if both learning locations complement each other regarding their potentials and goals and contribute their specific competencies accordingly (Walzik, 2004).

3.3 Research Questions

Part of the exploratory study involves the examination of the model multidisciplinary digital competencies formed from the theory. The implied taxonomy within the model presents the authors' considerations so far. A fixation of the individual cognitive steps and a more precise classification into taxonomy levels allows statements about the valuation of the individual dimensions within the model. The following three research questions arise and need to be examined:

Current state of competence requirements

The examination of the current state serves to categorize the statements on competence levels made during the expert interviews. The open key questions of the interviews are based on the model multidisciplinary digital competencies (referring to Figure 3.1), but allow for autonomous answers to modify the model.

<u>Question 3.1</u>: How do those responsible for training assess the current state of dimensions of multidisciplinary digital competencies among technical vocational students?

Future competence requirements

In order to enable a later renewed survey as part of a long-term study, it seems reasonable to also query the assessments of the future development of multidisciplinary digital competencies in the expert interviews. The openness of the questioning should allow practical and honest answers.

<u>Question 3.2</u>: What influence does Industry 4.0 have on the future multidisciplinary digital competencies of technical vocational students from the perspective of those responsible for training?

Integrative learning in the competence development process at work and at school

In addition to research questions 3.1 and 3.2, the extent to which Industry 4.0 can have an impact on cooperation between vocational schools and training in companies will be examined. Accordingly, the interviewees were asked which multidisciplinary digital competencies are acquired where.

Question 3.3: How will cooperation between vocational schools and companies be changed by Industry 4.0 in order to best promote multidisciplinary digital competencies?

3.4 Method

The following sections provide a description of the research design, subjects, and analysis method of this study.

3.4.1 Design and Participants

A qualitative research approach was chosen to examine the expectations of corporate instructors towards the acquisition of multidisciplinary digital competencies. The age range of the participants ranges from 24 to 62 years (*M = 42.36; SD = 10.79*). Ten of the interviewees are male, one is female. Thus, the sample selection is not heterogeneous in terms of gender distribution. A similar inhomogeneity applies to the whole distribution in the dual vocational education and training system in Germany (Leifels, 2018). The chosen experts were selected from a pool of companies of different sizes. The company size ranges between 380 and 27,500 employees (*M = 8,727.09*; *SD = 9,253.50*). The interviewed instructors are responsible for a total of 2,828 technical vocational students. The companies are from different fields, but all are in the industrial sector and are located in Germany. The interviewees were selected based on their leadership function in dealing with the companies' technical vocational students. Therefore, they are responsible for all or a segment of the corporation's training management. All interviewees deal with the consequences of Industry 4.0 in their training management and have an overview of how cooperation with (vocational, general education and higher education) schools works in their companies. They also have an idea of how and where technical vocational students can acquire certain skills and abilities. The experts were equipped with the relevant information, were able to reproduce it precisely, were also available for a sufficient amount of time and were motivated to exchange views on the topic. Therefore, all external prerequisites for a successful expert interview were given (Gläser & Laudel, 2010). All interviewed corporate instructors took part in the survey voluntarily, in eight cases by telephone. All interviewees gave their permission to record and subsequently evaluate the interviews.

3.4.2 *Procedure and Analysis*

A qualitative content analysis based on Mayring (2015) was conducted to evaluate the provided statements. The data was obtained through semi-structured expert interviews. The semi-structured interviews were conducted in September and October 2017 by experienced trained academic staff. The length of the interviews varied between 35 and 61 minutes ($M = 50.72$; $SD = 7.28$). The recordings were transcribed using the F5 transcription software and then encoded with the F4 analysis software. This was done by two experienced coders. The deductively sorted but open questions of the interviews led to categories being inductively coded. The interrater reliability was good with K = 0.65 (Cicchetti & Sparrow, 1981). The categories created were structured according to the principals of valence analysis (Mayring, 2015). Categories were created by assessing and assigning the individual statements, and from these categories competence dimensions were formed. These competence dimensions were each subdivided with a scale into "high level", "medium level", "low level" and "not available". This resulted in a weighting scheme which provided information on whether and how the skills and abilities depicted and explained in Figure 3.1 are available, to what extent these are needed in Industry 4.0 and how cooperation between schools and companies can contribute in promoting them. The results provide explorative and innovative indications and contribute to the understanding of the model development.

3.5 Results

To illustrate the results of the interview study, Figure 3.2 shows a modified summary of the multidisciplinary digital competencies. In the following, the statements and opinions of the corporate instructors are presented as examples.

3.5.1 *Current State of Multidisciplinary Digital Competencies*

The experts stated that technical vocational students consistently show a high intrinsic motivation when it comes to working with digital technologies: "I would say the motivation of the technical vocational students is very high (...) I have only recently had feedback on this. They are all enthusiastic... At least I have not heard of any inhibitions yet" (Interview 3.8). The evaluation of the ability to handle the hardware and software of digital technologies showed a slight tendency towards high levels of proficiency as "today's technical vocational students are part of the digital age, meaning they know how to handle mobile phones, iPads and so on very well" (Interview 3.5). According to the interviewees, the ability to find information is present given that the technical vocational students' search processes are run routinely and in a structured manner and that they creatively search for additional sources when necessary.

While searching for information seems to pose no problem for the majority of technical vocational students, organizing and evaluating the information is mostly classified as medium or lower: "But where does the data come from and can the source be trusted?" (Interview 3.2). The majority of those surveyed rank the protecting of data by technical vocational students as alarming, because "the apprentices are used to putting everything on Facebook. They take photos of production lines and are not even aware of the fact that this could lead to the violation of industry secrets" (Interview 3.5).

The ability to create content by using digital technologies is rated highly by the interviewees, as expert 11 states: "Most are already very good at visualizing things quickly using a smartphone or tablet" (Interview 3.11). In contrast, the skill of programming is given an insignificant role, because "currently, one does not need to have the competence to programme anything" (Interview 3.8). The ability to collaborate using digital technology is largely classified as low, as "the apprentices know how to use the devices to communicate and they also behave adequately when they speak face to face. But when they don't see each other, they sometimes seem to have real difficulties to find an appropriate way to articulate" (Interview 3.2). Opinions drift apart when it comes to the current ability to solve problems. While the ability to routinely solve problems is generally ranked as low by the corporate instructors, the technical vocational students are able to come up with creative ways of solving a problem. The following quotations exemplify the divergent standpoints of the instructors:

- "They have very intelligent, pragmatic and also creative approaches on problem solving" (Interview 3.6)
- "Regarding most things the new generation just walks up and immediately asks someone else for help without even giving it a second of thought" (Interview 3.3).

A high ability to reflect was defined by the coding rules as follows: the technical vocational students reflect of their own accord frequently and regularly. They can think holistically and are able to contextualize their work and the resulting consequences. Furthermore, they critically question the handling of digital technologies. The majority of uttered statements made did not fit into this concept and were therefore ranked as low:

> This ability of just having to question some things: What is connected with what and where? Currently, this is not happening with the technical vocational students to an appropriate extent, because they don't do it in their private lives either. They use all sorts of apps but don't

understand that all of it is connected in the background. And then transferring that to the work context doesn't work at all (Interview 3.5).

3.5.2 Future Requirements of Multidisciplinary Digital Competencies

In terms of being interested in learning and working with digital technologies, the interviewees do not see any urgent need for action in the future. They consider the current development of motivation to deal with new topics to be satisfactory. However, this high level would also be needed to handle new innovative technologies at work in the future. For example, Expert 11 believes "that the trainees will have to bring their good attitude with them in the future as well as to be open-minded" (Interview 3.11). The same applies to the resulting handling of digital devices, which is currently already rated as very good: Expert 3 states that "in the future they will also grow up with these future technologies and it will of course be important that they can handle them correctly, but I have a lot faith in them" (Interview 3.3).

Even though the ability to find information was rated positively, a majority of the interviewees called for this ability to be improved in the future, because "the half-life of knowledge is now so short that you have to keep yourself constantly informed. This is a big one!" (Interview 3.5). Similarly, the experts expressed strong concern about the cognitive structuring of information. Expert 9 claims that "it will become increasingly more important to be able to act in an organized, structured and considered manner under chaotic and new conditions" (Interview 3.9). Similarly, the instructors worry about the ability to evaluate newly acquired information and to decide based on this information in the future. Expert 6 asks: "how will technical vocational students filter from this large amount of available information what is important and what irrelevant?" (Interview 3.6). The sensitivity to data security, which is already currently rated as rather low by those surveyed, is also seen as being very relevant in the future, since "after all, the topic of data security is a very decisive feature and critical in terms of success in the course of digitalization" (Interview 3.1). The corporate instructors stated that less basic programming skills would be required in future. Expert 7 argued that "to me the maximum is that an apprentice might be able to use an auxiliary programming method. Thus, in my opinion, the actual programming, even basic program writing goes a step too far in most vocational training professions" (Interview 3.7). The interviewees agree that technical vocational students should be able to collaborate appropriately with digital technologies in the future, and Expert 7 thinks that "how and with whom I communicate is the essential competence employees must have in the future" (Interview 3.7). The corporate instructors emphasize the notion that "it is difficult, mainly speaking and working with other people and departments must be developed more. Especially in the tone of conversation" (Interview 3.2).

When it comes to the problem solving ability of future technical vocational students, the independence in editing tasks was highlighted in the interviews, through statements like: "we must get them to take personal responsibility and to be courageous even when faced with the unknown. This would certainly also accelerate problem solving processes" (Interview 3.4). The ability to reflect, think and act holistically will play a greater role in the future; "as an apprentice, I will have to think outside of the box in the future. I must understand the upstream and downstream processes. I have to understand that I am a part of the whole. This applies to work but also to private life" (Interview 3.1).

3.5.3 Competence Development cross Different Learning Contexts

In order to obtain assessments of the integration of school and work, the interviewees were asked about specific competencies and the place where they were obtained, among other things. In their responses to these questions, all experts commented on the current relationship between schools and companies as well as on the implementation of digitality within the cooperation between these learning locations. The skills and abilities of multidisciplinary digital competencies can be promoted at work. This is reflected in several references to skills and abilities in the context of in-company training. For example, Expert 1 states that "when engaging apprentices in a project, we don't give them strict guidelines. I simply tell them that they are supposed to inform themselves regarding components, guidelines, safety standards, etc. by using the internet" (Interview 3.1). The answers of the participating corporate instructors to the question of whether the relevant theory is also learned at the workplace differ considerably, as some "are far from doing this systematically with a methodology" (Interview 3.5). The experts then reported that learning theoretical content is the main task of vocational schools, because "the transfer of theoretical knowledge takes place at school and, at the end of the day, that's where it belongs" (Interview 3.10). Furthermore, the learning of practical skills in a vocational school context is assessed in a balanced way. Half of the interviewees comment positively on practical learning opportunities at school, as the vocational schools "have a good basic structure and vision with the 'Lernfeld' approach, which I find very good" (Interview 3.11). But the other half criticizes the vocational teachers' attitudes, as "some teachers are 'quite far away' from current practical relevance in their technical subject" (Interview 3.1) and "many teachers, especially the older ones, have not yet come to terms with this sophisticated 'Lernfeld' approach" (Interview 3.5). A minority of the interviewees made positive remarks about educational methods and the motivation of the teachers to include practice-oriented teaching content. For example, Expert 8 stated that "if you look at these vocational schoolteachers here, it's incredible! They often collaborate with the companies in their free time. That's a totally different connection [compared to general education schools]. Of course, they also depend on us more, for example on feedback" (Interview 3.8). Other interviewees, in contrast, found that in their case motivation was not as high as experienced by Expert 8. The cooperation with schools was often seen as compulsory for both sides and thus described as a rigid relationship, in which there is little talk about the didactic integration of the learning locations. Expert 4 claimed: "We have a regular exchange with the vocational schools, but this is merely an exchange at the organizational level. This is not yet the possible merging of contents" (Interview 3.4). However, the majority of corporate instructors wish for better cooperation with regard to a closer integration of content and a greater flexibility for both training partners:

> So, a closer connection between school-based learning and in-company training makes sense in any case when it comes to access to working materials and the transfer of professional experience into the vocational course. I do believe that there is still a great potential for optimization, because right now two systems are simply running side by side (Interview 3.3).

The interviewees noted that the skills and abilities needed in the future, as discussed in research question 3.2, should be included more in teaching. For example, holistic thinking/process understanding, protecting data, or the legal consequences of copyright usage "must be put more into focus! Something questionable is written or posted on the Internet so quickly. In any case, this would have to be addressed more at school" (Interview 3.1). Also, the ability to solve problems should be further promoted by the schools, because "the apprentices should learn problem solving skills at school" (Interview 3.6). However, the corporate instructors state that they consider it difficult, for example, to promote the desired self-reflection in vocational schools to the extent that would be desirable. Drawing conclusions about processes and organizations from one's own actions should take on a greater role at vocational school so that technical vocational students can relate theoretical content to practice. And "this relation to reality must be encouraged more at school!", claimed Expert 6 in interview 3.6.

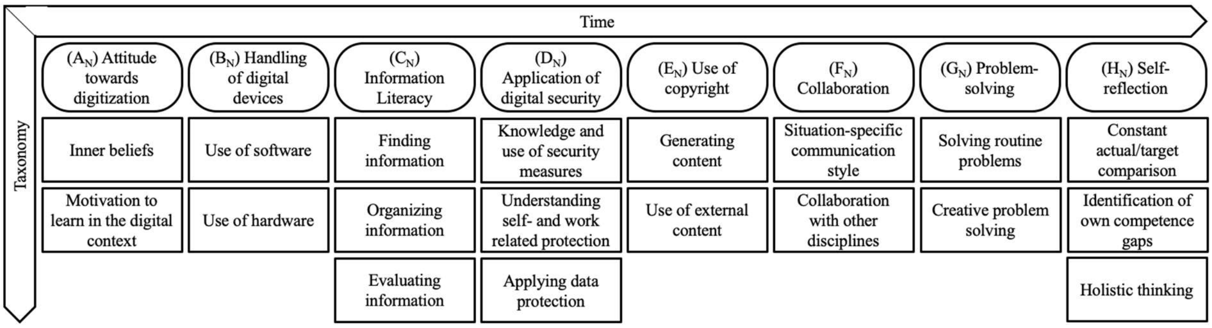
Finally, it was emphasized by all interviewees that while training programmes should be adapted to Industry 4.0, they are currently sufficiently flexible, so that there is no need for new diversification and sub-occupational groups. The responsible stakeholders should "be careful not to start reinventing any professions. The professional landscape actually offers enough openness to keep up with the development [of digital technologies]" (Interview 3.4). Five of the corporate instructors advocate for the dual vocational education and training system to be provided with a certain modularity, in which occupational groups learn overarching competencies and abilities in a basic module and then one trains and continues to train through modules in tune with the concept of lifelong learning. Therefore, in future, "the professions as well as their course of training should become much more modular. In the sense that you develop a basic module in which certain basic competencies are acquired" (Interview 3.9).

3.5.4 Key Findings and Model Modification

The illustrative answers shown here do not cover the entire distribution of answers, but are only intended as examples to show the clearest opinion in each case. In order to get a better overview, Figure 3.1 was revised based on all categorized statements. Thus, Figure 3.2. represents the summary of the future multidisciplinary digital competencies. Due to the statements regarding the emotional engagement of the technical vocational students, the competence dimension *(A) Interest* in Figure 3.1 was renamed to *(A_N) Attitude towards digitization* in Figure 3.2. Because the demand for the correct use of hardware and software was mentioned very frequently, this was introduced as a separate competence dimension, *(B_N) Handling of digital devices*. The skills and abilities listed below are based on further statements of the corporate instructors. With the decision to make *handling of digital devices* its own competence dimension, the dimension *(B) Information* of Figure 3.1 was changed to *(C_N) Information Literacy*. The structure of *(C) Security* from Figure 3.1 was thus confirmed by the corporate instructors and in Figure 3.2 merely renamed to *(D_N) Application of digital security*. The dimension *(D) Content* was not confirmed by the corporate instructors, but required a greater adaptation. Thus, the corporate instructors emphasized the importance of dealing adequately with copyright situations in the future, especially because young technical vocational students are so keen on creating or modifying content. Also, the ability to adequately communicate and collaborate with other departments was summarized in the competence dimension *(F_N) Collaboration*. The ability to have basic programming skills was not confirmed by the corporate instructors and was therefore not included in this new modified overview. The *(G_N) Problem solving* ability was divided into two areas by the corporate instructors: the ability to solve routine problems independently, and the ability to approach unknown situations creatively and courageously. For this purpose, the ability of contextualization of Figure 3.1 was assigned to *(H_N) Self-reflection*, whereas the corporate instructors often meant holistic thinking or general process understanding.

Figure 3.2

Summary of modified multidisciplinary digital competencies



3.6 Discussion

The findings show that the interviewees expect multidisciplinary digital competencies, as depicted in Figure 3.2, from the technical vocational students. However, the individual skills and abilities are weighted differently depending on the interviewee. It should be noted that the interviewees consider the curricula of the dual vocational education and training system to be flexible enough to cover Industry 4.0 content and to be able to include digital technologies (Löhr-Zeidler et al., 2016). On the other hand, more willingness and flexibility on the part of the educational partners are desired. At the same time, the corporate instructors criticized the fact that not all teachers would be open to new developments. Regarding this criticism, it must be kept in mind that it consists of subjective opinions expressed by the company partners and not by members of the educational institutions.

The interviewees confirm the view of Sappa and Aprea (2014) that the practically relevant activities are mostly learned on the job and the theoretical content at the vocational schools. They confirm corresponding statements that the promotion of the ability to self-reflect and attitude are more likely to be assigned to the learning location of vocational schools (Walzik, 2004). The interviewees also expressed the wish that the educational system would focus more on targeted support for problem solving skills and endorse an understanding of security as well as an increased integration of digital communication conventions in class. The ability to be enthusiastic about tasks in a digital context and with digital technologies was predominantly rated as "existing" and thus corresponds to the basics of emotional engagement of Fraillon et al. (2014). Technical vocational students' current handling of hardware and software was assessed by the majority as adequate. Even though the technical vocational students' abilities to find information was assessed as predominantly sufficient as of now, the instructors nevertheless diagnosed a need for more awareness here (Fraillon et al., 2013, 2014). The abundance of available information leads to an overall low ranking of the ability to structure information cognitively (Carretero et al., 2017; Ferrari, 2013). The same holds true for the ability to evaluate information and make decisions (Ferrari, 2013; Fraillon et al., 2014). This is currently not adequately developed and should be promoted more strongly by both partners in the context of vocational training.

With regard to dimension (D) from Figure 3.1, the experts complained of a missing sense of the essential – the so-called "looking beyond one's own nose". However, future technical vocational students should also develop self-reflection and question their own activities more critically and to a greater extent than they have done so far (Ifenthaler, 2012). In the questions on the ability to reflect, self-confidence and the courage to creatively search for new paths played a major role for instructors in the interviews. This point coincides with the model of Heckhausen and Heckhausen (2010), which among other things implies that self-reflection can lead to self-confidence and motivation. Even though the physical handling of digital technologies is viewed as appropriate by the interviewees, in their view technical vocational students usually act too carelessly and not in line with security guidelines in practice. The security aspect is currently regarded in the literature and also by the instructors as questionable and even possibly critical for future success (Carretero et al., 2017; Ferrari, 2013; Vanderhoven et al., 2016).

A more analytical, structured and creative way of solving problems is requested of the technical vocational students, as they will constantly have to face new problems and tasks due to the progressive and rapid changes within their working environment. To this end, it is advisable to promote these skills specifically through the cooperation of school teachers and instructors with practical experience on a project basis.

The interviewees did not shy away from self-criticism and acknowledged that they see potential for improvement in their own training company, particularly when it comes to promoting reflection, safe handling of digital technologies and communication skills. A closer exchange with didactically experienced teachers would consequently be beneficial. But, on the basis of the interviewees' statements, cooperation between schools and companies is usually based solely on the exchange of organizational information, such as certificates, absences and so forth, and therefore confirms the findings in the literature that cooperation relationships usually only work appropriately at the political and administrative level (Euler, 2004). But a purely administrative cooperation does not suit the demands of a closer substantive integration (Biemans et al., 2004). An agreement by the dual partners on a model of multidisciplinary digital competencies could be conducive to this cooperation (Biemans et al., 2004). Penk (2004) argues that an agreement on a common basis for the assessment of multidisciplinary digital competencies could foster coordination of content. The *Lernfeld* approach seems to be well received by the instructors and provides for a certain amount of orientation regarding processes at work (Lipsmeier, 2004). It is an interesting result that the interviewees, contrary to some research (Arntz et al., 2016; Ferrari, 2013), do not desire any sophisticated programming skills from the general workforce in the future (Delcker & Ifenthaler, 2017).

3.6.1 Limitations

The conducted qualitative study suffers from some limitations. The number of interviewees is sufficient for exploratory purposes, although a larger number of interviewees would have made it possible to also assign certain statements to specific industries or company sizes. Furthermore, the study is limited by an unequal ratio of male and female instructors. The companies surveyed all have the capital and human resources at their disposal to deal with change processes in the context of Industry 4.0 and their effects on the technical vocational students. A similar study devoted exclusively to small and medium-sized enterprises would generate enhanced insights. The available findings can only serve as an indicator to illustrate the differences in an exploratory way. In order to be valid for a corresponding population, the differences found here would have to be explored quantitatively.

3.6.2 Implications and Future Work

The findings of this study deliver insights for companies and educational institutions which are engaged in industrial and commercial occupational training and further education training within the framework of Industry 4.0. Technical vocational students must be adequately prepared for Industry 4.0 at school and during (vocational) training. This will be crucial for long-term success in the future (Kotter, 2007). In this respect, the blanket assessment of individual skills and abilities should make it possible to decide individually which competencies should be given more focus in which occupational profiles. The demand for a modular vocational education and advanced training culture is interesting. In order to establish such a way of learning, a closer cooperation between learning locations is fundamental. This cooperation could be realized, for example, by using a superordinate and open learning platform (Beiling et al., 2012).

Connectivity between schools and companies requires a close basis of collaboration (Tynjälä, 2009), such as the implemented Learning Factories 4.0 in Baden-Wuerttemberg (Klose & Wilbers, 2019). These model Industry 4.0 production facilities could function as didactic CPPS in vocational schools, both for cooperation between industrial and commercial schools as well as between vocational schools and companies (Scheid, 2018).

Regarding the connectivity of their company, the interviewees stated that the educational system is undergoing a digital transformation as well. So, the conclusion can be drawn that cooperation between learning locations must develop accordingly. The role of competence development that integrates learning locations is becoming increasingly central in a connected (working) world. The dimensions in which improvement of cooperation between learning locations is required are those of cognitive information processing due to the amount of information in the digital context, the security of company and personal data, the changing ability of technical vocational students to solve problems as well as the ability to reflect, which can be assumed to mutually influence the motivation to work and learn with digital technologies (Keller, 2010). In order to further modify the model of multidisciplinary digital competencies, a corresponding study with participants from vocational schools will take place. Subsequently, a special focus will be on teaching units related to Learning Factory 4.0.

3.7 References

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4. The Impact of Learning Factories 4.0 on Multidisciplinary Digital Competencies

This fourth chapter explores the perceptions of technical vocational teachers on which multidisciplinary digital competencies are necessary for working in Industry 4.0 and what impact Learning Factories 4.0 could have on developing them. After an introduction, the theoretical background is explained. Then the scientific methodology and its results are presented. At the end, the results are discussed and placed into context and avenues for further research are examined.

4.1 Industry 4.0 and the Dual Vocational Education and Training System

The following sections briefly describe Industry 4.0 as well as multidisciplinary digital competencies in the vocational school context.

4.1.1 Industry 4.0 – A Brief Introduction

The agitation about Industry 4.0 is a very German peculiarity. Outside the German-speaking world it frequently appears under the name "Industrial Internet of Things" (IIot) (Voigt et al., 2018). Both in the private sector and in scientific literature, the term Industry 4.0 has no distinct definition. However, the idea is slowly gaining ground that there is no fourth industrial revolution behind the politically motivated and artificially proclaimed term Industry 4.0, as was the case with the previous revolutions (1st industrial revolution: steam engine; 2nd industrial revolution: electrification; and 3rd industrial revolution: automation). It is rather an evolution linking the physical automation of the third industrial revolution bit by bit. The only "revolutionary" aspect seems to be the holistic view of a fully networked value chain, but the technological tools have been around for many years in practice.

Therefore, Industry 4.0 is especially understood as a holistic vision of the future, not only in production, in which people, machines and processes based on the Internet connect with each other. This means real time data exchange vertically within a company (from the management level to the production facility) and across the value chain horizontally. In this context, value-added networks are given preference over value chains (Gebhardt et al., 2015; Hecklau et al., 2016). These networks utilize data exchange between customers, employees, objects, and systems via cyber-physical systems (CPS) (Acatech, 2016). CPS are defined as integrated systems that use sensors to record physical data and use actuators to capture and influence physical processes in real time (Spöttl et al., 2016). The CPS are digitally networked and have user interfaces for human-machine interaction (Vogel-Heuser et al., 2012). Holistic interconnection through Industry 4.0 facilitates adaptations to spontaneous changes of the production environment (Hecklau et al., 2016). This may provide advantages to companies, such as the avoidance of redundancies and the reduction of storage and transportation costs. Through the value-added network and the real-time data transfer, the batch size of one enables individualized mass production (Gebhardt et al., 2015a). New business models relying on a more flexible and efficient production could provide a higher customer satisfaction due to possible individualization of products. Beside the expectation of creating new business models and boosting the economy through individualized mass production, there are also some issues which need to be critically assessed:

- Most companies view the digital transformation as the most urgent topic. But at the moment, only a few can see themselves in the value-added networks in Germany (Schäffer & Weber, 2018).
- An often-cited specific problem for a company while discussing Industry 4.0 is IT security. It is essential to protect the physical production line, but it is also a Herculean task for IT infrastructure (Thames & Schaefer, 2017). This applies especially to small and medium-sized companies (SMEs) (Sommer, 2015). The larger the company, the greater the chance that the complexity of Industry 4.0 can be mastered well by their human resources. For SMEs, the factor of human capital is a critical aspect in investing in Industry 4.0 (Sommer, 2015).
- Suitably trained employees will be the basis for Industry 4.0. But even if companies might know how the digital transformation within Industry 4.0 will affect the work of their employees, the stakeholders in the German dual vocational school system often do not. This will be a critical point for achieving a leading economic position (Gebhardt et al., 2015).

Furthermore, Industry 4.0 may have broad implications for its stakeholders, including changes in learning culture (Ifenthaler, 2018; Wilbers, 2017). It especially entails a change in employees' multidisciplinary digital competencies (Tisch & Metternich 2017; Berger, Granzer, and Lutz 2018).

4.1.2 Multidisciplinary Digital Competencies for Industry 4.0

Competence is multifaceted and has been interpreted in great variation (Westera, 2001). For example, Hartig and Klieme (2003) define competence as the combination of learnable skills and inherent abilities to behave adequate in non-standardized situations (Westera, 2001). There are numerous concepts of competence in the digital context, which usually differ from each other only in nuances (Meyers, Erickson, & Small, 2013; Ilomäki, Paavola, Lakkala, &

Kantosalo, 2014; Fraillon, et al., 2015; Vuorikari, Punie, Carretero, & Van Den Brande, 2016; van Laar, van Deursen, van Dijk, & de Haan, 2017). The concept of multidisciplinary digital competencies contains the *attitude towards digitization*, the *handling of digital devices* and *Information Literacy* (Fraillon et al., 2014). It also includes the aspect of *digital security* (Ferrari, 2013), digital *collaboration* (Carretero et al., 2017), *problem solving* and *reflection* (Eseryel et al., 2011), which are also part of the 21st century skillset (Ananiadou & Claro, 2009). Roll and Ifenthaler (2020) developed a model of non-subject-related digital competencies especially for technical vocational students. They define multidisciplinary digital competencies as the "combination of willingness, abilities and individual skills to behave adequately and socially responsibly in the digital context of multidisciplinary professional, but also social and private situations" (Roll & Ifenthaler, 2020a, p. 193).

4.1.3 Learning Factories 4.0 in German Technical Vocational Schools

Heyse (2018) notes that school policy and teaching in general must change in the digital age. This is especially crucial for industry-related vocational schools, where the learners train for their work life. A state-wide initiative supported by the Ministry for Economic Affairs and the Ministry of Education enabled technical vocational schools to install Learning Factories 4.0, which are thought to prepare students for the challenges of Industry 4.0 (Scheid, 2018). A Learning Factory 4.0 is a model-like production line-up implemented at several technical vocational schools in the federal state of Baden-Wuerttemberg since 2017. By the end of 2020 there will be more than 37 technical vocational schools with such a modern production facility in the state of Baden-Wuerttemberg (Ministry for Economic Affairs, Work and Housing of Baden-Wuerttemberg, 2017, 2018, 2019). Especially students of the metal and electrical industry are learning with Learning Factories 4.0. Scheid (2018) argues that subject-related and non-subject-related competencies are developable by teaching with Learning Factories 4.0. However, current Learning Factory 4.0 literature does not focus on competence development in technical vocational schools, and there are no empirical studies documenting the benefits of Learning Factories 4.0 for learning and teaching.

Learning Factories 4.0 never have the exact same technical structure. This is because the requirements for each Learning Factory 4.0 depend on the particular vocational school and its study programmes. Some of them focus on control engineering, some on the interface to Information Technology, and many focus on manufacturing (Scheid 2018). The popular term Learning Factory 4.0 includes two different but similar technical facilities in technical vocational schools:

1) Modular basic laboratory

There is a modular basic laboratory that allows teaching basic technical content. Individual industry-related topics can be learned at several different subsystems. These modules of a basic laboratory depend on each school's specification. So, the focus of the basic laboratory can be automation technology, electrical engineering, mechatronic or robotics. Usually students are allowed to work with the technology. The primary goal of the modular laboratory is to prepare learners for more complex tasks and problems at the large smart facility (Scheid, 2018).

2) Holistic smart factory

The larger holistic smart factory is a cyber-physical production system (CPPS). It is the more popular form of Learning Factory 4.0. In contrast to the modular laboratory, the CPPS combines physical production with appropriate control software. The physical production is linkable via Ethernet to Manufacturing Execution Systems (MES) and Enterprise Resource Planning (ERP) software. The CPPS also does not focus on only one subject but combines everything a real smart factory could have. Therefore, it includes components of automation technology, electrical engineering, mechatronics, and robotics. The CPPS models complex production lines and batch size one production. In addition, the effects of networked production are shown with the CPPS.

While Learning Factories 4.0, especially the CPPSs, differ from each other, common elements include a holistic production line combining a chaotic warehouse, the pneumatic conveying systems, one or more automated robots, several quality control elements, pressing modules, and heating modules (Scheid, 2018). However, research focusing on the instructional design of learning environments for Industry 4.0 including Learning Factories 4.0 at (vocational) schools is scarce.

4.2 Research Questions

This chapter seeks to close the research gap of how to design learning environments utilizing Learning Factories 4.0 to develop multidisciplinary digital competencies using an explorative qualitative study approach. Hence, the goal of this research is to gain insight into fostering multidisciplinary digital competencies in Learning Factories 4.0. It does so with through the following three research questions (RQ):

(RQ 4.1) What role do digitization and Industry 4.0 play in the technical vocational schools?

(RQ 4.2) Which multidisciplinary digital competencies do the technical vocational teachers most value for Industry 4.0?

(RQ 4.3) How do teachers integrate the Learning Factories 4.0 into their teaching?

4.3 Method

The following sections provide an explanation of the research design, participants, and analysis method of this qualitative study.

4.3.1 Design and Participants

As Scheid (2018) concludes, there is no research about the "teaching-learning arrangements within a Learning Factory" and about which "required competencies [are important] for future shop-floor workers" (Scheid, 2018, p. 287). In order to investigate the teachers' perspective on this research gap, a qualitative exploratory research approach was chosen. For the present exploratory qualitative study, interviews with a focus on the implementation of Learning Factories 4.0 at German vocational schools were conducted. The participants are teachers of electrical engineering or mechatronics. The main criteria for selecting the teachers were: (a) they have teaching experience with a Learning Factory 4.0 and (b) they were involved in the planning and implementation process of the Learning Factory 4.0 in their vocational school. On the basis of these criteria, 28 teachers were selected and contacted by email and phone to explain the research aim and project. A total of 19 interviews were conducted with teachers satisfying the above-mentioned requirements. The sample size should be adequate to investigate and answer the three research questions (Patton, 1990). The interviewees agreed to audio recording, participated on a voluntary basis, had the relevant information, and could reproduce it precisely. They were also available on time and were motivated to discuss the topic. Thus, all external conditions for a successful exploratory interview were given (Gläser & Laudel, 2010). Given the general gender inhomogeneity of the technical vocation (Leifels, 2018) it is not surprising, that all interviewed teachers are male. Unfortunately, because not all teachers wanted to provide information about their age, this important demographic information cannot be completely stated here. Based on the information provided, however, the age span is between 28 and 54 years. The interviewees teach between 75 and 385 ($M = 220.61$; $SD = 89.26$) students, of the relevant professions at the Learning Factory 4.0.

4.3.2 Procedure and Analysis

A semi-structured interview guide was designed beforehand, based on a prior literature review and consisted of four parts. First, the interviewees were asked demographic and general questions about their school. The second part included questions about the impact of digitization and Industry 4.0 on their technical vocational school. In this section, the teachers were also asked which multidisciplinary digital competencies future shop-floor workers should have in general. In the third part, the teachers were asked about the collaboration between their vocational school and regional companies. The fourth part of the interview focused on the pedagogical usage of the Learning Factories 4.0. The interviews lasted from 17 to 37 minutes (*M* = 27.15; *SD* = 6.78). Due to holidays and several exams, the period for conducting the interviews stretched between the end of April and November 2018. All the interviews were conducted via phone, recorded and then transcribed with the f4transkript transcription software (Dresing, 2019). The gathered material met all six criteria of objectivity (Mayring, 2002). Two trained employees of the University of Mannheim coded the statements (K = 0.68) via f4analyse analysis software (Dresing, 2019). The questions of the semi-structured interview guide were open-ended and therefore the statements were coded and recoded inductively (Mayring, 2015). The interviews were held in German. For this chapter the responses were translated and paraphrased.

4.4 Results

The technology of Learning Factories 4.0 is complex and currently one step ahead of the industrial standard a majority of companies use. Therefore, findings highlight the importance of structured implementation of Learning Factories 4.0 and the preparation of all stakeholders for Industry 4.0 processes on the organizational and staff level in vocational schools.

4.4.1 What Role do Digitization and Industry 4.0 Play in Technical Vocational Schools?

The responses regarding the role of digitization in vocational technical schools revealed two tendencies. Concerning the general technical infrastructure and the integration of digital technology in teaching, the participating teachers emphasized that schools “recognized the sustainability and necessity of digitization and must now be instructional” (Interview 4.15). The participants claimed that digitization is “priority no. 1 at our school!” (Interview 4.1) and that they aimed “to make our school more effective due to several applications of digitization. This includes also providing fast Wi-Fi, which should be available in every corner of our building” (Interview 4.11). While the school administration is organizing the acquisition of appropriate infrastructure, the teachers are thinking about the impact of digitization on their teaching. Most of the interviewed teachers interpreted the role of digitization not only in integrating digital devices, but also in discussing the consequences of digitization. “Our school administration made me discuss the advantages and disadvantages of the increasing role of digitization in our everyday world” (Interview 4.16). The minority of interviewees are still busy with the digitization of their analogue materials. This was expressed in statements like: “Right now I am concentrating on the digitization of my materials” (Interview 4.2) and “I just started to integrate digital devices into my lessons" (Interview 4.7). Industry 4.0 seems to be on the rise within technical vocational schools. The interviewees told us that "Industry 4.0 affects every curriculum at our school" (Interview 4.14) and "We have to discuss the opportunities and threats of Industry 4.0" (Interview 4.4).

With regard to the implementation of Learning Factories 4.0, the teachers are aware that these are "possibilities to teach with the most modern production technology at the time and that means you have to integrate this technology into the class. Otherwise it would be just a big expensive demonstration object" (Interview 4.19). While the will to integrate Industry 4.0 topics is present, the teachers warn that "you have to adapt the new [Industry 4.0] content for the varying level of students" (Interview 4.13). While "basic topics can be taught with all classes, how deep you can go into the matter depends on the profession of the students" (Interview 4.11). However, the motivation to teach with and about Industry 4.0 seems high. Through the implementation of Learning Factories 4.0 these schools have a technological lead in comparison to most companies: "these vocational schools with a Learning Factory 4.0 are more technologically advanced than many companies" (Interview 4.12). To conclude and answer research question 1: even if the infrastructure, like fast Wi-Fi, tablets, and smartboards, is improvable, the teachers are aware of the need to integrate digital devices and topics into their classrooms. The extraordinary technological standard of Learning Factories 4.0 is currently ahead of that of companies.

4.4.2 What Multidisciplinary Digital Competencies do the Technical Vocational Teachers Most Value in Industry 4.0?

The interviewees had many different ideas regarding the multidisciplinary digital competencies of their students. The interviews revealed: process understanding (nine interviewees with high expectations), problem solving (eight interviewees with high expectations), advanced IT skills (seven interviewees with high expectations), and broad expertise and holistic thinking (6 interviewees with high expectations each). One example for the latter is: "They must understand the consequences of technology for their individual life. This must be brought more into focus" (Interview 4.18).

Digital communication and collaboration seemed to be important for the teachers. Six participants expressed their view that the students should have a basic knowledge of other subjects. This would allow them to express themselves and understand problems in another profession. Interviewee 14 said: "They have to learn how to communicate with professionals of other disciplines. For example, a mechatronics student should be able to explain his problem to an IT specialist and vice versa" (Interview 4.14). Seven of the nineteen participants expected students' IT skills to be more advanced. They explained this with the example of programming serial ports or handling subject-specific IT software. The interviewed teachers did not expect their students to have deep programming skills, but typical basic programming ones. Interviewee 9, for example explained: "They must be able to act absolutely safely, especially in interface programming. Because networking in combination with data security and data analysis will become more and more important" (Interview 4.9).

In the school context, Information Literacy will also become increasingly important. "Students must have a proper research strategy. That will definitely become more important. Otherwise, as is the case today, they will only scratch the surface and not go into informal depth" (Interview 4.1). The opinion on copyright is summarized by this statement: "Copyright? Yes, this is of course always required in presentations here at school. But I think that in the future it will not be as important in practice as it is in school, where more theory is taught and where it is important to know where the facts come from" (Interview 4.18). To have a structured, critical strategy for solving problems seems a general but very important skill for acting safely in Industry 4.0. "To analyse a problem systematically" (Interview 4.6) and to "develop a creative way to problem solving, if the usual actions did not work" (Interview 4.4) appear to be important for future shop-floor workers.

The most often-cited skill students of technical vocational schools should develop to be prepared for Industry 4.0 is an understanding for processes, as shown in statements like: "They should be able to understand and analyse processes in general" (Interview 4.2). The recognition of individual processes should "be promoted by their systematic thinking to recognize processes" (Interview 4.5). Furthermore, the teachers interviewed did not appreciate the relevance of self-reflection in the digital context. To summarize the results of RQ 4.2: The interviewed teachers highlighted multidisciplinary digital competencies which are not subject-specific but are needs-oriented and important for young individuals to act adequately, individually and socially responsibly in the professional digital context.

4.4.3 How do Technical Vocational Teachers Integrate the Learning Factories 4.0 into Their Daily Teaching?

The responses were divided into three categories: (1) there is no pedagogical concept usable daily, (2) a pedagogical concept is under development, and (3) teachers integrate the Learning Factory 4.0 daily with functional pedagogical concepts. Before the participating teachers responded to the pedagogical integration of the Learning Factories 4.0 they were asked about the infrastructure of the Learning Factories 4.0. Most of them were built up by FESTO (Scheid, 2018). The majority of the teachers stated that the installed Learning Factory 4.0 works just fine and “over time you can easily handle minor problems” (Interview 4.15). Larger problems, however, can usually not been resolved without external support from the manufacturer. Interview 17 summarizes this fact quite well: “Overall, the system works well, but maintenance and preparation are very time-consuming” (Interview 4.17). Two participants admitted that they cannot integrate the Learning Factory 4.0 because they actually have no concept for its pedagogical use. However, this is also due to the fact that in these two schools the modules of the Learning Factory 4.0 were technically integrated only shortly before. Interviewee 3 revealed: “We have not developed any concepts yet, because we still have to integrate all the modules” (Interview 4.3). By contrast, there are several statements that reveal a different situation. These schools are testing and developing different pedagogical concepts right now; “[We had] the rough idea for quite a long time. But we are now finally in the actual development phase” (Interview 4.2). Many schools developed a concrete idea before they implemented their Learning Factory 4.0. But “conversion and adaptation are part of a bigger process. It took us quite a long time at our school to understand how to integrate our Learning Factory 4.0, especially the CPPS” (Interview 4.13). Given the complexity, it takes a lot of time until teaching at the Learning Factory 4.0 works. It seems like teaching with the CPPS works best on a project basis, in larger time slots and across class structures, but this requires a high level of school organization. The interviewees “have already been able to implement many ideas, but we still see no light at the end of the tunnel. Because the actual development and the actual improvement of the concepts come from experiences and routine” (Interview 4.1). Other participants agreed with Interviewee 1 and told us that “there are many small steps but we are slowly going in the right direction” (Interview 4.19).

Beyond the pedagogical integration of the CPPS, some schools go further and try to integrate a “virtual twin of the Learning Factory 4.0. This is our current development task” (Interview 4.17). The interviews show that the longer the Learning Factories 4.0 have been installed, the more sophisticated the concepts seem to be, and the more they are already used by the teacher. This is also reflected in the last category, in which the five affiliated schools have already been using their Learning Factories 4.0 for a long time and use “completely elaborated lessons [which] could also be used for further education” (Interview 4.9). The fact that some schools, after their concepts have already been tested, give further thought to the issues is shown by the following quote: “We are trying to integrate smartphones and tablets for exploring the Learning Factory. Therefore, we are building up simple AR [Augmented Reality] and VR [Virtual Reality] functions on our CPPS” (Interview 4.9). Furthermore, the interviews reveal a trend: the higher the degree of the students, the more the Learning Factory 4.0 is integrated into teaching. Many participants mention that “there are many more elaborate lessons and concepts for teaching future state-certified technical engineers with the Learning Factory 4.0 than for a lower educational level" (Interview 4.18). The lower the performance level of the several trained professions, the fewer concepts are already integrated into daily teaching within the Learning Factory 4.0.

4.5 Discussion

In summary, the interviewed teachers understood the necessity of multidisciplinary digital competence development (Berger et al., 2018; Tisch & Metternich, 2017). For a minority, the focus of the digitization of schools is still on providing fundamental responsive digital infrastructure. At first glance, this is a bit unexpected, considering that the interviewees work at schools equipped with the latest smart factory equipment. At second glance, it becomes clear that in addition to the Learning Factory 4.0, challenges such as the implementation of digital class books, fast and reliable Wi-Fi that is available in the entire school, not just in the room with the Learning Factory 4.0, or the procurement of digital devices still have to be mastered, even though German vocational schools are usually above average in their technical and digital equipment (Krützer & Probst, 2006).

But schools are also focusing on how to integrate digitization into their teaching. This means both the pedagogically meaningful usage of digital devices, but also digitality and its effects as a topic (Ifenthaler & Schweinbenz, 2013, 2016). The complexity of Learning Factories 4.0 and the fact that most companies in the vicinity of the technical vocational schools do not have similar facilities and adequate human resources at the moment (Sommer, 2015) could make it difficult to get help to fix bugs or further develop pedagogical concepts. A better orientation could be the universities, which work with their students at Learning Factories 4.0 (Abele et al., 2015). However, as Scheid (2018) already mentioned, there are major differences between the demands of universities and technical vocational schools. For example, while universities can work with their learners at the project level (Baena et al., 2017; Schuhmacher & Hummel, 2016), this form is only seldom teachable in the school context because of the often rigid timetables (Scheid, 2018). The digitization of schools and Industry 4.0 as a topic are strongly prioritized in the interviewed schools.

The competencies of RQ 4.2 are not tied to specific training occupations. Therefore, the claimed skills fit in a model of multidisciplinary digital competencies. Advanced IT skills could be a level of *handling digital devices*. The ability to use the internet for adequate information retrieval is attributed to the competence dimension *Information Literacy*. Protecting technical infrastructure from external access is assigned to *application of digital security*. Collaborating digitally matches the idea of the competence dimension of *collaboration*. To solve problems creatively or systematically fits *problem solving.* The ability to understand processes and holistic thinking could be assigned to *self-reflection.* They can therefore be considered part of the required multidisciplinary competencies (Wilbers, 2016) to work in an interconnected industry. Only the stated broad expertise of technical vocational students seems at a first glance not to fit a specific aspect of multidisciplinary digital competencies. It could either be part of *reflection*, *problem solving*, or *digital collaboration*, or of none of these (Roll & Ifenthaler, 2020a). Current literature claims that most schools do not have fitting pedagogical concepts to help develop competencies through teaching with the Learning Factory 4.0 (Scheid, 2018). But the current state of integration of Learning Factory 4.0 has to be assessed differently. While schools that have implemented a Learning Factory 4.0 for some time now have more mature concepts, most schools are in the developing process. The time factor and the experiences made should be taken into consideration. It is not surprising that the use of Learning Factories 4.0 varies, considering that many students in vocational schools have a lack of basic knowledge, like math, grammar, and languages (Scheid, 2018). While Scheid (2018) points out that various additional technologies, such as augmented reality (AR) and virtual reality (VR), should complement the pedagogical concepts of the Learning Factories 4.0, the findings show that some schools have already left the planning stage and are developing concepts on how to integrate AR and VR into their lessons with the Learning Factory 4.0. The biggest difficulty is breaking down the complexity to a level appropriate for each technical student. In five cases of our sample, this seems to work quite well. The findings of RQ 4.3 reflect the opinion of Kotter and Schlesinger (2008) that major technological implementations and change processes need to be very well prepared. The difficult and unresolved question here is how the teachers could have been better prepared for the complexity of the Learning Factories 4.0.

4.6 Implications and Future Research

The findings may be of interest to organizations that have identified Industry 4.0 as a major topic of their technical vocational education. School authorities should have detailed ideas about the later use of expensive and modern equipment such as Learning Factories 4.0 and the involved stakeholders should have concrete plans on how to prepare teachers. Also, creating new teaching or technical positions that support existing vocational teachers might have accelerated the actual pedagogically thought-out usage of Learning Factories 4.0. Technical vocational students must be properly prepared for Industry 4.0 in vocational schools and occupational training. In line with Spöttl et al. (2016) and Wilbers (2016), the awareness of which multidisciplinary digital competencies should be promoted could also help to consciously integrate them into teaching. The results may help to develop teaching scenarios for other Learning

Factories 4.0 in technical vocational schools or to adapt existing ones. The findings with regard to the multidisciplinary digital competencies could be applied to the occupational part of the dual training. The required interdisciplinary cooperation in training of companies (Spöttl et al., 2016) can be more intensively promoted than in the organizational environment of the vocational schools (Scheid, 2018).

This study is limited by the fact that the statements are the subjective personal opinions of the teachers (Flick, 2014; Kidd, 2002). The sample's validity is also limited: the present findings are based on a specific group of 19 respondents. However, given the fact that there are very few technical vocational schools with Learning Factories 4.0, the sample can be considered to provide a broad coverage. Based on these limitations, existing pedagogical concepts should be scientifically investigated in the next step in order to evaluate the effectiveness of Learning Factories 4.0 as new concepts in vocational schools. Competence tests that analyse the subject-related, but also the multidisciplinary digital competencies, of the technical vocational students should be at the centre of this evaluation. The fact that the model-based representation of Industry 4.0 can promote competencies in university is scientifically confirmed (Abele et al., 2015; Cachay & Abele, 2012; Cachay, Wennemer, Abele, & Tenberg, 2012), and to prove this also for technical vocational schools is the next step of this research.

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5. Multidisciplinary Digital Competencies of Pre-Service Vocational Teachers

In this chapter a structural equation model is used to analyse the relations between the competence dimensions, whether they are self- or externally and qualitative assessed. After an introduction, the theoretical background is provided. This is followed by the explanation of the research design and participants, before the results are presented and discussed.

5.1 Introduction

The current digital changes in the industrial world of work are often referred to as the "fourth industrial revolution" or Industry 4.0 (Acatech, 2016a; Mertens et al., 2017). While originally this was a German particularity, research on the topic is constantly growing in many different fields worldwide and is no longer limited to German industry (Belinski et al., 2020; Liao et al., 2017). In this paper, Industry 4.0 is understood as the horizontally and vertically interconnected digitization of entire industrial value chains. This includes the real-time data exchange between customers, employees, objects and systems via cyber-physical systems (CPS). This turns industrial value chains into value-adding networks (Gebhardt et al., 2015; Kagermann et al., 2013). Within these value-adding network, smart products, which carry operational data for their own individual building plans (Weyer et al., 2015), communicate with self-organized and decentralized cyber-physical production systems (CPPS). The resulting smart production lines enable batch size 1 production with maximum cost efficiency (Wilbers, 2017). This interconnection facilitates adaptation to spontaneous changes in the environment (Hecklau et al., 2016). A particularity of working in Industry 4.0 is that the contents of work change due to the interconnection, the real-time transmission of data due to CPS and the increasing automation of production.

Even if most studies on Industry 4.0 are still visionary or conceptual in nature (Veile et al., 2019), publications already focus on the resulting and necessary changes of occupational structures and work activities as well as additional requirements for employees, i.e., digital competencies (Gronau et al., 2017a; Hecklau et al., 2016; Hummel et al., 2015; Tisch & Metternich, 2017), such as procurement of information and holistic thinking ability (Spöttl, Gorldt, Windelband, Grantz, & Richter, 2016). There are already numerous studies on digital competencies (Carretero et al., 2017; Ferrari, 2013; Fraillon et al., 2013, 2019; Ilomäki et al., 2016) and 21st century skills (Ananiadou & Claro, 2009; Siddiq et al., 2016; van Laar et al., 2017, 2020). However, few studies have been conducted on the digital competencies of technical vocational students (Seufert, 2020; Spöttl et al., 2016; Tenberg & Pittich, 2017). These often have one thing in common: in the mostly explorative approaches, the pool of experts is very broad and stakeholders who are not directly involved in the training are often interviewed. This somewhat dilutes the statements of the respective studies (Hambach et al., 2017; Spath et al., 2013; Ziegler & Tenberg, 2020). Based on two previous exploratory studies which focused on German corporate instructors and (technical) vocational teachers regarding required multidisciplinary digital competencies for future technical vocational students, Roll and Ifenthaler (2020a) suggest that multidisciplinary digital competencies consist of specific knowledge, motivational aspects, cognitive abilities and skills, which technical vocational students in Germany require in order to be prepared for the upcoming changes of Industry 4.0. The multidisciplinarity identified in these two exploratory studies is based on the findings of Tenberg (2020) and Walker et al. (2016) that, due to the interconnectedness of Industry 4.0, it is important in the various training professions to possess multidimensional digital and multidisciplinary skills and abilities that are not purely professional or purely technological to in order to face multidisciplinary problems. Accordingly, multidisciplinary digital competencies should be understood from a dispositional perspective in which they are the sum of various motivational and cognitive competence dimensions (Blömeke et al., 2015).

Teaching all kinds of Industry 4.0-related competencies in the 21st century requires correspondingly competent teachers (Instefjord & Munthe, 2017; Maderick et al., 2015; Rubach & Lazarides, 2019) and therefore a change in the competencies of technical vocational students has implications for all educational stakeholders in the vocational and educational training (VET) system (Sloane, 2019). For example, school development will change because teachers must ensure that lessons are developed in such a way that the current state of digitization is discussed and the corresponding digital competencies are developed alongside current subject-related ones (Seufert et al., 2018).

In addition to the subject-related changes that Industry 4.0 brings to technical and commercial vocational school teachers, new adjustments of multidisciplinary perspectives are also highly relevant for general vocational teaching (Kutscha, 2017). Technical vocational students must also be prepared in schools for the multidisciplinary challenges of Industry 4.0 (Wittmann & Weyland, 2020). In addition to subject-related competencies, research is increasingly showing that all kinds of digital competencies such as dealing with IT security (Sîmandl et al., 2017) or Information Literacy (Scherer et al., 2017) are becoming important in the vocational classroom (Seufert, 2020). However, there is a need to address this issue, because the training of vocational school teachers is not systematically prepared for developing such competencies, and there is no empirical evidence describing the level of multidisciplinary digital competencies of vocational teachers (Gössling et al., 2020; Tenberg, 2020).

Self-assessment is a legitimate instrument to obtain information about the multidisciplinary digital competencies of pre-service vocational teachers in a resource-efficient manner (Calvani et al., 2008). But multiple or single choice questions are not fitting for every dimension of a multidisciplinary digital competencies framework (Calvani et al., 2008). Self-assessment in general can only measure competence indirectly (Meritt et al., 2005) and studies show that especially with regard to computer-related competencies, individuals tend to overestimate their skills and abilities (Ihme & Senkbeil, 2017). However, self-assessment can determine self-efficacy by asking for the participants' own subjective assessment of whether they are capable of dealing with specific situations (Bandura, 1982).

Another measurement technique requires observation of a large group over a longer time (Calvani et al., 2008) or a qualitative approach via semi-structured interviews (Lundkvist & Gustavsson, 2018). In contrast to Maderick et al. (2015) and their objective assessment via multiple choice questions, this study provides a qualitative approach to assessing pre-service vocational teachers' multidisciplinary digital competencies. Guzmán-Simón, García-Jiménez and López-Cobo (2017) recommend a qualitative measurement approach to provide further insights into obtained quantitative data. Accordingly, the focus of the study is to investigate the paths of the various competence dimensions of multidisciplinary digital competencies identified in an exploratory study (Roll & Ifenthaler, 2020a) among pre-service vocational school teachers through self- and external qualitative assessment. Specifically, this study has three aims: (1) to validate the proposed structure of the multidisciplinary digital competencies; (2) to examine the influence of attitude towards digitization on self- and externally assessed multidisciplinary digital competencies; and (3) to investigate the prediction of the externally and qualitatively assessed multidisciplinary digital competencies through self-assessment of multidisciplinary digital competencies.

5.2 Theoretical Framework of Competence Dimensions

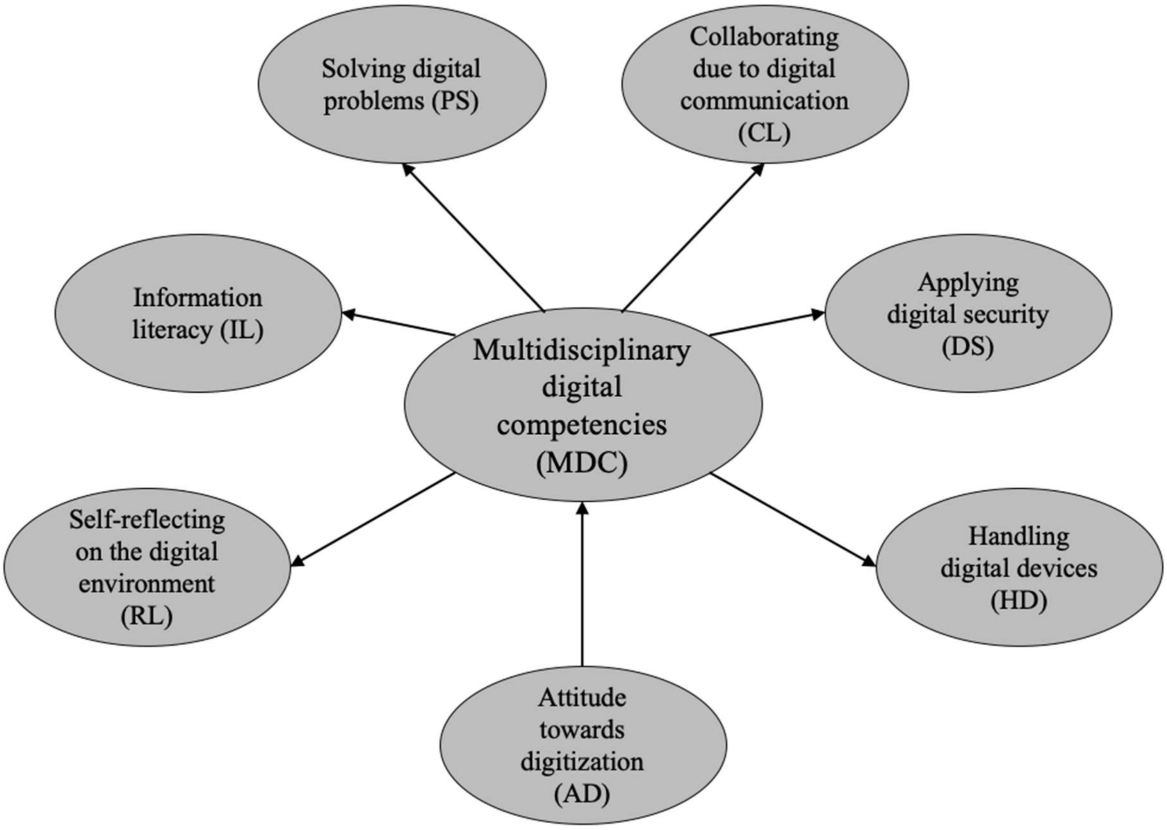
Given the numerous concepts of competencies (e.g. Ferrari, 2013; Ilomäki, Kantosalo, & Lakkala, 2011), literacies (e.g. Fraillon, Schulz, & Ainley, 2013; Meyers, Erickson, & Small, 2013; Pettersson, 2017) and 21st century skills (van Laar et al., 2017) in the digital context, the variety of meanings can be irritating (Ilomäki et al., 2016; Pettersson, 2017; Weinert, 2001). A specific research stream involves the models dealing with the integration of technology in the classroom that examine when, why, how and with what quality teachers integrate digital technologies into their lessons – for example, the will, skill, (access to technological) tool model, which the authors expanded by a pedagogical dimension in 2016 (Knezek & Christensen, 2016). It shows how teachers' attitudes towards digital technologies, skills and technological equipment determine whether or not they integrate digital technologies into their lessons (Petko, 2012). Another model for examining pedagogical, content and technological knowledge is the TPACK model by Mishra and Köhler (Schmid et al., 2020; Tondeur et al., 2020). It can be used as a basis, but taking into consideration that the present model does not explicitly ask for content knowledge, but for multidisciplinary competencies. Furthermore, this study is not intended to ask whether and how pre-service teachers have a pedagogical understanding of how to teach this interdisciplinary and technical content (Mishra & Koehler, 2006).

The dispositional sum of multidisciplinary digital competencies, which is presented in the following, can be located in the competence dimension of technological knowledge in the TPACK model (Koehler et al., 2014). In the following, however, the focus is on whether pre-service vocational teachers also have the multidisciplinary digital competencies that are required of technical vocational students in Industry 4.0. Multidisciplinary digital competencies are thought of as competencies that orientate themselves on the changing work environments brought about by the implementation of Industry 4.0 (Gebhardt et al., 2015; Ifenthaler, 2018; Sommer, 2015; Veile et al., 2019). Multidisciplinary digital competencies specifically address the "necessary and sufficient conditions" of "tasks, goal and success criteria" (Weinert, 2001, p. 51) related to Industry 4.0.

Multidisciplinary digital competencies, however, do not stand in contradiction with a domain-specific focus (Weinert, 2001). Domain-specific skills, abilities and knowledge are crucial for solving complex problems within a specific domain (Weinert, 2001). The focus of multidisciplinary digital competencies lies in the demanding problems of an interconnected Industry 4.0 work environment. Therefore, multidisciplinary digital competencies affect all professions that have to deal with Industry 4.0, regardless of their main discipline. Besides, if domain is described as a "universe of tasks and responses" (Shavelson, 2010, p. 46) the universe of Industry 4.0 and its specific digital tasks marks multidisciplinary digital competencies as a domain-specific competence model. Vocational teachers require knowledge, abilities and skills in their specific subject domains (Rausch & Wuttke, 2016). Considering the change of work requirements through Industry 4.0 (Ifenthaler, 2018) pre-service vocational teachers should have digital competencies that are not only bound to their subject but are multidisciplinary (Roll & Ifenthaler, 2020b). Based on the statements of corporate instructors, multidisciplinary digital competencies combine specific dimensions of several digital competencies or digital literacy frameworks to ensure that an individual has the willingness, abilities and skills to behave adequately, individually and socially responsibly in the digital context of professional, social and private situations (Roll & Ifenthaler, 2020a, 2020b). Figure 5.1 shows the seven dimensions of multidisciplinary digital competencies: (1) *attitude towards digitization*, (2) *handling of digital* *devices*, (3) *Information Literacy*, (4) *application of digital security*, (5) *collaboration due to digital communication*, (6) *solving of digital problems* and (7) *reflection* on the interconnected and digital environment.

Figure 5.1

Dimensions of multidisciplinary digital competencies



5.2.1 Attitude towards Digitization

The interviewed corporate instructors in Roll and Ifenthaler (2020a) emphasized a positive attitude towards learning and working with digital devices as essential for all kinds of work in Industry 4.0 (Roll & Ifenthaler, 2020a). Ferrari (2012) indicates that an integration of attitude is the key difference between a digital literacy framework and digital competencies models. Weinert (2001) describes attitude as the motivational, volitional and social willingness to act. For example, a positive attitude towards digitization can foster the self-efficacy beliefs of pre-service vocational teachers for technology integration in the classroom (Farjon et al., 2019; Lee & Lee, 2014; van Braak et al., 2004). Knezek and Christensen (2016) identified willingness as the greatest predictor in their will, skill, tool model. Therefore, *attitude towards digitization* (AD) is a predictor for this suggested theoretical framework of multidisciplinary digital competencies.

5.2.2 *Handling of Digital Devices*

Pre-service vocational teachers who want to integrate digital devices in the classroom need to know how to deal with the associated daily challenges (Koehler et al., 2014). Ilomäki et al. (2016) state that "technology-oriented terms describing general competences are diminishing in research papers" (Ilomäki et al., 2016, p. 668), but the *handling of digital devices* (HD) is still fundamental to models of digital competencies (Selwyn & Husen, 2010) due to the growing number of portable digital devices (Delcker et al., 2016; Martin & Ertzberger, 2013) This competence dimension includes both the handling of physical devices and the efficient use of corresponding software (Johnson et al., 2006; Roll & Ifenthaler, 2020a). The term "handling" emphasizes the action-oriented and practical use of digital devices (Calvani et al., 2012). Therefore *handling of digital devices* includes skills such as "basic computer operations, email, Internet, word processing programmes and presentation programmes" from "technology proficiency" (Mah & Ifenthaler, 2018, p. 122). But *handling of digital devices* does not involve programming skills (Fraillon et al., 2013).

5.2.3 *Information Literacy*

Based on the concept of the future "knowledge worker" (Tenberg & Pittich, 2017), it is important from a company trainer's perspective to have a certain degree of *Information Literacy* (IL) (Roll & Ifenthaler, 2020a). *Information Literacy* refers to accessing, analysing, evaluating and adequately communicating information (Fraillon et al., 2013, 2014, 2019). In contrast to media literacy, *Information Literacy* focuses on the procedural knowledge of managing information from static texts rather than understanding accordingly edited information (Fraillon et al., 2013, p. 17). Due to the large amount of information available, and to the fact that it can be incorrect, it is increasingly challenging for an individual to evaluate the authenticity, reliability and validity of information (Bundy, 2004). That is why using information responsibly and safely is part of *Information Literacy* (Fraillon et al., 2019) and part of the multidisciplinary digital competencies framework.

5.2.4 *Application of Digital Security*

In addition to *Information Literacy*, the *application of digital security* (DS) is usually a main dimension of digital competencies frameworks (Carretero et al., 2017; Ferrari, 2013; Vuorikari et al., 2016). Sommer (2015) identified the mishandling of data security issues as a major problem in Industry 4.0, especially for small and medium-sized enterprises (SME). Corporate instructors also added that this refers not just to the work, but also to the carefree private presence on the Internet of young people (Roll & Ifenthaler, 2020a). It is becoming increasingly important to learn about *application of digital security* in school to develop adequate skills in this competence dimension (Fraillon et al., 2019; Sîmandl et al., 2017; Šimandl & Vaníček, 2017). As a result, employees and teachers should know how to apply digital security measures (Šimandl & Vaníček, 2017). *Application of digital security* deals, for example, with the impact of malware, the simple securing of digital devices and networks, creation of safe passwords, identity theft, risks of digital communication (e.g. phishing emails), and sharing private and work-related information (Sîmandl et al., 2017).

5.2.5 Collaboration

The more devices are integrated in daily routine, the more popular virtual *collaboration* (CL) with digital communication devices becomes (Carretero et al., 2017; Ferrari, 2013). Adequate digital communication is often directly linked to the manner and rules of virtual collaboration. Therefore *collaboration* implies skills in communicating via digital devices, exchanging information and negotiating with mutual respect (van Laar et al., 2017). This affects the choice of suitable communication tools for specific situations (private vs. work-related situations) and an appropriate verbal diction towards achieving a common goal. Corporate instructors, interviewed by Roll and Ifenthaler (2020a), claimed that vocational teachers should integrate virtual communication habits in the classroom in order to develop their students' multidisciplinary digital competencies.

5.2.6 Solving Digital Problems

Interconnectivity through Industry 4.0 often helps in decision making processes through "generating, collecting, and processing required information" (Abdel-Basset et al., 2019, p. 2). However, with growing interconnectivity the complexity increases (Arnold et al., 2017). Complex problem solving is described as crucial for the 21th century (Eseryel et al., 2011). The corporate instructors added that it is certainly not a new requirement calling for better problem solving skills, but in an increasingly networked world, such skills are of great importance (Roll & Ifenthaler, 2020a). As a result, in order to be digitally competent teachers need skills in digital *problem solving* (PS) within the digital and interconnected context (Grzybowska & Łupicka, 2017; Müller et al., 2018). Therefore, structuring and planning a strategy to solve digital problems is required. In addition, it also requires Information Literacy skills, such as comparing, evaluating and selecting information from the current problem (Grzybowska & Łupicka, 2017).

5.2.7 *Self-Reflecting on the Digital Environment*

The digital environment is becoming increasingly complex due to Industry 4.0 and the interconnection of CPS in private, work and educational situations (Arnold et al., 2017). It is crucial to understand the consequences of ones' own digital actions and to *self-reflect* about one's actions in the interconnected and digital environment (RF) (Roll & Ifenthaler, 2020a). Reflection is systematic and ensures a continuity of learning (Lin et al., 2014). Therefore reflection within the interconnected and digital context of Industry 4.0 affects the individual attitude towards digitization (Ferrari, 2012) and the development of multidisciplinary digital competencies in general. Chen, Kinshuk, Wei and Liu (2011) argue that reflection skills are crucial for gathering and evaluating new information. Following Dewey (1910), Rodgers (2002) interprets reflection as a meaning-making process that encourages a deeper understanding of the respective content and its consequences. As a result, RF includes the ability to reflect on one's own actions within an interconnected world. This includes actions in private situations, such as sharing personal photos, but also affects the individual's workplace. However, RF implies an understanding of the consequences of the specific working steps within a supply chain network.

5.3 Research Questions and Hypotheses

The three aims of this study are (1) to validate the proposed structure of the multidisciplinary digital competencies, (2) to examine the influence of *attitude towards digitization* on self- and externally assessed multidisciplinary digital competencies, and (3) to validate the prediction of the external and qualitative multidisciplinary digital competencies assessment through the self-assessment of multidisciplinary digital competencies. The first research objective focuses on the proposed structure and related model fit of the multidisciplinary digital competencies model of Roll and Ifenthaler (2020a). To develop students' multidisciplinary digital competencies, vocational teachers must also possess the corresponding multidisciplinary digital competencies (Maderick et al., 2015). Therefore, the first research question aims to validate the influences of variables shown in Figure 5.1. Accordingly, *it is assumed that the theoretical dimensional structure of multidisciplinary digital competencies can be confirmed in this study* (Hypothesis 5.1).

The second research objective focuses on the effect of *attitude towards digitization* on multidisciplinary digital competencies for pre-service vocational teachers (Petko, 2012). The literature indicated a significant relationship between *attitude towards digitization* and self-assessed digital competencies (Bunz et al., 2007; Lee & Lee, 2014; Pamuk & Peker, 2009; Scherer et al., 2017; Wu & Tsai, 2006). Yerdelen-Damar et al. (2017) found that pre-service teachers' attitudes towards the use of digital devices had a direct influence ($\beta = .20$) on their self-efficacy beliefs in terms of the technological pedagogical content knowledge (TPACK-S). Other studies have confirmed a relationship between *attitude towards digitization* and self-efficacy (Prior et al., 2016), but focused less on the relationship between *attitude towards digitization* and actual performance. In a study by Aesaert et al. (2015), the authors neglect the relationship between these two variables. Bunz et al. (2007), meanwhile, found an influence of attitude on self-efficacy, but no relationship between attitude and performance. While Aesaert et al. (2015) clearly had younger participants in their study, the participants examined by Bunz et al. (2007) were first-year university students. In the following, based on the advanced studies and experience of the participants, the authors assume that the *attitudes towards digitization* also have an influence on multidisciplinary digital competencies. Accordingly, it is expected that *attitude towards digitization (AD) influences the self-assessed multidisciplinary digital competencies* (Hypothesis 5.2a) because attitude can be a predictor of self-assessed competencies (Yerdelen-Damar et al., 2017). And since *attitude toward digitization* is a driver for the use of digital media in education (Rubach & Lazarides, 2019), it is expected that *attitude towards digitization (AD) influences the external and qualitatively assessed multidisciplinary digital competencies* (Hypothesis 5.2b).

The third research objective focuses on how self-assessment may predict the score of the external and qualitative assessment of multidisciplinary digital competencies. This would be indicated by an effect of self-assessed multidisciplinary digital competencies (SAMDC) on the achievement in QAMDC. The meta study by Multon, Brown, and Lent (1991) shows that self-assessed competencies correlate with actual performance. In addition, Hatlevik, Ottestad and Throndsen (2015) found that self-efficacy predicts actual digital competencies. Due to the central assumptions of self-efficacy and performance, the third research question investigates the prediction on the actual performance of multidisciplinary digital competencies, externally and qualitatively assessed, through the self-assessment of multidisciplinary digital competencies (Bandura, 1986; Pajares, 1996) of pre-service vocational teachers. If pedagogical content knowledge positively influences the quality of teaching (Backfisch et al., 2020), then one can expect that the self-assessed multidisciplinary digital competencies, as specific advanced technological knowledge of the TPACK model, influence the quality of the actually displayed multidisciplinary digital competencies. Hence, following the findings of Hatlevik, Ottestad and Throndsen (2015), it is assumed that *self-assessed digital multidisciplinary competencies (SAMDC) can predict achievement in externally and qualitatively assessed multidisciplinary digital competencies (QAMDC) positively* (Hypothesis 5.3).

5.4 Method

The following sections present the participants in the study, the two instruments, the survey procedure, and the analysis strategy.

5.4.1 Participants

The participants of this study were N = 222 students of business and economic education at a European university. Seventeen were deleted from the dataset because they rushed through the online instruments. The critical threshold of minimum time needed to answer all questions truthfully was set at 25 minutes before the study (M = 40.48; SD = 9.02). Participants were between 18 and 35 years old (M = 22.78; SD = 2.89; 64.9% female; 74.1% undergraduates). At N = 205, the rule of thumb for critical CN = 200 is just exceeded. Exceeding CN indicates that its particular structure equation model could adequately reproduce an observed covariance structure (Bagozzi & Yi, 2012; Hoelter, 1981; Kline, 2015). Of these 205 participants, 48 (23.49%) completed vocational training themselves prior to their studies to become vocational teachers. While business and economics are the major subjects within their study programme, the pre-service vocational teachers also have to choose a second subject to subsequently teach in schools (see Table 5.1). They usually choose their second subject in the fifth semester of their bachelor course, thus explaining why, at the time of this study, 58.5% had not yet chosen a subject. Sixty-one students were in the second semester, three in their third, and fifty-six participants stated that they were currently in the fourth semester and therefore had not had the chance to choose a second subject.

Table 5.1

Minor subjects of participating pre-service vocational teachers

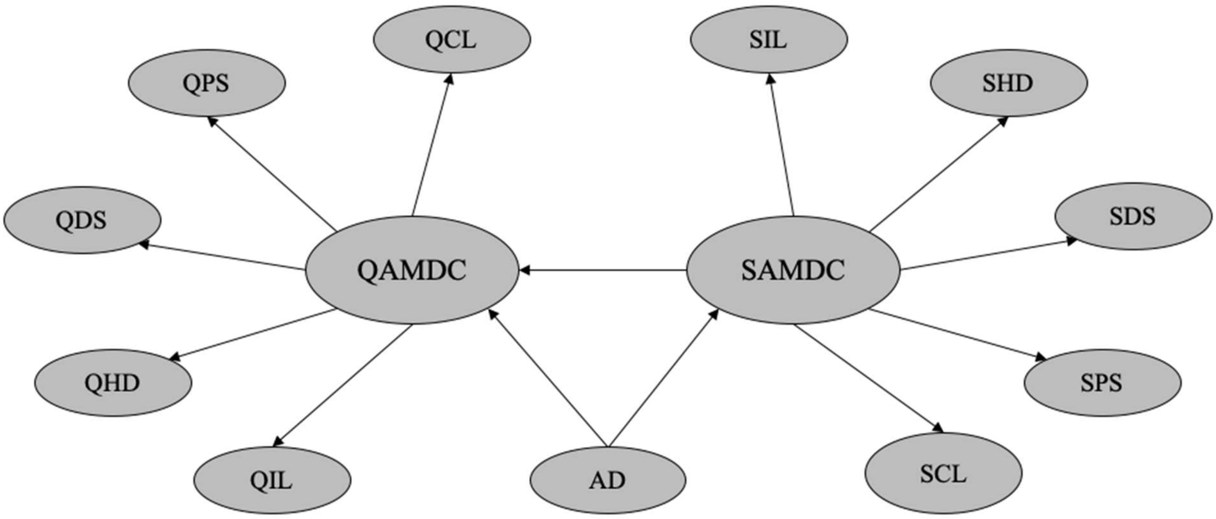
	Social Science	Linguistics	IT	Natural Sciences	Physical Education	Other	No subject chosen yet
Fre-quency	35	31	6	6	5	2	120
Percent-age	.17	.15	.03	.03	.02	.01	.59

5.4.2 Instruments and Procedure

In order to measure the declarative and procedural knowledge of the competence dimensions, measuring instruments were developed to measure the respective constructs through self-assessment as well as through scaling of responses to scenario-based tasks (Blömeke et al., 2015). The participants were invited to a computer room, where they received instructions via a presentation and a link to a website, which led to the two instruments – first a self-assessment questionnaire, and then a survey with open questions. Figure 5.2 shows the second order measurement model including the two instruments SAMDC and QAMDC and how the dimensions of multidisciplinary digital competencies influence them.

Figure 5.2

Measurement model of self- and externally and qualitatively assessed multidisciplinary digital competencies



5.4.3 Self-Assessed Multidisciplinary Digital Competencies

SAMDC is an instrument for measuring the self-efficacy of the several dimensions of multidisciplinary digital competencies. Therefore, it contains seven latent variables, which are presented in Table 5.2. Each of these consists of four items, which were measured through self-assessed five-point Likert scales. Within SAMDC the participants had the options "strongly agree", "agree", "neutral", "disagree" or "strongly disagree" with regard to the given statements. The reliability and the descriptive statistics are shown in Table 5.2. Cronbach's alpha indicates that the internal consistency is acceptable ($\alpha \geq .7$) for all dimensions used within the model except *self-reflection* (Bagozzi & Yi, 2012), Cronbach's alpha of RF was not improved by removing any items. However, because SAMDC measures the individual's own judgement on its multidisciplinary digital competencies, the construction of the latent variable SAMDC made the integration of *self-reflection* obsolete, because SAMDC already reflects the judgment as a self-efficacy variable (Bandura, 1986). This follows Roll and Ifenthaler's (2020b) exploratory study, in which vocational teachers ranked self-reflection as less important than the other multidisciplinary digital competencies. The self-assessed constructs are marked in the following with an "S" in front of the actual construct abbreviation (for example, the self-assessment for the competence dimension *handling of digital devices* (HD) is called SHD).

Table 5.2

Summary of self-assessed scales

	Items	Min	Max	M	SD	α	Skew-ness	Kurto-sis	SE	N
AD	4	2.33	5	4.00	.71	.79	-.58	-.21	.05	205
SHD	4	1	5	2.04	.85	.71	.85	.45	.06	205
SIL	4	1.75	5	3.95	.77	.79	-.54	-.22	.05	205
SDS	4	1	5	2.80	.92	.80	.02	-.51	.06	205
SCL	4	1.25	5	3.74	.77	.80	-.49	-.04	.05	205
SPS	4	1.4	4.7	3.53	.74	.71	-.43	.14	.04	205
RF	4	2	5	3.76	.62	.61	-.57	.63	.05	205

Note: Min = Minimum; Max = Maximum; M = Mean; SD = Standard Deviation; α = Cronbach's alpha; SE = standard errors; N = Number of participants; AD = Attitude towards digitization; SHD = Self-assessed handling of digital devices; SIL = Self-assessed Information Literacy; SDS = Self-assessed application of digital security; SCL = Self-assessed collaboration; SPS = Self-assessed solving of digital problems; RF = Reflecting on interconnected and digital environment.

5.4.4 Externally and Qualitatively Assessed Multidisciplinary Digital Competencies

The dimensions of multidisciplinary digital competencies were rated through qualified and trained researchers following criteria of qualitative content analyses. *Attitude towards digitization* and RF were not integrated into external and qualitative assessment of multidisciplinary digital competencies, because self-assessment seemed to be an adequate method of evaluating these two dimensions (Grant et al., 2002; Richter et al., 2000). QAMDC is designed as a fictive general work scenario. Within this problem setting, participants are asked to imagine that they work in a small to medium sized enterprise in the production sector, which is financially limited but it is under pressure to digitize processes. The participants are employees for the administration and have several tasks to deal with, such as procurement, human resources and marketing. Their supervisor has asked for a presentation about "Industry 4.0 and opportunities" for the firm. This scenario was divided into several questions and tasks, which were adapted from van Deursen and Van Dijk (2010) and created on the base of the particular examples of the DigComp 2.1 framework by Carretero, Vuorikari and Punie (2017):

- QHD – including what basic and advanced software would be helpful to solve the specific tasks (QBasc and QAdvc),
- QIL – explaining the strategy of searching for, structuring (QIorg) and evaluating information from the internet (QIeva),
- QDS – questioning how to handle upcoming security threats within the scenario (QShnd),
- QCL – questioning how you would collaborate via digital devices with
  - a.) your new supervisor and
  - b.) and old friend of yours, in terms of communication tools and rules (QCL)
- QPS – explaining how to deal with upcoming routine/well-structured problems, such as a sudden dysfunctional Internet connection (QProu), and writing down strategies for solving further complex ill-structured problem settings (QPcrt) (Seel et al., 2009).

QAMDC is based on a qualitative research approach, where participants had to answer open-ended survey questions (Hsieh & Shannon, 2005) that were directly related to the given scenario. Responses to these questions were clustered by three qualified raters into a five-point Likert scale. The criteria to assess the responses were pre-tested and defined within a workshop. The constructs evaluated in this way are marked in the following with a "Q" before the actual construct abbreviation (for example, the self-assessment for the competence *handling of digital devices* (HD) is called QHD). Table 5.3 shows the interrater reliability and a summary of the assessed tasks. The interrater reliability, calculated via the Intraclass correlation (ICC3,1), demonstrated the two-way mixed consistency (Shrout & Fleiss, 1979) of the three raters. Therefore, the scores in QAMDC can be compared with the self-assessed scores of the latent variables in SAMDC.

Table 5.3

Intraclass correlation (ICC3.1) and summary of externally and qualitatively assessed competence dimensions

Construct		Raters	ICC	F	p	Lower bound	Upper bound	M	N
QHD	QBasc	3	.80	13	.000	.76	.84	3.57	205
	QAdvc	3	.84	17	.000	.81	.87	3.23	205
QIL	QIorg	3	.69	7.8	.000	.63	.75	3.20	205
	QIeva	3	.77	11	.000	.72	.81	3.58	205

QDS	QDS	3	.84	17	.000	.81	.87	3.29	205
QCL	QCL	3	.77	11	.000	.73	.82	3.38	205
QPS	QProu	3	.65	6.5	.000	.58	.71	3.12	205
	QPcrt	3	.85	18	.000	.82	.88	3.10	205

Note. ICC = Intraclass correlation coefficient; F = F-Test; p = probability; M = Mean, N = Number of participants; QHD = Externally and qualitatively assessed handling of digital devices; QBasc = Externally and qualitatively assessed basic handling of digital devices; QAdvc = Externally and qualitatively assessed advanced handling of digital devices; QIL = Externally and qualitatively assessed External and qualitative-assessed Information Literacy; QIorg = Externally and qualitatively assessed organization of information; QIeva = Externally and qualitatively assessed evaluation of information; QDS = Externally and qualitatively assessed application of digital security; QCL = Externally and qualitatively assessed collaboration; QPS = Externally and qualitatively assessed solving of digital problems; QProu = Externally and qualitatively assessed solving routine problems; QPcrt = Externally and qualitatively assessed solving of problems creatively.

5.4.5 Analytic Strategy

To validate hypothesis 5.1, structural equation modelling (SEM) was used to evaluate the relations of the dimensions in SAMDC and QAMDC. SEM can test direct effects between constructs. This was used to validate Hypothesis 5.2a and Hypothesis 5.2b, because the applied SEM also contains the regression analysis for the influence of *attitude towards digitization* on SAMDC and QAMDC. The measurement model integrates the internal consistency within the dimensions of SAMDC and the assessments of the three qualified raters of QAMDC. By integrating all covariations and influences of the relevant dimensions, the SEM used shows the direct effect of SAMDC on QAMDC (Hypothesis 5.3). Due to the lack of normal distribution (Table 5.2), for the final SEM (with SAMDC and QAMDC) the robust maximum likelihood estimator (MLR) was used and adjusted through the Yuan-Bentler correction. Due to the settings of the applied self-programmed online survey tools, participants could not finish SAMDC and QAMDC if boxes had been left blank. Therefore, there was no missing data to deal with. To analyse the model of Figure 5.2, the statistics software R (version 3.6.1), R-Studio (version 1.1.463) and the R-package lavaan (version 0.6-7) were used (Rosseel, 2019; Steinmetz, 2015).

5.5 Results

Dependent t-tests showed that there were no significant differences between participants with and without prior vocational training on self-assessed multidisciplinary digital competencies, $t(203) = -2.70$, $p > .05$ and externally and qualitatively assessed multidisciplinary digital competencies $t(203) = -2.43$, $p > .05$.

5.5.1 Confirmation of the Dimensional Structure

An adequate model fit is essential to confirm that the model properly represents the data (Hooper et al., 2008). The SEM of Figure 5.2 shows a fit of χ^2 (846, N = 205) = 1105.378, p = .000, Comparative Fit Index (CFI) = .938, Tucker Lewis Index (TLI) = .934, Root Mean Square Error of Approximation (RMSEA) = .039 and Standardized Root Mean Square Residual (SRMR) = .071. According to Bagozzi and Yi (2012), one can reduce the stringent cut off rules that CFI and TLI are ≥.95 to CFI ≥ .93 and TLI ≥ .92 if SRMR ≤ .07. Considering the unsatisfactory internal consistency of RF (see Table 5.2) and the fact that SAMDC measures the individual's judgment of their multidisciplinary digital competencies (Bandura, 1986), it was decided to modify the model and not integrate RF (Grant et al., 2002) any further. Overall, the structural equation model now shows a good fit of χ^2 (689, N = 205) = 863.001, p < .001, CFI = .956, TLI = .952, RMSEA = .035, SRMR = .068. To examine the relations within the model in Figure 5.3, Table 5.4 shows the path estimates of the structural model. Hypothesis 5.1 is accepted because the significant path estimates and the fit indices confirm the theoretical dimensional structure of multidisciplinary digital competencies.

Figure 5.3

Structural model and influence of attitude towards digitization on the dimensional structure of self- and externally and qualitatively assessed multidisciplinary digital competencies (p < .01)

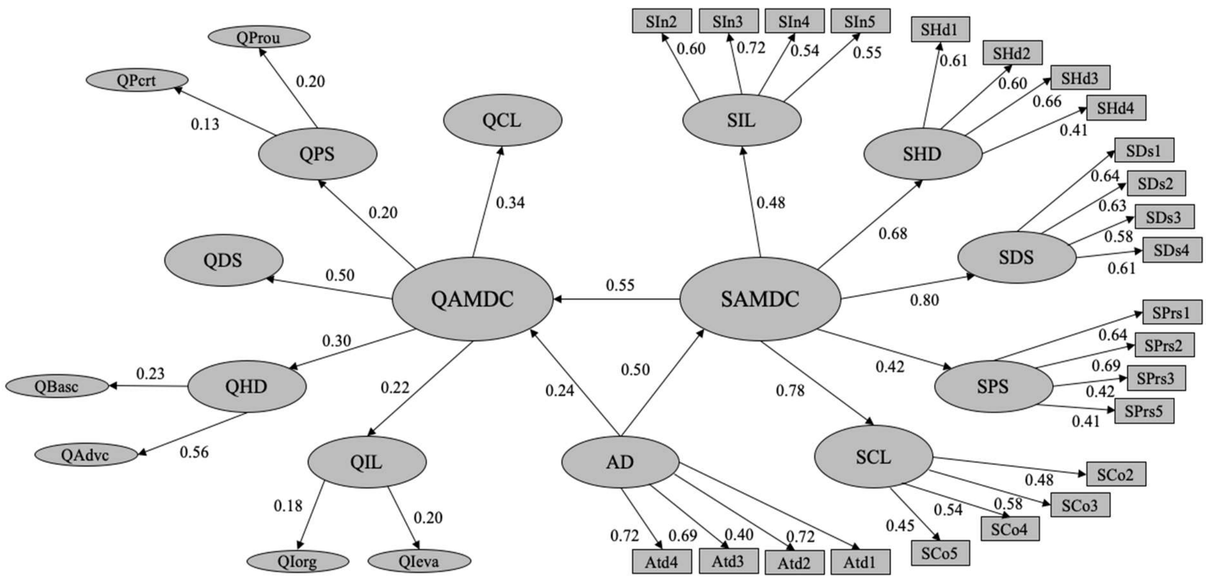


Table 5.4

Path estimates of the structural model

	Estimates	*SE*	*z*-value	*p*
AD - SAMDC	.501	.134	3.738	.000
SHD - SAMDC	.682	.161	4.235	.000
SDS - SAMDC	.797	.226	3.529	.000
SCL - SAMDC	.783	.185	4.228	.000
SPS - SAMDC	.418	.117	3.578	.000
AD - QAMDC	.241	.177	1.361	.174
QHD - QAMDC	.299	.115	1.758	.079
QIL - QAMDC	.220	.125	2.595	.009
QDS - QAMDC	.499	.143	3.487	.000
QCL - QAMDC	.345	.131	2.641	.008
QPS - QAMDC	.196	.105	1.860	.063
SAMDC - QAMDC	.553	.226	2.442	.015

Note.; AD = Attitude towards digitization ; SHD = Self-assessed handling of digital devices; SIL = Self-assessed Information Literacy; SDS = Self-assessed application of digital security; SCL = Self-assessed collaboration; SPS = Self-assessed solving of digital problems; QHD = Externally and qualitatively assessed handling of digital devices; QIL = Externally and qualitatively assessed Information Literacy; QDS = Externally and qualitatively assessed application of digital security; QCL = Externally and qualitatively assessed collaboration; QPS = Externally and qualitatively assessed solving of digital problems; SAMDC = Self-assessed multidisciplinary digital competencies; QAMDC = Externally and qualitatively assessed multidisciplinary digital competencies.

5.5.2 *Effects of Attitude towards Digitization on Self- and Externally and Qualitatively Assessed Multidisciplinary Digital Competencies*

Hypothesis 5.2a explores the relationship between pre-service vocational teachers' *attitudes towards digitization* and their self-assessed of multidisciplinary digital competencies, which was analysed through structural equation modelling. Figure 5.3 shows a medium standard regression weight of *attitude towards digitization* to SAMDC and Table 5.4 confirms its significance at a more conservative level ($\beta = .5$, $p < .000$). Therefore, hypothesis 5.2a is accepted.

Hypothesis 5.2b investigates the effects of pre-service vocational teachers' *attitudes towards digitization* and their achievement in QAMDC, which was also analysed using structural equation modelling. Figure 5.3 and Table 5.4 present a small but not significant standardized regression weight of *attitude towards digitization* towards QAMDC ($\beta = .24$, $p = .174$). Hypothesis 5.2b is rejected because of its level of significance of $p > .05$.

5.5.3 *Prediction of External and Qualitative Assessment of Multidisciplinary Digital Competencies through Self-Assessment*

Hypothesis 5.3 examines whether the self-assessed digital multidisciplinary competencies (SAMDC) can positively predict achievement in externally and qualitatively assessed multidisciplinary digital competencies (QAMDC). As can be seen in Figure 5.3 and Table 5.4, SAMDC significantly predicts the achievement in QAMDC ($\beta = .55$, $p = .015$). Therefore, Hypothesis 5.3 is accepted because $p < .05$.

Table 5.5

Summary of correlation between the constructs

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
AD (1)	-													
SHD (2)	.34***	-												
SIL (3)	.09	.11	-											
SDS (4)	.21**	.29***	.28***	-										
SCL (5)	.24***	.36***	.23***	.35***	-									
SPS (6)	.35***	.39***	.40***	.34***	.41***	-								
RF (7)	.25***	.25***	.43***	.41***	.34***	.54***	-							
QHD (8)	.24***	.31***	.03	.26***	.28***	.26***	.19**	-						
QIL (9)	.14*	.15*	.20**	.07	.13	.20**	.24***	.11	-					
QDS (10)	.19**	.10	.27***	.27***	.12	.22**	.25***	.25***	.12	-				
QCL (11)	-.11	.02	-.03	.05	-.05	-.05	.05	-.10	-.01	.12	-			
QPS (12)	.13	.23***	.12	.07	.12	.18**	.10	.15*	.30***	.22**	.07	-		
SAMDC (13)	.39***	.63***	.51***	.61***	.67***	.74***	.56***	.36***	.27***	.28***	-.02	.24***	-	
QAMDC (14)	.26***	.32***	.20**	.34***	.26***	.37***	.32***	.53***	.61***	.52***	.15*	.58***	.48***	-
M	4.00	2.04	3.95	2.80	3.74	3.53	3.76	3.37	3.39	3.29	3.38	3.10	3.35	3.30
SD	0.71	0.85	0.77	0.92	0.77	0.74	0.62	0.89	0.72	1.19	0.87	0.78	0.48	0.45

Note.; ***$p < .001$; **$p < .01$; *$p < .05$; AD = Attitude towards digitization ; SHD = Self-assessed handling of digital devices; SIL = Self-assessed Information Literacy; SDS = Self-assessed application of digital security; SCL = Self-assessed collaboration; SPS = Self-assessed solving of digital problems; QHD = Externally and qualitatively assessed handling of digital devices; QIL = Externally and qualitatively assessed External and qualitative-assessed Information Literacy; QDS = Externally and qualitatively assessed application of digital security; QCL = Externally and qualitatively assessed collaboration; QPS = Externally and qualitatively assessed solving of digital problems; SAMDC = Self-assessed multidisciplinary digital competencies; QAMDC = Externally and qualitatively assessed Multidisciplinary Digital Competencies; M = Mean, SD = Standard deviation.

When exploring dependencies in a structural equation model one has to be aware of the adverse effects of multicollinearity (Mansfield & Helms, 1982). To test the model on multicollinearity the variance inflation factors (VIF) of each predicting variable were calculated (Mansfield & Helms, 1982). A maximum of 1.53 of the VIFs meet the – surely debatable (O’Brien, 2007; Thompson et al., 2017) – rule of thumb that they must be less than 4 (O’Brien, 2007).

5.6 Discussion

Based on the fact that no significant differences regarding SAMDC and QAMDC were found between pre-service vocational teachers with and without vocational training, it can be assumed that the following results might also be interesting for the implementation of multidisciplinary digital competencies in the dual vocational education and training system.

To explore the misfit of SEM, fit indices are essential, and the results show that all fit indices support the primary hypothesis, whether the model can be validated or not (Cheung & Rensvold, 2002; Marsh et al., 2005). The decision about whether the SEM fits is based on four widely known fit indices, which provide an insight in the model's ability to reproduce an input covariance matrix (Bagozzi & Yi, 2012; Hooper et al., 2008; Taasoobshirazi & Wang, 2016). This study is based on the usual "goodness of fit" indices (GFIs), namely the Confirmatory Fit Index (CFI) and the Tucker-Lewis Index (TLI) (Hooper et al., 2008; Hoyle & Panter, 1995; Taasoobshirazi & Wang, 2016). Applying clear cut-off criteria, CFI and TLI should be $\geq .95$ (Hu & Bentler, 1998; Rigdon, 1996). These severe values (Bagozzi & Yi, 2012) were achieved after excluding RF from the SEM. Absolute fit indices gauge a "badness of fit" (BFI), which means that a value of zero would indicate an optimal fit (Hoyle & Panter, 1995). An absolute fit index is the Root Mean Square Error of Approximation (RMSEA), which depends on N. Considering $N = 205$ in this study, the RMSEA should be less than .06 (Hu & Bentler, 1998; 1999). Another absolute fit index is the Standardized Root Mean Square Residual (SRMR) (Taasoobshirazi & Wang, 2016), which should not be higher than .08 (Hooper et al., 2008; Hu & Bentler, 1998; 1999). By excluding RF, the absolute fit indices met these cut off criteria and the model fit became acceptable. Due to the good fit of the model there was no need to apply modification indices and change the model any further (MacCallum et al., 1992).

The estimates in Table 5.4 that relate to QAMDC are less strong than those that are associated with SAMDC, but the relative path estimates are similar. The estimates of the used latent variables to QAMDC are small to medium and not as highly significant as the self-assessed latent variables. The standardized path coefficients between SAMDC to SDS and SCL are quite high in Figure 5.3. The dimension *application of digital security* with SDS and QDS has the greatest impact on SAMDC or QAMDC. SCL and QCL have the second largest estimates. The constructs for *handling of digital devices* are in third position and *Information Literacy* in fourth. The externally and qualitatively measured variable of *Information Literacy* (QIL) has a weak estimate on QAMDC, while SIL has a medium path estimate on SAMDC. Solving of digital problems seems to have the weakest bound to multidisciplinary digital competencies. In conclusion, the model shows an acceptable fit and Table 5.4 provides mostly significant path coefficients.

The second hypothesis examined the influence of the *attitude towards digitization* on the participants' multidisciplinary digital competencies. The results show that the *attitude towards digitization* influences the self-assessed multidisciplinary digital competencies of pre-service vocational teachers. This significance confirms the finding of Yerdelen-Damar et al. (2017) that pre-service teachers' attitudes towards technology use had an effect on their technological competence. The hypothesized assumption (Hypothesis 5.2b) that the *attitude towards digitization* would also directly influence the external and qualitative assessment of pre-service vocational teachers' multidisciplinary digital competencies was not verified by this study. However, this supports the findings of Aesaert et al. (2015), who found no relationship "between pupils' ICT attitudes and their actual ICT competence" (Aesaert et al., 2015, p. 67). Whether ICT is implemented in teaching seems to depend on the general mindset of teachers (Hermans et al., 2008; Tearle, 2003). The findings confirm the conclusion of Bunz et al. (2007) that there is a direct relationship not between computer anxiety and actual computer-email-web-fluency, but between attitudes and self-perception of the participants. As the data shows, SAMDC could be a good and significant predictor for actual QAMDC. In other words, this study confirms that ICT self-efficacy correlates positively with the achievement in ICT competence tests (Fraillon et al., 2014; Hatlevik et al., 2015). Table 5.5 shows the latent correlation between the constructs of Figure 5.2. The instruments significantly correlate at an almost medium level and positively with each other ($r = .48, p < .0001$), which is a significant and higher correlation than Ihme and Senkbeil found in 2017 ($r = .22, p < .01$). This is not surprising because, according to Hargittai and Hinnant (2008), digital competencies usually increase with the level of education, and while Ihme and Senkbeil (2017) focused on adolescents, the present study focuses exclusively on pre-service teachers in their bachelor's or master's programme. Table 5.5 shows the latent correlations of the corresponding (self-assessed and externally assessed) competence dimensions of the multidisciplinary digital competencies. While the dimensions *handling of digital devices*, *Information Literacy*, and *application of digital security* show weak but significant correlations, no significant correlation between QCL and SCL was found for *collaboration*. A minimal correlation was found within the dimension *problem solving*. This is not surprising, because even though the latent constructs aimed at the same content, they measure different realities, since the open questions in QAMDC were designed specifically for a fictive scenario.

5.6.1 Limitations

Studies which aim to measure digital skills are often limited in their definitions, small sample sizes or methods of data collection (van Deursen & van Dijk, 2009). Firstly, the sample was limited to pre-service vocational teachers, who studied business and economic education. Consequently, the findings should not be generalized, although the sample size was adequate for applying SEM. Secondly, the self-assessments of pre-service vocational teachers should be treated with caution (Aesaert et al., 2017; Ihme & Senkbeil, 2017). For this reason, the externally and qualitatively evaluated statements were added as QAMDC. An explanation for the weak to medium path coefficients could be the invalid evaluation of the three raters. However, Table 5.3 shows an acceptable interrater reliability. Therefore, the low performance of the QAMDC model does not result in multicollinearity or falsifying the items through different ratings of the open-ended questions.

5.6.2 Implications and Future Research

Based on the explorative studies of Roll and Ifenthaler (2020b, 2020a) on multidisciplinary digital competencies, this study can be seen as a specific conceptual addition to the TK dimension of the TPACK model (Koehler et al., 2014) in the multidisciplinary context of the dual vocational education and training system, because the origin of the multidisciplinary digital competencies dimensions focused on technical vocational students as a target group. As mentioned at the beginning of this paper, teachers should also have these digital competencies in order to be prepared for teaching in Industry 4.0. The results validate the conception of the named dimensions in multidisciplinary digital competencies, with the exception of the construct of reflecting on interconnected and digital environments. The path estimates of SAMDC and QAMDC are slightly different, but this can give pedagogically worthwhile insights into the dimensions that most influence the multidisciplinary digital competencies of pre-service vocational teachers. This could help to foster specific competence development of pre-service vocational teachers within their curricula (Ertmer, 2005; Mishra & Koehler, 2006). In addition to the education of vocational teachers, the curricula of further education of in-service vocational teachers could also benefit from such studies by specifically focusing on the development of such multidisciplinary digital competencies in training units (Seufert et al., 2018).

Furthermore, the findings indicate that *attitude towards digitization* has a large effect on the multidisciplinary digital competencies of pre-service vocational teachers (Ifenthaler & Schweinbenz, 2013). To integrate digital devices in the classroom, vocational teachers' self-efficacy in this context should be improved during their pre-service training. Looking at the low self-assessment in SHD and comparing it with the higher values in QHD or QAMDC, one notices that most students underestimate their handling of digital devices (Aesaert et al., 2017; Bunz et al., 2007; Dunning et al., 2003). Therefore, digital devices should be increasingly integrated into the training of pre-service vocational teachers to avoid an underestimation and boost their self-efficacy in handling digital devices (Brevik et al., 2019). In particular, a systematic integration of multidisciplinary and digital competencies into the curriculum of vocational teacher education would be of great benefit (Tenberg, 2016, 2020).

In the following studies, a critical reflection on the fictitious scenario and the wording of the tasks is required. Even if measuring digital skills via self-assessment is a resource-saving method, it does not provide accurate evidence of digital competence (van Deursen & Van Dijk, 2010). The aim of this study was to test if the approach of a formative external and qualitative assessment of open-ended questions could be a resource-saving alternative to modelling complex scenarios via programming specific dashboards (Rausch, 2017). Certainly, this is not valid if you want to use it as high-stakes testing. Self-assessment is not really suitable here. The partial convergence of the results with the existing research literature at least indicates that the applied approach is suitable, even if the instrument still needs to be optimized and tested on a larger sample size. This study provides an overview of the general structure of multidisciplinary digital competencies; however, a further investigation of each dimension would be desirable. Furthermore, it would be of interest to apply QAMDC to validate the multidisciplinary digital competencies of technical vocational students, exploring their readiness for Industry 4.0.

5.7 References

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6. Learning Factories 4.0 in Technical Vocational Schools – Can They Foster Competence Development?

This chapter describes the fourth study of this thesis. It deals with how different levels of Learning Factory 4.0 integration can support the development of competencies. In order to understand this, following an introduction the theoretical background is explained, before the method is presented and the results are discussed.

6.1 Introduction

Industry 4.0 is the vision of a horizontally and vertically interconnected digitization of entire industrial value chains (Stecken et al., 2019; Veile et al., 2019). This is based on the real-time data exchange between customers, employees, objects and production via cyber-physical systems (Lee, Bagheri, & Kao, 2015). Current studies focusing on Industry 4.0 indicate that it will induce changes in occupational structures and work activities as well as additional requirements for employees (Groß et al., 2017; Liboni et al., 2019). These changes also affect the dual vocational and education training system in Germany. It is necessary to prepare technical vocational students with the competencies needed to cope with the challenges of Industry 4.0 (Gebhardt et al., 2015; Pfeiffer, 2015). Especially students in technical vocational education and training will be confronted by the future requirements and impacts on their work (Gebhardt et al., 2015).

To qualify technical vocational students as future skilled workers in authentic and interconnected working environments, technical vocational schools installed so called Learning Factories 4.0. Learning Factories 4.0 simulate an Industry 4.0 production line as part of a learning environment (Scheid, 2018). Initial research indicates that such interconnected model-like smart factories can foster competence development among students (Bauernhansl et al., 2018; Hummel et al., 2015). In addition, research suggests that Learning Factories 4.0 can help to develop not only technical, but other Industry 4.0-relevant competencies like Information Literacy, problem solving, or collaboration (Balve & Ebert, 2019; Tisch et al., 2013). However, current studies largely focus on learners at the university level (Abele et al., 2015; Balve & Ebert, 2019; Belinski et al., 2020; Enke et al., 2018; Liebrecht et al., 2017; Müller-Frommeyer et al., 2017). Studies about the impact of Learning Factories 4.0 in the context of technical vocational educational training are scarce (Roll & Ifenthaler, 2020b; Scheid, 2018). Therefore, this study aims to investigate competence development through Learning Factories 4.0 at technical vocational schools.

6.2 Theoretical Background

It is indispensable for technical vocational students to develop the competencies needed to work and participate in Industry 4.0. Such competencies include the handling of digital devices and software, adequate Information Literacy, the application of digital security, the ability to collaborate digitally, and the ability to solve digital problems (Roll & Ifenthaler, 2020b). Learning Factories 4.0 could support the development of these competencies.

6.2.1 Learning Factories 4.0

Abele (2016) defines a Learning Factory 4.0 on behalf of the International Academy for Production Engineering as a learning environment including four distinguishing characteristics:

- processes that are authentic, include multiple stations, and comprise technical as well as organizational aspects
- a setting that is changeable and resembles a real value chain
- a physical product being manufactured
- a didactical concept that comprises formal, informal and non-formal learning, enabled by the actions of the trainees in an on-site learning approach (Abele, 2016, p. 1).

The interconnection of a Learning Factory 4.0, which is the fundamental idea of Industry 4.0, is based on cyber-physical production systems (CPPS). CPPS “are collaborating computational entities which are in intensive connection with the surrounding physical world and its on-going processes, providing and using, at the same time, data-accessing and data-processing services available on the internet” (Monostori, 2014, p. 9) and enable an entire Industry 4.0 production line. Because a fitting instructional design is crucial for competence development within Learning Factories 4.0 (Tisch et al., 2013), most didactical concepts of Learning Factories 4.0 in technical vocational schools are not only based on learning with CPPS, but also have several separate, specific modular basic components in a foundation laboratory. As a consequence of these concepts, the separated modules of the foundation laboratories are more often integrated into daily teaching than the complex CPPS (Scheid, 2018). Due to the complexity of CPPS, students can develop a necessary understanding of the consequences of such interconnected processes (Abele et al., 2015; Scheid, 2018; Tisch & Metternich, 2017). The separate modules in the foundation laboratory are similar or equivalent to the components of the CPPS, but here they stand on their own. But as they are sometimes moveable, they can be put together to simulate the product transfer from one module to another. However, the foundation laboratory and the CPPS are equipped with the newest technology (Scheid 2017, 2018). This allows technical vocational students to learn basic technical content with modern technology that is not physically linked to other production components. These modules are intended to prepare learners for the complex tasks and problems at the holistic CPPS of the Learning Factories 4.0 (Scheid, 2018). Efficient competence acquisition and development connects streams of self-directed, game-based, action-based and hands-on learning (Belinski et al., 2020; Hummel et al., 2015), basing on ideas of the constructive alignment approach (Biggs, 1996). At universities these approaches are often integrated in Learning Factories 4.0 through project-based learning, which is organizationally difficult to implement at technical vocational schools due to organizational challenges (Scheid, 2018). And even in higher education it remains a challenge to develop and implement adequate didactical-methodological approaches in Learning Factories 4.0 in order to develop competencies (Pittich et al., 2020).

In any case, the literature indicates professional and methodological competence development through Learning Factories 4.0 in higher education (Kreimeier et al., 2014; Müller-Frommeyer et al., 2017). There, action-based learning seems to have positive effects on subject-related competence development, improves the transfer of knowledge and motivates learners, because of the realistic workplace scenario (Lanza et al., 2016; Nickolaus, 2019). These high-tech learning environments are particularly well-suited for developing problem solving skills (Abele et al., 2019). These considerations on competence development should be partially transferable from the tertiary education sector to technical vocational schools (Scheid, 2018). To summarize, Learning Factories 4.0 can still be seen as “laboratories for developing methods of competence development for specific value adding systems” (Groß et al., 2017, p. 297).

6.2.2 Competence Development through Learning Factories 4.0

Industry 4.0 may bring changes in occupational learning culture (Belinski et al., 2020; Ifenthaler, 2018). In order to develop appropriate competencies, teachers should intentionally address these in their instructional designs for lessons with Learning Factories 4.0 (Lanza et al., 2016; Liebrecht et al., 2017). Industrial processes are becoming more complex due to real-time interconnectivity, which means an overlap of several field of operations within a value added network to finalize a product (Gebhardt et al., 2015). Different fields of operations have to deal with each other and employees have to understand content from other disciplines to create synergies between the specific departments within and outside the enterprise (Gebhardt et al., 2015; Liboni et al., 2019). This melting of several fields of operations is also relevant for technical vocational students (Scheid, 2018). As Learning Factories 4.0 are didactic simulations of smart factories, they should help learners to develop the needed competencies (Abele et al., 2017; Hummel et al., 2015). Developing technical vocational students’ competencies, either related to the professional and technical disciplines or to the digital competencies which are necessary for several disciplines, is the aim of the Learning Factories 4.0 (Scheid, 2018). But first of all Learning Factories 4.0 should enable students to work with its technology, which is usually the state of the art in 2020 (Tisch et al. 2013).

The Learning Factories 4.0 in technical vocational schools are usually designed to foster those subject-related technical competencies (STC) in all relevant modern production technologies like automation technology, electrical engineering, mechatronics and so on (Scheid, 2018). But technical competencies are not sufficient for preparing technical vocational students for Industry 4.0 (Lanza et al., 2016). According to Gebhardt et al. (2015), in order to solve occupational tasks, which demand knowledge and skills in more than just one discipline, technical vocational schools need to integrate several other competencies that are related to general digitization rather than specifically subject-related. The literature provides many suggestions for non-subject related multidisciplinary digital competencies which university students should properly develop for Industry 4.0 with Learning Factories 4.0 (Bauernhansl et al., 2018; Enke et al., 2018; Pittich et al., 2020; Tisch et al., 2016). Unfortunately, similar studies for the technical vocational educational training are scarce. Scheid (2018) mentions several competencies relating to technical vocational educational training based on relevant studies in higher education. But he also emphasizes the difficulty of comparing the high level of university students to the much more basic competence level of technical vocational students.

This research gap was minimized through a recently conducted qualitative interview study (Roll & Ifenthaler, 2020a). In that study, interviews were conducted with the responsible corporate instructors of several companies to investigate the question of which non-subject-related competencies technical vocational students should possess to be prepared for Industry 4.0. Based on the work of Abele et al. (2015), Hummel et al., (2015) and Tisch et al. (2016), semi-structured interview guidelines were created. These were supplemented by the literature review of Ilomäki et al. (2016), the competence dimensions of the DigComp 2.0 project by Carretero et al. (2017) and Vuorikari et al. (2016) and the concept of Information Literacy (Fraillon et al., 2014). The result of this exploratory study is a set of multidisciplinary digital competencies:

- The *attitude towards digitization* (AD), which involves the motivational, volitional and social willingness to act (Weinert, 2001) within the digital, technical and vocational context (Abele et al., 2017).
- The *handling of digital devices* (HD) as well as software in general. This emphasizes the action-orientated knowledge of the efficiency of devices (Johnson et al., 2006; Selwyn & Husen, 2010).

- The correct usage of *copyright* (CU) issues (Fraillon et al., 2019) as part of
- *Information Literacy* (IL), which includes gathering, processing and evaluating online information (Fraillon et al., 2014).
- Careful *application of digital security* (DS) standards is a major topic for corporate instructors within an interconnected world. *Application of digital security* involves adequate and cautious behaviour to comply with (corporate) digital security standards (Carretero et al., 2017; Sîmandl et al., 2017).
- An appropriate virtual *collaboration* (CL), which basically includes common rules to follow when exchanging information or negotiating via digital devices (Carretero et al., 2017; van Laar et al., 2017) when working with experts from others fields, as well as in the student's private life.
- Solving problems within the context of interconnectivity is crucial. Therefore *problem solving* (PS) contains the skills, expertise and choice of suited methods to solve problems in a structured manner (Abele et al., 2015).
- The *self-reflection* (RF) on one's own digital actions within an interconnected world ensures the continuity of learning (Lin et al., 2014), which is not only about consequences at work, but about gaining a deeper understanding of the content and its consequences (Dewey, 1910; Rodgers, 2002) in private life, too.

These multidisciplinary digital competencies should be understood as action-oriented competence dimensions, which are not just work related but would fit in every young person's mindset of everyday life (Roll & Ifenthaler, 2020a). For this reason, multidisciplinary digital competencies are defined as a combination of willingness, abilities and individual skills that enable the individual to act adequately and socially responsibly in the digital context of professional, social and private situations (Roll & Ifenthaler, 2020a, p. 193).

6.2.3 Research Questions and Hypotheses

This study aims to validate the development of subject-related technical competencies within a discipline and non-subject-related, multidisciplinary digital competencies through Learning Factories 4.0. Previous research indicates that the integration of Learning Factories 4.0 in vocational learning environments may support the competence development of technical vocational students (Lanza et al., 2016; Liebrecht et al., 2017; Tisch et al., 2016). For example, in a pre-posttest design, Aymans et al. (2018) found a significant development of self-assessed computer-related competencies in a group which was learning with a Learning Factory 4.0. Hence, the first research objective of this study focuses on this development of multidisciplinary digital competencies supported through Learning Factories 4.0 (Roll & Ifenthaler, 2020b; Scheid, 2018). Accordingly, *it is assumed that the higher the level of interaction (LOI) of technical vocational students with a Learning Factory 4.0, the higher the level of their multidisciplinary digital competencies (MDC) will develop over time* (Hypothesis 6.1).

Reining et al. (2019) have stated that students who learned with a Learning Factory 4.0 discussed professional competencies significantly more than a control group. This control group learned the respective content through a normal seminar and without working with the Learning Factory 4.0. Hence, the second research objective emphasizes the development of subject-related technical competencies supported by Learning Factories 4.0 (Abele et al., 2015; Hummel et al., 2015; Scheid, 2018). *It is expected that the higher the level of interaction (LOI) of technical vocational students with a Learning Factory 4.0, the higher their level of subject-related technical competencies (STC) will develop over time* (Hypothesis 6.2).

6.3 Method

In the following sections, the participants of the study are briefly described, before the survey instruments are presented and the procedure is discussed in more detail.

6.3.1 Participants

Technical vocational schools were asked to join this study to explore the research objectives. The Ministry of Education, Youth and Sports in Baden-Wuerttemberg, Germany, helped with the acquisition by providing incentives for participating schools. Conditions for receiving incentives included providing the researchers access to classes of electrician vocational students in their second year of training with a typical performance level. The topic of the examined lessons had to be "an introduction into sensor technology". The participants of this study were $N = 71$ electrician vocational students learning in four comparable classes from four technical vocational schools. Data for eight students was deleted from the dataset because they did not participate at all three required subsequent tests. Students were between 18 and 37 years old ($M = 20.48$; $SD = 3.04$). All participants were in their second year of training for several different electrician professions. Only five students were female (8%), which reflects the typical non-heterogenic population of technical vocational students (Kroll, 2017; Statistic Office of Baden-Wuerttemberg, 2019b). Demographics and class sizes are shown in Table 6.1. The total sample size is representative of the average class size of technical vocational schools measured by the official Statistic Office of Baden-Wuerttemberg (2019). All classes were described by their teachers as typical electricians' classes with the typical heterogenic level of performance.

Table 6.1

Summary of participating classes and level of interaction with the Learning Factory 4.0

Classes	Number of students	Number of female students	Average age	Minutes interacted with LF 4.0	Percentage of lessons	LOI
1	21	1	20.81	00:00	0.00 %	no
2	24	2	19.91	67:00	18.61 %	medium
3	8	1	21.38	118:00	32.78 %	high
4	10	1	20.40	136:00	37.78 %	high

Note. LOI = Level of Interaction with the Learning Factory 4.0; LF 4.0 = Learning Factory

6.3.2 Design

In order to analyse differences in competence development supported through Learning Factories 4.0, this study uses a mixed repeated-measures design (Keselman et al., 1998). The researchers and participating teachers discussed several opportunities to measure competence development within this topic. Previous research used written examinations for competence evaluation linked to Learning Factories 4.0 (Abele et al., 2019; Liebrecht et al., 2017). Hence, written exams were identified as an economical way to measure and evaluate competence development within the setting of an on-going school year. Therefore, the complex competence constructs were measured through adequately transferred open questions including the specific settings (Abele et al., 2019). The researchers provided the part of the written exam focusing on multidisciplinary digital competencies. The teachers provided a pool of subject-related exam questions. These questions were expected to have the same level of difficulty as they would have in any exam within this topic.

6.3.3 Instrument

The authors received the didactical concepts of the examined lessons from each teacher. On the basis on these lesson plans, a discussion was held on how to properly design the instruments to meet a fair level of students' performance and which dimensions of multidisciplinary digital competencies would play a major role, a minor one or no role during the teaching of the topic. First the students' prior knowledge in the subject and state of multidisciplinary digital competencies were measured in a pre-test ("T0" at time point 0; TP0). The subsequent measurement instrument "T1" followed immediately after the last lesson in the chosen topic (in time point 1; TP1). To prove competence development in the long-term (Ilomäki et al., 2016), the participants were given a third test "T2" four weeks (in time point 2; TP2) after TP1. The setting of TP2 four weeks after TP1 had practical reasons, because all teachers and classes were available for a maximum of four weeks after TP1 was absolved. After the tests were completed, the answers were deductively rated and correspondingly graded with points (Abele et al., 2019). However, the graded points were transformed into Likert scales for further analysis. All these tests were done per paper and pencil and consisted of two parts. In the first part, the students had to answer open questions about their subject-related competencies. In the second part of the instrument they answered open questions intended to measure their multidisciplinary digital competencies. The students filled out the instruments with pseudonyms, so that they could not be identified by their teachers or the authors.

6.3.4 Subject-Related Technical Competencies

As experts in their field, teachers provided a pool of open questions, because the tasks in the first part of the instrument should have a similar difficulty over all three time points. The test at TP1 was conducted as a regular short exam to obtain a more realistic evaluation of those competencies (Aymans et al., 2018). Consequently, the teachers graded all tasks of all three time points as they would usually do for an exam in this subject. The grading of the given answers was transformed into a five-point Likert scale. When students left the answer blank, teachers rated this as zero, whereas a complete and perfect answer was rated as a four. Table 6.2 shows the general summary of the subject-related technical competencies for each time point. Due to organizational aspects, each teacher graded only his/her own class. Therefore, Table 6.2 includes Cronbach's alpha instead of an interrater reliability.

Table 6.2

Summary of subject-related technical competencies

	Items	**M**	**SD**	**α**	**Skew-ness**	**Kurto-sis**	**SE**
STC0	7	1.65	1.19	0.74	0.37	-0.90	0.15
STC1	6	2.94	1.24	0.57	-0.62	0.04	0.16
STC2	10	2.14	1.07	0.50	-0.25	-0.32	0.13

Note. STC0, STC1, STC2 = subject-related technical competencies at time point 0, 1, 2; M = mean; SD = Standard deviation; α = Cronbach's alpha; SE = standard error.

6.3.5 Multidisciplinary Digital Competencies

For the second part, the authors provided open-ended survey questions (Hsieh & Shannon, 2005) to measure all dimensions of their multidisciplinary digital competencies. These were rated by three qualified and trained researchers following criteria of qualitative content analyses (Mayring, 2015). After consultation with teachers, it was decided to integrate the following competence dimensions in order to measure if the announced multidisciplinary digital competencies are really fostered by the didactical concepts of the teachers. The competence dimension *attitude towards digital devices* was not integrated because the tests had to be shortened at the request of all participating teachers. The teachers claimed that *Information Literacy* and *application of digital security* are the most fitting and most important non-subject-related competencies in these lessons. The Learning Factories 4.0 also should improve the *collaboration* (CL) and *problem solving* (PS) abilities in the long term. *Handling of digital devices* (HD) would play a minor role within the topic, although students would have to use tablets and smartphones. The criteria to assess the responses to these competence dimensions were pre-tested and defined within a workshop. A summary is shown in Table 6.3, which also provides the interrater reliability by presenting the Intraclass correlation (ICC3,k), proving the two-way mixed consistency of the three raters (Shrout & Fleiss, 1979) for each item at each time point.

Table 6.3

Intraclass correlation (ICC3,k) and summary of the rated items at several time points

Time point	Item	Raters	ICC	F	p	Lower bound	Upper bound	M	SD
0	HD1	3	.91	31	.000	.87	.94	2.33	0.83
	HD2	3	.95	56	.000	.93	.96	1.51	1.37
1	HD1	3	.89	23	.000	.85	.92	2.16	0.98
2	HD1	3	.92	35	.000	.89	.94	2.02	1.09
0	CU1	3	.73	9.3	.000	.65	.81	2.01	0.75
1	CU1	3	.67	7.2	.000	.58	.76	1.80	0.84
2	CU1	3	.82	14	.000	.75	.87	1.80	0.88
	IL1	3	.89	24	.000	.84	.92	1.39	1.12
0	IL2	3	.85	18	.000	.80	.89	1.67	1.00
	IL3	3	.91	33	.000	.88	.94	1.77	1.2
	IL1	3	.67	7	.000	.57	.75	1.56	0.80
1	IL2	3	.83	16	.000	.77	.88	1.44	1.03
	IL3	3	.81	14	.000	.74	.86	1.66	0.95

	IL1	3	.74	9.7	.000	.66	.81	1.73	0.86
2	IL2	3	.76	10.8	.000	.69	.83	1.51	0.85
	IL3	3	.88	24	.000	.84	.92	1.62	0.94
	DS1	3	.77	11	.000	.69	.83	1.73	0.92
0	DS2	3	.71	8.5	.000	.62	.79	1.51	0.84
	DS3	3	.86	19	.000	.81	.90	2.35	0.81
	DS1	3	.77	11	.000	.69	.83	1.8	0.83
1	DS2	3	.86	20	.000	.81	.90	1.82	0.75
	DS3	3	.84	17	.000	.78	.89	1.93	0.89
	DS1	3	.73	9.3	.000	.65	.81	1.86	0.72
2	DS2	3	.82	15	.000	.76	.87	1.72	0.85
	DS3	3	.87	20	.000	.82	.91	2.16	0.97
0	CL1	3	.86	20	.000	.81	.90	1.78	0.98
	CL2	3	.84	16	.000	.78	.88	1.83	0.93
1	CL1	3	.84	17	.000	.79	.89	1.50	0.91
	CL2	3	.86	19	.000	.81	.90	1.33	0.95
2	CL1	3	.90	29	.000	.86	.93	1.01	0.98
	CL2	3	.82	15	.000	.75	.87	2.04	0.86
0	PS1	3	.92	36	.000	.89	.95	1.37	1.19
	PS2	3	.95	59	.000	.93	.97	1.89	1.10
1	PS1	3	.84	17	.000	.78	.89	1.73	1.02
	PS2	3	.86	20	.000	.81	.90	1.17	0.89
2	PS1	3	.78	12	.000	.70	.84	1.59	0.84
	PS2	3	.85	17	.000	.79	.89	1.64	1.05

Note. ICC = Intraclass correlation coefficient; F = F-Test; p = probability; M = Mean, N = Number of participants; HD = Handling digital devices; CU = Copyright usage; IL = Information Literacy; DS = Application of digital security; CL = Collaboration; PS = Problem solving

6.3.6 Data Collection

Data was collected between September 2019 and January 2020. The videos of the examined lessons show how much Learning Factories 4.0 are used within the lessons by the technical vocational students. Given the fact that the topic was taught in eight lessons à 45 minutes, a total of 360 minutes was controlled for each class for how many minutes the students worked and learned with the CPPS or some modules of the foundation laboratory. As mentioned before, both components belong to the didactical concept of Learning Factories 4.0 and therefore this study does not differentiate between them. Beside the control group, Table 6.1 shows the actual minutes of hands-on learning with the Learning Factories 4.0 in the viewed lessons. Every action of the technical vocational students which dealt in some way with Learning Factories 4.0 was counted. The authors did not distinguish between the quality of each learning process on the Learning Factories 4.0 as long as the students solved hands-on and action-oriented tasks with or on the Learning Factories 4.0 (Abele et al., 2019; Cachay et al., 2012). Quartiles were calculated based on the time spans in Table 6.1. Consequently, class 3 and 4 form the group of the highest level of interaction with their Learning Factory 4.0, which means in sum $N = 18$ students learned on a high interaction level with the components of Learning Factory 4.0 and 24 students had a medium level of interaction. The control group included 21 students and had no interaction with a Learning Factory 4.0 during the lesson.

6.3.7 Analytic Strategy

Hypotheses 6.1 and 6.2 require identical independent variables, namely the *level of interaction with Learning Factories 4.0* (LOI) and *time*, while *subject-related technical competencies* and *multidisciplinary digital competencies* are the dependent variables. To validate the differences in learning outcomes due to LOI between the three groups, a repeated-measure two-way multivariate analysis of variance (MANOVA) would have been the adequate analytic strategy. However, the Shapiro-Wilk test showed a significant violation ($p < .001$) of the multivariate normality distribution of the dependent variables. In addition, Box's M-test was statistically significant ($p < .001$); hence, the data also violated the assumption of homogeneity of the variance-covariance matrices. Therefore, a nonparametric procedure was used (Keselman et al., 1998). The non-parametric equivalent of a two-way multivariate analysis of variance is the Scheirer-Ray-Hare test (Dytham, 2017), which is a derivation of the multivariate Kruskal-Wallis test (Scheirer et al., 1976). To analyse differences over time and different levels of interaction with Learning Factories 4.0, post-hoc analyses were conducted. Therefore, pairwise Wilcoxon tests and Wilcoxon test effect sizes were chosen as adequate procedures after using Scheirer-Ray-Hare tests (Sokal & Rohlf, 2001). The statistics software R (version: 4.0.2), R-Studio (version 1.2.502) and the R-package rcompanion (version 2.3.25) were used for data analysis (Mangiafico, 2020).

6.4 Results

The following subsections present the results.

6.4.1 Development of Multidisciplinary Digital Competencies through Different Levels of Interaction with a Learning Factory 4.0 over Time

To evaluate the effect of different *LOI* over *time* on *multidisciplinary digital competencies* and their relevant competence dimensions, several Scheirer-Ray-Hare tests were performed. Table 6.4 shows the results, including the generalized Eta-square (Olejnik & Algina, 2003), which provides comparable effect sizes for studies with repeated-measures design (Bakeman, 2005). As shown in Table 6.4, there was no significant interaction between *LOI* and *time* on *multidisciplinary digital competencies* ($df = 4$, $SS = 10091$, $H = 3.37$, $p = .497$, $\eta^2 = .018$) and its competence dimensions, except for *problem solving* (PS; $df = 4$, $SS = 28812$, $H = 9.66$, $p = .047$, $\eta^2 = .051$). Further, Table 6.4 shows that *LOI* has a significant impact on all competence dimensions of *multidisciplinary digital competencies*. The generalized η^2 shows medium to large effect sizes, based on Cohen's benchmarks (Cohen, 1988; Richardson, 2011). The factor *time* had no significant effect on these competence dimensions, except for *collaboration* ($df = 2$, $SS = 60032$, $H = 20.47$, $p < .001$, $\eta^2 = .108$).

Even though the interaction effect of *LOI* and *time* was not significant, *LOI* had an impact on *multidisciplinary digital competencies* and their competence dimensions. Therefore, they were analysed pairwise via Wilcoxon post-hoc analyses. Table 6.5 shows the differences via pairwise comparisons at each time points for the significant *LOI* of Table 6.4. Adjusted p-values using the Bonferroni multiple testing correction method within post-hoc Wilcoxon tests were applied, and Wilcoxon r as a measure of effect size was chosen (Fritz et al., 2012). To measure a development of competencies over *time*, groups should not differ significantly in their achieved level of *multidisciplinary digital competencies* and *subject-related technical competencies* in the pre-test. This would indicate a comparable level of these competencies. Nevertheless Table 6.5 shows that the control group (with) differs significantly from the group of medium LOI in three competence dimensions of *multidisciplinary digital competencies* (*copyright usage*: $Diff = -.647$, $p = .004$, $r = .455$; *application of digital security*: $Diff = -.815$, $p < .001$, $r = .5$; *problem solving*: $Diff = -.979$, $p = .009$, $r = .445$). However, the control group showed no significant difference to the group with the highest *LOI* (except for the competence dimension *application of digital security* ($Diff = -.512$, $p = .048$, $r = .319$).

Table 6.4

Summary of the Scheirer-Ray-Hare test and effect sizes

	LOI					Time					LOI x Time				
	df	SS	H	p	η^2	df	SS	H	p	η^2	df	SS	H	p	η^2
HD	2	37623	13.57	.001	.072	2	5070	1.83	.401	.009	4	6875	2.48	.648	.013
CU	2	87805	29.98	.000	.159	2	7747	2.65	.267	.014	4	17264	5.89	.207	.031
IL	2	85102	28.54	.000	.151	2	937	0.31	.855	.002	4	4807	1.61	.807	.008
DS	2	140440	47.14	.000	.251	2	1054	0.35	.838	.002	4	22695	7.62	.107	.041
CL	2	50154	17.10	.000	.091	2	60032	20.47	.000	.108	4	24037	8.19	.084	.044
PS	2	99392	33.31	.000	.177	2	6028	2.02	.364	.010	4	28812	9.66	.047	.051
MDC	2	141369	47.25	.000	.251	2	16700	5.58	.061	.029	4	10091	3.37	.497	.018
STC	2	1610	0.54	.763	.003	2	99461	33.36	.000	.177	4	44361	14.88	.005	.079

Note. df = Degrees of Freedom; SS = Sum of Squares; H = H-Test; p = probability; η^2 = Generalized eta squared effect size; HD = Handling digital devices; CU = Copyright usage; IL = Information Literacy; DS = Application of digital security; CL = Collaboration; PS = Problem solving, MDC = Multidisciplinary digital competencies; STC = subject-related technical competencies

As can be seen in Table 6.5, *handling of digital devices* witnessed the only significant differences between *LOI* groups at TP2, when both groups with *LOI* differ significantly from the control group (no to medium: *Diff* = -.683, *p* = .019, *r* = .35; no to high: *Diff* = -.757, *p* = .017, *r* = .385) but not from each other (*p* = .481). In Table 6.5 the medium *LOI* group of *copyright usage* differs significantly from no in TP0 (*Diff* = -.647, *p* = .004, *r* = .455) and high *LOI* (*Diff* = .472, *p* = .002, *r* = .469), which both do not show any significant differences between them for this competence dimension at any time point (TP0: *p* = .66, TP1: *p* = .359, TP2: *p* = .109). For *Information Literacy* there were no significant differences at TP0 (no to medium *LOI*: *p* = .077; no to high *LOI*: *p* = .291; medium to high *LOI*: *p* = .291), but there were at TP1 and TP2 between the control group and the groups with *LOI*. There was no significant difference between the LOI groups in TP1 (*p* = .618) and TP2 (*p* = .532). The significantly different level of *application of digital security* in the pre-test between the control group and the groups with *LOI* (no to medium: *Diff* = -.82, *p* < .000, *r* = .5; no to high: *Diff* = -.51, *p* = .048, *r* = .32) was still significant at TP1 (no to medium: *Diff* = -.571, *p* = .007, *r* = .421; no to high: *Diff* = -.825, *p* = .002, *r* = .553) and TP2 (no to medium: *Diff* = -.772, *p* < .000, *r* = .63; no to high: *Diff* = -.965, *p* < .000, *r* = .750). The only relevant significant difference between *LOI* groups for *collaboration* can be found at TP1 between no to medium level (*Diff* = -1.161, *p* < .000, *r* = .577) and no to high level of *LOI* (*Diff* = -.619, *p* = .017, *r* = .386).

Table 6.6 provides the results of the pairwise comparisons for each construct, which had a significant effect of the factor *time*, detected by the Scheirer-Ray-Hare tests in Table 6.4.

Therefore, Table 6.6 is grouped by time points and shows that the control group had a significantly higher level of *collaboration* in the pre-test than at TP1 (*Diff* = .841, *p* = .012, *r* = .413), but no significant difference to TP2 (*p* = .808). The effect of *time* on *collaboration* was not significant for the medium *LOI* group (TP0 to TP1: *p* = .194; TP0 to TP2: *p* = .393; TP1 to TP2: *p* = .265). The group with the highest *LOI* did not have a significantly higher level from TP0 to TP1 (*p* = .138). In addition, this group had a significantly higher level in TP0 than in TP2 (*Diff* = -.667, *p* = .003, *r* = .536). In TP2 they even reached a significantly lower level than in TP1 (*Diff* = -1.019, *p* = .003, *r* = .626).

Table 6.5 shows significant differences for *problem solving* between the control group and the group of medium *LOI* over all three time points (TP0: *Diff* = -.979, *p* = .009, *r* = .445; TP1: *Diff* = -.881, *p* < .000, *r* = .580; TP2: *Diff* = -.665, *p* = .034, *r* = .342). Here the differences between the control group to high *LOI* were not significant at TP0 (*p* = .06) and TP1 (*p* = .322) but in TP2 (*Diff* = -1.003, *p* = .002, *r* = .542). The medium to high *LOI* does differ significantly at TP1 (*Diff* = .704, *p* = .001, *r* = .523), but not at TP0 (*p* = .06) and TP2 (*p* = .147). Overall, Table 6.5 shows that the level of accumulated multidisciplinary digital competencies was significant different for all three groups over all time points with the exceptions at TP0 between the control group and high *LOI* (*p* = .099) and at TP2 between medium and high *LOI* (*p* = .889).

6.4.2 Development of Subject-Related Technical Competencies through Different Levels of Interaction with a Learning Factory 4.0 over Time

To evaluate the effect of different *LOI* with a Learning Factory 4.0 over *time* on *subject-related technical competencies* a Scheirer-Ray-Hare test was performed. The results are presented in Table 6.4. There was a statistically significant interaction impact of *LOI* over *time* with a medium effect size (*df* = 4, *SS* = 44361, *H* = 14.88, *p* = .005, η^2 = .079). As can be seen in Table 6.4, the factor *time* had a significantly large effect on *subject-related technical competencies* (*df* = 2, *SS* = 99461, *H* = 33.36, *p* < .000, η^2 = .177). Therefore, post-hoc analyses were conducted and the pairwise comparisons in Table 6.6 were grouped by time points. Table 6.5 proves that within the pre-test at time point 0 there were no significant differences between the three groups (no to medium *LOI*: *p* = .126; no to high *LOI*: *p* = .955; medium to high *LOI*: *p* = .055). As Table 6.6 shows, there were no significant differences *in subject-related technical competencies* for the control group over *time* (TP0 to TP1: *p* = .648; TP0 to TP2: *p* = .827; TP1 to TP2: *p* = .648). But the students who had a medium *LOI* had a highly significant higher level of *subject-related technical competencies* in TP1 in comparison to the pre-test in TP0 (*Diff* = -

2.42; $p < .000$; $r = .77$). Their results in TP2 were also significantly higher than in TP0 (*Diff* = -1.104; $p < .000$; $r = .522$) but lower than in TP1 (*Diff* = 1.313; $p < .000$; $r = .599$).

Table 6.5

Summary of the pairwise comparisons using Bonferroni Holm correction grouped by "Level of Interaction"

TP	LOI		HD			CU			IL			DS			CL			PS			MDC			STC		
			Diff	p	r	Diff	p	r	Diff	p	r	Diff	p	r	Diff	p	r	Diff	p	r	Diff	p	r	Diff	p	r
0	no	medium	-0.91	.14	.25	-0.65	.00	.46	-0.59	.08	.34	-0.82	.00	.50	-0.63	.09	.29	-0.98	.01	.45	-0.76	.01	.44	0.73	.13	.26
0	no	high	-1.14	.13	.32	-0.18	.66	.07	-0.31	.29	.18	-0.51	.05	.32	-0.13	.83	.04	-0.53	.06	.30	-0.47	.10	.27	-0.01	.96	.01
0	medium	high	-0.23	.74	.06	0.47	.00	.47	0.28	.29	.17	0.30	.06	.29	0.50	.08	.34	0.45	.06	.31	0.30	.04	.35	-0.74	.06	.76
1	no	medium	-0.45	.08	.26	-0.30	.17	.21	-0.81	.01	.45	-0.51	.01	.42	-1.16	.000	.58	-0.88	.00	.58	-0.70	.00	.63	-1.19	.01	.43
1	no	high	-0.23	.45	.13	0.14	.36	.15	-0.79	.01	.46	-0.83	.01	.55	-0.62	.02	.39	-0.18	.32	.16	-0.42	.02	.41	-0.21	.72	.06
1	medium	high	0.28	.34	.15	0.44	.02	.36	0.02	.62	.08	-0.25	.11	.25	0.54	.07	.29	0.70	.00	.52	0.28	-0.03	.35	0.98	.00	.45
2	no	medium	-0.63	.02	.35	-1.13	.00	.64	-0.81	.00	.52	-0.77	.00	.63	-0.40	.25	.17	-0.67	.03	.34	-0.73	.00	.62	-0.30	.99	.00
2	no	high	-0.66	.02	.39	-0.55	.11	.26	-0.71	.01	.46	-0.97	.00	.75	-0.65	.08	.36	-1.00	.00	.54	-0.73	.00	.61	-0.07	.47	.12
2	medium	high	-0.74	.48	.11	0.57	.03	.34	0.10	.53	.10	-0.19	.29	.17	-0.26	.25	.20	-0.34	.15	.23	-0.00	.90	.02	0.23	.73	.06

Note. TP = time point; LOI = Level of Interaction with a Learning Factory 4.0; Diff = difference between LOI groups; p = probability; r = effect size Wilcoxon's r; HD = Handling digital devices; CU = Copyright Usage; IL = Information Literacy; DS = Digital Security; CL = Collaboration; PS = Problem solving, MDC = Multidisciplinary digital competencies; STC = subject-related technical competencies

The group with the highest *LOI* reached a significantly higher level *of subject-related technical competencies* at TP1 than at TP0 (*Diff* = -.696; *p* = .002; *r* = .329), but the level at TP2 was not significantly different from the level of *subject-related technical competencies* at TP0 (*Diff* = -.133, *p* = .468, *r* = .026). However, the score for *subject-related technical competencies* at TP1 was significantly higher than at TP2 (*Diff* = .563; *p* = .024; *r* = .354).

Table 6.6

Summary of the pairwise comparisons using Bonferroni-Holm correction grouped by "time"

				CL			**STC**	
LOI	Time Point		Diff	p	r	Diff	p	r
no	0	1	0.84	.01	.41	-0.50	.65	.21
no	0	2	-0.13	.81	.07	-0.07	.83	.00
no	1	2	-0.84	.01	.49	0.43	.65	.12
medium	0	1	0.31	.19	.18	-2.42	.00	.77
medium	0	2	0.08	.39	.10	-1.10	.00	.52
medium	1	2	-0.22	.27	.11	1.31	.00	.60
high	0	1	0.35	.14	.21	-0.70	.00	.33
high	0	2	-0.67	.00	.54	-0.13	.00	.03
high	1	2	-1.02	.00	.63	0.56	.02	.35

Note. LOI = Level of Interaction with the Learning Factory 4.0, Diff = estimated difference of means, p (adj.) = adjusted level of significance by Bonferroni-Holm correction, r = Wilcoxon rank test effect size; CL = Collaboration; STC = Subject-related Technical Competencies

6.5 Discussion

The following sections highlight the key findings, the implications and limitations of this study and present ideas for future research.

6.5.1 Key Findings

To summarize the results, there was no significant interaction effect of *LOI* and *time* on *multidisciplinary digital competencies*. It is not surprising that *time* had no significant effect on *multidisciplinary digital competencies*, because developing any digital competencies is rather a long-term (Ilomäki et al., 2016) or even a life-long (Ferrari, 2012) story. The multivariate design of the Scheirer-Ray-Hare test provided significant effects of *LOI* in this study on *multidisciplinary digital competencies*. According to Cohen's benchmarks (Cohen, 1988), the effect sizes of *LOI* on *multidisciplinary digital competencies* and its competence dimensions, presented through a generalized eta squared (Bakeman, 2005) in Table 6.4, are medium (HD, CL) or large (CU, IL, DS, PS, MDC). To interpret the particular effects of the level of interaction between these groups one has to look at the post-hoc test results in Table 6.5 and Table 6.6. Looking at these pairwise comparisons, the group which had a medium *LOI* seems often to score higher than the group with the highest level of interaction in terms of *multidisciplinary digital competencies* and its dimensions. This started at the pre-test, with *a multidisciplinary digital competencies* level which was .295 points better (p = .039) than the group of students with the highest *LOI*. With a difference of .279 (p = .023), the *multidisciplinary digital competencies* level was almost the same at TP1. At TP2 there was no significant difference anymore between these two groups.

Grouping the students into different *LOI* groups instead of dividing them based their *multidisciplinary digital competencies* level was not a part of this study but had the effect that the level of *multidisciplinary digital competencies* was already different in TP0, which also explains that the Scheirer-Ray-Hare test shows significant results for the factor *LOI*. Table 6.5 supplements this and shows that in TP2 there was no significant difference between the medium and high *LOI*. Because Table 6.4 does not show an interaction effect of *LOI* and *time*, and the differences of *multidisciplinary digital competencies* within the pre-test were significant, Hypothesis 6.1 has to be rejected. Even if *LOI* had no significant effect on *subject-related technical competencies*, the interaction effect of *LOI* and *time* on *subject-related technical competencies* was significant and has a medium effect (Cohen, 1988). The significant impact of time on *subject-related technical competencies* had a medium effect as well.

The pairwise comparisons in Table 6.6, grouped by the significant factor *time* of Table 6.4, showed that there was no significant change in *subject-related technical competencies* level over *time* within the control group. The students who had a medium *LOI* improved their level of *subject-related technical competencies* significantly but had their peak at TP1, immediately after the lesson was over. *Their subject-related technical competencies* decreased from TP1 to TP2 significantly, by about 1.313 points ($p < .000$), which is confirmed by a large effect size of $r = .522$. But their level *of subject-related technical competencies* at TP2 was still significantly higher (*Diff* = 1.104) than at TP0 ($p < .000$), which also had a large effect ($r = .599$). The students with the highest *LOI* also improved their subject-related technical competencies significantly from TP0 to TP1 (*Diff* = -.696, $p = .002$, $r = .329$), which was also their peak performance. At TP2 their subject-related technical competencies were .563 lower than at TP1 (p =

.024, $r = .354$) and not significant in comparison to their achieved score at TP0, which also showed a negligible effect size.

Table 6.6 clearly demonstrates that using Learning Factories 4.0 within the lesson seems to have a positive impact on the learning outcome. The control group showed no significant improvements over time, but both groups with *LOI* did at least at TP1. The fact that all groups showed their maximum of *subject-related technical competencies* at TP1 is not surprising, because T1 was conducted in the lesson after the topic was finished. So T1 measured the competencies, when they were as fresh in the students' minds as they could be. To sum this up, Hypothesis 6.2 is accepted, because Table 6.4 shows a significant interaction effect of *LOI* and *time* on *subject-related technical competencies*. In addition, Table 6.6 shows that the control group had no significant differences between the three time points at all. The group with medium *LOI* improved their *subject-related technical competencies* also in the long term (at TP2), in contrast to the group with the highest *LOI*, which had their peak performance at TP1. Their level of *subject-related technical competencies* decreased from TP1 to TP2, when it was not significantly different from that at TP0. As a side effect, the Scheirer-Ray-Hare test also showed significant results of a small interaction effect of *LOI* and *time* on *problem solving* ($df = 4$, $SS = 28812$, $H = 9.66$, $p = .047$, $\eta2 = .051$). This supports the current literature, which argues that Learning Factories 4.0 could foster the development of this competence dimension (Abele et al., 2015; Cachay & Abele, 2012; Tisch et al., 2016).

6.5.2 *Implications*

Even if these results have to be interpreted with caution due to the limitations, they surely have implications for the stakeholders, like school authorities, teachers, students and researchers. As the focus of Learning Factories 4.0 is action-oriented competence development, Tisch et al. claimed in 2016 that there were "no pragmatic and reliable instruments to evaluate the development of intended competencies in Learning Factories" (Tisch et al., 2016, p. 1358). This study scientifically explored the opportunities of repeated measures design with open questions as a first step to provide such an instrument. The detected development of subject-related technical competencies indicates a comprehensive didactical concept, which is essential for effective competence development (Lanza et al., 2016), and which Tisch et al. (2013) saw as a crucial problem for the design of Learning Factories 4.0 at universities, and Scheid (2018) at vocational schools. The number of stakeholders who are involved with Learning Factories 4.0 in vocational teaching is increasing, because the Ministry of Economic Affairs, Work and Housing of Baden-Wuerttemberg provided funding to more than 37 technical vocational schools to implement Learning Factories 4.0 (Ministry for Economic Affairs, Work, and Housing, 2017, 2018, 2019). This means that these findings are interesting arguments for the ministry, but also for technical vocational schools, which are interested in procuring Learning Factories 4.0. Stakeholders should have a strong interest in academic results like this, which validate their arguments to install such expensive facilities (Wilbers, 2017) to foster the development of technical competencies with the newest technology on the market to prepare the future shop-floor staff for Industry 4.0 (Scheid, 2018).

6.5.3 Limitations

The first limitation is surely the competence evaluation using knowledge tests. The relation between competence and measured performance (Chomsky, 1966) is scientifically recognized but still not precisely explicable (Tisch et al., 2016). According to Pittich (2014), conceptual knowledge tasks can be a good predictor of competencies. Still, it is questionable to interpret the results of subject-related technical competencies, which are basically written answers evaluated by technical vocational teachers, and multidisciplinary digital competencies, which are written answers rated by experienced raters, as competencies. But the competence evaluation with simulated problem scenarios (Abele et al., 2019) was not an adequate alternative in this study, due to its organizational consequences on the on-going school year and the resources it would have required. In addition, all competencies relating to digitization need to be observed in a long-term, problem-based and technology-rich scenario, where they can be developed (Ilomäki et al., 2016). Learning Factory 4.0 as a learning environment provided two of these criteria, because of its up-to date technology and problem-based didactical design (Abele et al., 2019; Hummel et al., 2015). To counteract the problem of long-term multidisciplinary digital competencies development, the competence tests were repeated with similar problem-based tasks four weeks after the content was learned. Within these four week it was not possible to observe the informal learning aspects within this study (Dehnbostel, 2014).

Another limitation that should be considered is that the participants were in four classes from different schools. The Learning Factories 4.0 of these technical vocational schools are also not completely identical, just as Learning Factories 4.0 are rarely similar (Abele et al., 2019). In order to keep this limiting factor as low as possible, the participating teachers were consulted and after a discussion they confirmed that the concepts are comparable and can be implemented with these classes and with the respective Learning Factories 4.0 at these technical vocational schools. Due to the many different companies where the students worked, the resources would have not been enough to control for such variables, too.

A related limitation is the art of grouping the technical vocational students into the level of interaction with the Learning Factories 4.0. This study did not differentiate by the quality of learning processes on the Learning Factories 4.0, as for example Reining et al. (2019) did by analysing the content of conversations. Even though competence dimensions were defined for multidisciplinary digital competencies (Roll & Ifenthaler, 2020a), they still contain too many skills and abilities to measure a significant development through working with or without Learning Factories 4.0. But concentrating on just measuring one particular skill of a competence dimension would not have supported the idea of multidisciplinary digital competencies (Roll & Ifenthaler, 2020a). At the university level, the learning tasks for Learning Factories 4.0 are openly designed and aim to avoid any predefined approaches (Hummel et al., 2015). While teachers in technical vocational schools also try to design their instructions similarly, they have to coach their learners much more than university students need to be (Scheid, 2018). Therefore, one should use caution when comparing findings on vocational training students to university level learners (Müller-Frommeyer et al., 2017). Even if the teaching approaches, subjects and technical infrastructure might be similar, the cognitive level of learners is not.

6.5.4 Future Research

Given the limitation of not differentiating by different learning actions with the Learning Factories 4.0, further video analysis needs to be done to investigate the individual learning more specifically. One option could be to integrate a content analysis on the "act4learning framework", like Reining et al. (2019) did, or to develop specific coding guidelines to evaluate each action of the learners within the Learning Factories 4.0 context. To dig deeper into the application of constructive alignment (Biggs, 1996), sustainable competence development and its iterative assessment within Learning Factories 4.0 needs further research, which may focus on formal and informal assessment of technical vocational students (Dehnbostel, 2014). To validate these findings, a larger sample would be required. Stakeholders such as school authorities should be interested in developing the basis of this research further and providing more empirical findings to all related stakeholders. In the context of higher education it is scientifically justified that Learning Factories 4.0 could foster competence development (Abele et al., 2015; Cachay et al., 2012; Gronau et al., 2017b).

The contribution to science of this study is the validation of competence development on the much lower educational level of vocational educational training within technical vocational schools (Roll & Ifenthaler, 2020b). But there is still room for a lot of didactical improvements for integrating Learning Factories 4.0. For example, the Learning Factories 4.0 should be connected to commercial vocational schools, which are learning with ERP software to manage the procurement, marketing and sales (and much more) of manufactured products (Scheid, 2017; Wilbers, 2017). Wilbers (2017) explained this lack of connection by the insufficient technical connection between these different types of schools. But praxis shows that even if the technical infrastructure is ready, real didactical concepts, which are applicable in the daily business of vocational teaching, are non-existent. How to provide logical, resource saving teaching to a mix of commercial and technical students should be the next big stage of research on the topic of Learning Factories 4.0 within vocational schools.

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7. Discussion and Future Research

In this final chapter the contribution of this thesis to research and the most important findings are recapitulated in section 7.1. Based on these key findings, section 7.2 discusses practical implications for dual training in vocational schools and companies, as well as for the use of Learning Factories 4.0. In section 7.3 the limitations of the present work are discussed and possibilities for future research are suggested. Finally, a conclusion is presented in section 7.4.

7.1 Main Findings and Theoretical Contribution to Field of Research

The overarching research question posed in section 1.2 of this thesis asked *which multidisciplinary digital competencies will educational stakeholders require from technical vocational students in the future in order to compete in Industry 4.0, and what role can Learning Factories 4.0 play in the acquisition of competencies in technical vocational schools?* The conducted studies showed that a positive *attitude towards digitization*, the experienced *handling of digital devices*, an adequate *Information Literacy*, the secure *application of digital security*, adequate *copyright usage*, *collaboration* strategies and *problem solving* skills will be necessary for future technical vocational students to act adequately and socially responsibly in the digital context of multidisciplinary professional, but also private situations in Industry 4.0. Built as realistic, model Industry 4.0 facilities, Learning Factories 4.0 in technical vocational schools can promote the respective technical competencies. The development of multidisciplinary digital competencies should be reviewed again over a longer period of time.

The specific findings of each study are summarized in the following sections. First, the underlying educational perspectives of studies 1 and 2 (7.1.1) are presented. Then the findings of the structural equation model from Study 3 (7.1.2) and competence development through Learning Factories 4.0 from Study 4 (7.1.3) are summarized.

7.1.1 Findings on Educational Perspectives of Future Multidisciplinary Digital Competencies

Through its explorative design, the first and second study contribute to the identification of necessary competency dimensions of technical vocational students from the perspective of the digital competency literature, which, beyond the professional-technical competencies (Tenberg, 2016), are necessary for Industry 4.0 (Tenberg & Pittich, 2017). Based on the statements from the interviews with corporate instructors (study 1) and technical vocational teachers (study 2), the overview of the competence dimensions, shown in Figure 3.1 and derived from scientific literature, was modified. The findings of study 1 indicate that a positive *attitude towards digitization* will continue to be important in Industry 4.0 in order to cope with all technical challenges in everyday working life. This is in line with Ilomäki et al. (2016), who state that volitional components are essential for a model of digital competencies, and other studies that suggest that *attitude towards digitization* can be a predictor of actual technology use (Moran et al., 2010; Scherer et al., 2018; Yerdelen-Damar et al., 2017). But *attitude towards digitization* was not viewed as having the same relevance by the participating teachers in study 2. Likewise, the teachers do not consider the physical *handling of digital devices* to be as important in the future as the corporate instructors in the first study did. However, the corporate instructors stated that they are optimistic that the *attitude towards* and *handling of digital devices* will also be present among technical vocational students in Industry 4.0, just as it is already well developed at present.

In both studies, the participants emphasize that they expect the technical vocational students' occupational group not to need deeper programming skills for Industry 4.0, which is in line with Delcker and Ifenthaler (2017). In their answers, both participating groups displayed a particular focus on the core of Information Literacy (van Deursen et al., 2016; Yu et al., 2017), which emphasizes strategies for information retrieval, structuring and evaluation of different models (Fraillon et al., 2019; Parsazadeh et al., 2018; Yu et al., 2017). The teachers in particular pointed out that these skills need to be improved, because at the moment their students lack strategies on how to find what information on the Internet and where (van Deursen et al., 2016; van Deursen & van Dijk, 2011).

For the corporate instructors, the *application of digital security* is the decisive factor in assessing whether technical vocational students are digitally competent and whether digitization in the company is successful or not (Veile et al., 2019). The importance of this competence dimension is also reflected by its integration into other models (Ferrari, 2012; Šimandl & Vaníček, 2017). The majority of the participating teachers assigned this competence dimension to practical work, arguing that it is more about protecting the technical infrastructure from external cyber-attack, which is a design challenge in general for Industry 4.0-relevant cyber-physical systems anyway (Lee, 2008).

In addition to the two previous competence dimensions, the corporate instructors rated not only knowing about copyright guidelines, but also applying them, as important for future technical vocational students (Burkell et al., 2015). The participating teachers consider this to be important in the future as well, but more in a school context than in a corporate context. This contrasts with the statements of corporate instructors of study 1 and also with the study by Chinien and Boutin (2011), who attach increased importance to the application of copyright by (Canadian) workers.

The interviewees from study 1 confirmed that young technical vocational students in particular need to develop not only their communication of content, but also cross-disciplinary cooperation with other hierarchical levels and disciplines. The teachers emphasized the need for the ability of *collaboration* in a similar way. With regard to *problem solving* competence, the teachers' statements agree with those of the corporate instructors that the students will need clear problem solving strategies as well as creative approaches in Industry 4.0 (Scherer & Gustafsson, 2015; van Laar et al., 2020; Wüstenberg et al., 2014). However, the instructors emphasized that in an increasingly complex world, it becomes more important to reflect on oneself, one's actions and processes (Quieng et al., 2015), and also to promote self-directed learning in this way (van Laar et al., 2020). The findings of study 2 show that the participating teachers focused less on *self-reflection* in the sense of reflecting on one's own actions within a process, but rather on holistic thinking and a technical understanding of the process, which is in line with Gronau et al. (2017) and Wank et al. (2016). The resulting approach from different competence dimensions corresponds to the competence understanding according to Weinert (2001).

In summary, the results of study 1 and 2 as well as the eight identified competence dimensions can serve as indications for further instructional design of learning environments in technical vocational education and for the orientation of future research.

7.1.2 Findings of the Model Structure Specification of Multidisciplinary Digital Competencies

In the third study, pre-service vocational school teachers first filled out a self-assessment instrument before they had to answer open scenario-based questions in a second instrument. Due to the low internal consistency, the latent variable of the self-assessed *self-reflection* was removed from the dataset. By removing this competence dimension, the examined model, consisting of self-evaluated multidisciplinary digital competencies and externally evaluated multidisciplinary digital competencies, showed acceptable fit indices (Hooper et al., 2008; Hu & Bentler, 1999). The findings of the applied structural equation model showed that the latent constructs of the *application of digital security* have the largest estimates on the measured multidisciplinary digital competencies. The self-evaluated and externally evaluated answers on *collaboration* had the second largest estimate. Furthermore, the results showed that the *handling of digital devices* had the third largest influence on both the self- and externally assessed multidisciplinary digital competencies. The impact of *attitude towards digitization* on multidisciplinary digital competencies is in fourth place. *Information Literacy* has a lower path coefficient and is in fifth position. The structural equation model showed that the *problem solving* constructs had the lowest path coefficient towards the multidisciplinary digital competencies.

Further results of the third study were that *attitude towards digitization* has a direct and significant impact on self-assessed multidisciplinary digital competencies, as Yerdelen-Damar et al. (2017), but also Senkbeil and Ihme (2017), have stated. However, no direct influence of *attitude towards digitization* on the objective and externally assessed multidisciplinary digital competencies could be found in the study. This is in agreement with Aesaert et al. (2015) and Bunz et al. (2007), who found that the motivational factors have an influence on the self-assessed, but not on the actual digital competencies. Even if the *attitude towards digitization* has no significant direct influence on the actual multidisciplinary digital competencies, it probably has an influence on the self-evaluated multidisciplinary digital competencies. These in turn, as the results of study 3 show, can be a good predictor of objectively measured multidisciplinary digital competencies. Thus, it can be assumed that the *attitude towards digitization* probably has an indirect effect via the general self-assessment. The fact that self-assessed competencies can be a good predictor of actual competence has been confirmed by research on several occasions (Bandura, 2009; Pajares, 1996; Senkbeil & Ihme, 2017).

Due to this significant prediction from the self-assessed competencies, the loss of the self-assessed ability to reflect on oneself can be classified as acceptable. Thus, study 3 is in line with these other research results, but contradicts for example Porat et al. (2018), who found that self-assessed digital literacy can only serve as a predictor of actual digital literacy to a limited extent. In summary, the findings showed that by removing the construct of *self-reflection* a functional structural equation model could be calculated.

7.1.3 Findings on the Development of Required Competencies through Learning Factories 4.0 in Technical Vocational Schools

Even though the corporate instructors (study 1) were aware of their own educational duties, they argued that the competencies mentioned above could and should be increasingly promoted at the technical vocational school. According to the interviewed teachers in study 2, the longer the Learning Factories 4.0 had already been in place at the respective schools, the more sophisticated was the didactic integration of these complex systems into the daily lessons. With these statements, the interviewees also contradict the statements that no didactic concepts are yet available for Learning Factories 4.0 at vocational schools and, on the one hand, that these could not be integrated into everyday vocational school life at all (Scheid, 2018).

In order to test this claim, the fourth study examined the progress made in competence development at the technical subject-related level and at the multidisciplinary digital competence level. After consultation with the teachers, the *attitude towards digitization* and *self-reflection* were removed from the survey. The technical process understanding from the competence dimension *self-reflection* was integrated into the subject-related technical tasks. In any case, the results of the Scheirer-Ray-Hare test show that there is no interaction effect of *time* and *level of Learning Factory interaction* on multidisciplinary digital competencies. However, the *level of Learning Factory interaction* has a significant effect on them. Furthermore, a significant influence of the interaction effect *level of Learning Factory interaction* with *time* on *problem solving* as well as the *subject-related technical competencies* could be determined. The resulting post hoc-analyses showed the following:

- There were significant differences in *handling digital devices* between the groups with *level of Learning Factory interaction* and the control group only at the last measurement time.
- The measured *Information Literacy* of the groups with Learning Factory 4.0 interaction was significantly higher than for the control group at all times.
- The control group had a significantly lower value at all times in *application of data security* than the groups learning with Learning Factories 4.0.
- The adequate *usage of copyright* of the control group did not differ significantly from the group with the highest Learning Factory 4.0 interaction at any time during the study.
- There were hardly any significant differences in *collaboration* except at time point 1 between the control group and the other two groups. Within the medium group, there were no significant changes over the course of the study.
- In the *problem solving* ability, no noticeable structure could be seen in the differences.
- Overall, it can be said that the *multidisciplinary digital competencies* in the pairwise comparisons usually differed significantly. Nevertheless, the medium group already differed significantly from the other two groups at time point 0. However, the results also show that the non-significant difference of *multidisciplinary digital competencies* at TP0 between the control group and the group with the highest *level of Learning Factory interaction* became a significant difference that became larger in the further course of the study.
- For *subject-related technical competencies*, the previous knowledge test at TP0 showed that the levels of the different groups do not differ significantly. There were no significant changes in the control group over time. The groups with *level of Learning Factory interaction* had the highest significant levels of *subject-related technical competencies* at time TP1. This then decreased again by TP2.

The development of digital competencies is a lifelong task (Carretero et al., 2017; Ferrari, 2012) and can only be developed and measured in the long term (Ilomäki et al., 2011, 2016). For this reason, and because of the different class levels of *multidisciplinary digital competencies* at the time of the pre-knowledge test, an interpretation in favour of the use of Learning Factories 4.0 to better promote generic competencies is difficult. This does not apply to subject-related technical competencies. The findings showed that these improve significantly depending on the integration of Learning Factories 4.0. To summarize the post-hoc analyses, this study contradicts the statement by Tenberg and Pittich (2017) that Learning Factories 4.0 in vocational schools can only promote very specific competencies. Scientific results which claim that Learning Factories 4.0 in the university context could promote competence development (Abele et al., 2015, 2019; Cachay & Abele, 2012; Tisch et al., 2016) were confirmed for the first time also in the vocational school context (Scheid, 2018).

7.2 Practical Implications

The implications of the present work are twofold. First, there are contributions on the use of the conceptual model of multidisciplinary digital competencies in the technical professional and educational system based on the empirical findings. Second, there are practical implications with respect to Learning Factories 4.0 at technical vocational schools, whose benefits for stakeholders are explained.

7.2.1 Further Integration of Multidisciplinary Digital Competencies in Technical Vocational Training

An orientation for how to teach Industry 4.0-related topics to technical vocational students is provided by the Ministry of Education, Youth and Sports of Baden-Wuerttemberg (Hörner et al., 2016). This guideline consists of six different thematic scenarios in which Industry 4.0 is relevant for the technical vocational training. The different scenarios include Industry 4.0 content on (1) production development and production planning, (2) flexible manufacturing, (3) integration of manufacturing execution systems, (4) service and maintenance, (5) energy management, and (6) network connectivity and data security. The scenarios, in turn, are each subdivided into three different requirement areas. For each requirement area, the associated technical subject-related competencies are listed in the respective description of the scenarios. For example, the Industry 4.0-related contents of vocational training mechatronics technician include in scenario 1 the requirement area 1, in scenario 2 the requirement area 2, in scenario 3 again requirement area 1, in scenarios 4, 5 and 6 in each case requirement area 2. This suggests that mechatronics technicians will already have many points of contact with Industry 4.0

content in the scenarios. Based on the taxonomic wording, the respective difficulty can then be taken from here. However, hardly any multidisciplinary digital competencies are specifically mentioned here. One practical implication of this thesis would be to expand the system of technical, subject-specific competencies described here to include generic digital competencies, depending on the requirements (and perhaps on the occupational group). In consideration of the necessity of these (study 1 & 2), they should also be systematically included here in order to be able to give the vocational teachers corresponding guidelines or ideas on where it is possible to develop multidisciplinary digital competencies (Hörner et al., 2016; Löhr-Zeidler et al., 2016).

7.2.2 Enhancing Multidisciplinary Digital Competencies in Vocational Teacher Education

About one third of companies indicated in a study by the German Economic Institute (IW) that they were dissatisfied with the digital competencies of vocational school teachers and that the promotion of digital competencies by (all) vocational schools was unsatisfactory (Flake et al., 2019). The research into this is currently still insufficient (Seufert et al., 2019). Blossfeld et al. (2018) explicitly advocate the development and validation of competency models for vocational school teachers in the context of digitization. As there is still a need for research on these digital and other professional competencies, the idea of multidisciplinary digital competencies presented in this thesis can be a basis for further discussion and investigation. Therefore, the findings of study 3 can contribute to bringing a new perspective to the (digital) training of vocational school teachers. Although this topic is current in the research literature, it rarely refers to multidisciplinary or socially relevant tasks, but is mostly focused on the computer-aided implementation of lesson planning (Tenberg, 2020). Both theoretical and practical awareness is needed in teacher training in order to be able to specifically promote these multidisciplinary digital competencies on an individual level (Krumsvik, 2014).

The integration of multidisciplinary digital competencies into the curricula of vocational teacher education can have worthwhile consequences for the dual vocational education and training system, even with little effort (Tenberg, 2020). This does not require changing the curricula from the ground up. Rather, consideration could be given to the topics in which interdisciplinary anchoring is to be carried out in order to bring the required competencies into vocational teacher education. A prerequisite for this, however, is that the integration is systematic and based on relevant scientific findings (Seufert, 2020; Tenberg, 2020).

7.2.3 *Integration of Multidisciplinary Digital Competencies to Enable Cooperation in the Dual Vocational Education and Training System*

Even if no one can make accurate forecasts about future activities and work requirements (Gebhardt et al., 2015; Sloane, 2019), the multidisciplinary digital competencies identified through the qualitative interviews (study 1 & 2) by both sides of the dual technical education and vocational training system should be systematically anchored in the curricula for actual development. In research, digital competence development is considered to be a task of lifelong learning (Carretero et al., 2017; Ferrari, 2012). And Ilomäki et al. (2016) emphasize the long-term time frame of development also with regard to measuring it. Accordingly, a more systematic and serious integration of these competencies should be carried out in a targeted manner over a longer period of time and across several different subject areas (Sloane, 2019). With such long-term didactics, multidisciplinary digital competencies would no longer be a by-product of subject-specific competence development (Tenberg, 2020), even though this will undoubtedly and quite rightly continue to be at the forefront of professional teaching.

In order to prepare technical vocational students for Industry 4.0, more use should be made of projects that require virtual collaboration beyond the subjects. However, based on the arguments in Scheid (2018), the companies that provide vocational training must be explicitly included in the process because, although their training structures are not as didactically experienced as those of vocational schools, they can address multidisciplinary and digital topics much more flexibly. In the relatively rigid organization of vocational schools, it is currently difficult to break up the class structures in favour of multidisciplinary projects (Scheid, 2018). Therefore, in Industry 4.0-oriented dual education, project-oriented forms of learning will prevail in the long run (Gebhardt et al., 2015).

Findings on multidisciplinary digital competencies indicate that competencies can be promoted not only through cooperation in the classical sense between vocational schools and the respective companies, but also between several technical vocational schools among themselves, or between technical and commercial vocational schools (Scheid, 2017; Sloane, 2019). Through projects involving different vocational fields and experiences, the necessary competencies of the technical vocational students can be developed with regard to the desired multidisciplinarity in order to prepare them adequately for the work tasks in Industry 4.0. A further implication of the above is that the idea of multidisciplinary digital competencies could be transferred to commercial training with minor adaptations due to the different commercial tasks, since Industry 4.0 will also provide correspondingly modified tasks in this domain and require collaboration with industrially trained employees (Klose & Wilbers, 2019; Wilbers, 2017). On this basis, it can be assumed that a more differentiated understanding of the multidisciplinary digital competencies required in vocational training can lead to vocational training regulations not having to be revised again (Flake et al., 2019; Sloane, 2019).

7.2.4 Expansion of Cooperation between Vocational Schools and Companies through Learning Factories 4.0

Based on the idea that the model of multidisciplinary digital competencies could also be applied to commercial vocational students, Learning Factories 4.0 could also be integrated here. As the findings of study 4 indicate, these competencies (including non-technical ones) can be fostered and, above all, help to understand Industry 4.0 as a process. A cooperation between technical vocational schools that have installed Learning Factory 4.0 and commercial schools with their ERP software could be established (Scheid, 2017). Accordingly, the use of MES could also be combined with commercial content. It would be important to use the actual Learning Factory 4.0 and not a digital twin. This could strengthen the multidisciplinary digital competencies of both sides and above all the collaboration between these disciplines (Molter et al., 2017). This development of competencies through Learning Factories 4.0 could have an impact on cooperation within the training and educational vocational system, especially since companies are often able to provide the technological input regarding Learning Factories 4.0 during the training, but do not have the capability to promote key competencies in these technologies (Flake et al., 2019; Scheid, 2018; Windelband & Faßhauer, 2016).

A central problem of all vocational schools is that the acquisition of digital infrastructure and the state of digitization, as well as the digital competencies of the teaching staff, are very often the result of individual dedicated teachers (Flake et al., 2019). Since there are only occasional financial resources for structural digital innovations or technical support (Gössling et al., 2020), it makes sense for regional companies to become more involved in the maintenance and further development of Learning Factories 4.0 (Windelband & Faßhauer, 2016) – not only to solve the technical problems together when necessary, but also to work together on didactic innovations. Due to the empirically proven effectiveness of the competence development of Learning Factories 4.0 at vocational schools (study 4) and universities (Abele et al., 2019; Tisch et al., 2015), Learning Factories 4.0 can indeed be designed as regional Industry 4.0 training centres (Windelband & Faßhauer, 2016). Therefore, companies and vocational schools could work together to counteract a possible de-qualification of the later skilled worker (Windelband & Dworschak, 2015). However, because the resources of vocational schools are already fully utilized (Flake et al., 2019; Windelband & Faßhauer, 2016), this could be achieved with the support of and cooperation with regional companies.

7.2.5 Utilization of Learning Factories 4.0 to Enhance Competency Development of Technical Vocational Students

This thesis will probably provide the first empirical results on competence development through Learning Factories 4.0 in vocational schools (Abele et al., 2019; Scheid, 2018; Windelband & Faßhauer, 2016). This evidence suggests that the arguments in favour of implementing a Learning Factory 4.0 at universities could largely also apply to vocational school instruction. On this basis, further Learning Factories 4.0 (and not only in Baden-Württemberg) should be acquired. Then many more technical vocational students would experience such a hands-on learning, a high level of activation, a high and real contextualization, and would be allowed to solve problems at the facilities in a realistic but low-risk way in a learning environment that is just as suitable for Industry 4.0 (Abele et al., 2019).

The corporate workplaces of the students in a vocational school class are equipped with different technical equipment and accordingly place different demands and tasks on the students. As workplaces change technologically over the next few years, learning environments must adapt to prepare learners authentically for what is coming (Billet, 2020). By combining theory and authentic practice (Tynjälä et al., 2020), desired competencies can be developed more sustainably in more complex, realistic learning environments with real-life problems (Zinn, 2014). Therefore, *handling of digital devices* such as smartphones, tablets, etc. should be also integrated into the lessons at Learning Factories 4.0 in a situationally and didactically well thought-out manner (Pittschellis, 2015). Occasionally, these devices are already being integrated into the classroom, especially when it comes to Augmented or Virtual Reality components of teaching (Scheid, 2018). However, this is still very sporadic and should definitely be used more for information acquisition, processing and evaluation.

Another major implication concerns the stakeholders of technical vocational schools that have installed a Learning Factory 4.0 since 2016 or are in the process of doing so (Ministry for Economic Affairs, Work, and Housing of Baden-Wuerttemberg, 2018). Due to the finding that technical competencies and, over a longer period of time, also multidisciplinary digital competencies can be better promoted by the Learning Factories 4.0 than without them, responsible politicians, regional school boards, school administrations and practicing teachers should feel validated in these purchases. The competence development of the respective handouts on how to integrate Industry 4.0 and Learning Factories 4.0 in the classroom seems to work as well (Hörner et al., 2016). This could lead to the further integration of these expensive investments (Wilbers, 2017) into the dual training process throughout Germany.

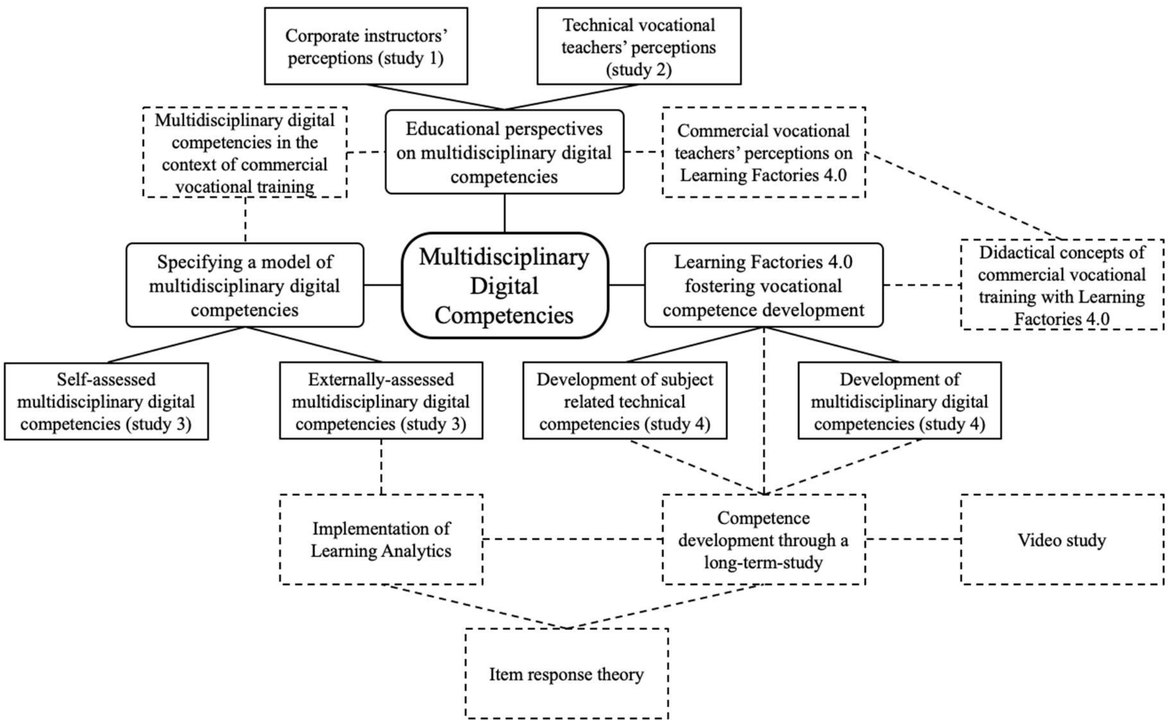
Altogether, the results, but also the theoretical considerations, can help to adapt the respective didactic considerations in industrial training through Learning Factories 4.0 where it is particularly appropriate to promote the respective multidisciplinary digital competencies.

7.3 Limitations and Future Research

Each of the studies conducted in this thesis has its limitations, which must be considered when interpreting, discussing and generalizing the findings. For each study, the respective limitations were explained in the corresponding chapters. However, there are also some limitations that apply to the entire thesis. How these limitations can be integrated into future research to validate the identified findings and improve the empirical evidence is summarized in Figure 7.1 and presented in the following sections. Figure 7.1 is based on the research foci of Figure 1.1 and schematically presents a possible future extension of the studies conducted in this thesis. These ideas are further discussed in the following sections and may provide a starting point for future studies.

Figure 7.1

Overview of explored and future research foci



7.3.1 Didactic Integration of Commercial Vocational Training in the Classroom with Learning Factories 4.0

For technical vocational students, there are already corresponding handouts on how Industry 4.0 and Learning Factories 4.0 can be used in the classroom. In Baden-Wuerttemberg, there is a differentiation between six scenarios for the relevant technical occupations, each with a different level of difficulty for the occupational groups (Hörner et al., 2016; Löhr-Zeidler et al., 2016). Since Industry 4.0 will not only affect technical training occupations but also commercial occupations because of the vertical networking (Jordanski, 2017), more didactically integrated Learning Factories 4.0 would certainly lead to an increase in competencies in these occupations as well (Scheid, 2017). However, there are no comparable recommendations for commercial vocational training so far (Landesbildungsserver, 2021). Even though companies are not expecting any such major changes in the commercial professions in terms of tasks and technical competencies as a result of Industry 4.0, multidisciplinary digital competencies will become more important here as well (Hollatz, 2017).

As can be seen in Figure 7.1, this would also first require exploratory analysis of experts' perceptions as to whether the multidisciplinary digital competencies would also be suitable for commercial vocational students. Industrial Management Assistants are a frequently cited example of commercial occupations that are more severely affected. During their training, these vocational students learn to independently and autonomously conduct business transactions in a holistic manner on the commercial side (Jordanski, 2017). Especially commercial professions that deal with Enterprise Resource Planning (ERP) systems have an interface to Industry 4.0 production and thus also to the Learning Factories 4.0 (Scheid, 2017), because ERP is used to govern all commercial and manufacturing processes of a company (Hesseler, 2009).

Some commercial and technical vocational schools already have an infrastructural connection of instructional ERP systems with installed Learning Factories 4.0 (Hilber, 2019), but firstly, this is a rather small percentage, and secondly, a systematic cooperation in everyday instruction is rare. Because there are not many functioning didactic concepts that are already regularly used in practice, the commercial vocational schools are actually not able to integrate the (real) holistic Learning Factory 4.0 (and not its digital 3D model on the computer) into their teaching (Scheid, 2017; Wilbers, 2017). Figure 7.1 shows that a qualitative survey of commercial teachers regarding Learning Factories 4.0 would make sense as a basis for a scientific analysis of the concepts for their implementation. For these reasons, a future study should deal with the following research questions analogously to this thesis:

- Do commercial vocational students need the same multidisciplinary digital competencies?
- How can the holistic Learning Factories 4.0 be integrated in the daily teaching process so that not only technical but also commercial vocational students develop the necessary competencies?

- How do commercial vocational students develop which competencies through the integration of Learning Factories 4.0 into the classroom?

7.3.2 Investigating Development of Competencies through a Long-Term-Study

While in study 4 the participants in the field of technical competencies had no prior knowledge at all, the multidisciplinary digital competencies were already present at various levels. These different levels are due to the fact that the handling of digital media as well as the learning and further development of digital competence is a life-long task (Ferrari, 2013; Ifenthaler, 2018). It must also be considered that the development of these competencies is more likely to be informal (Seufert & Scheffler, 2016). That is crucial to understand, because digital technologies are developing rapidly, and lifelong and informal learning are important to keep up with the development of new technologies (Schumacher, 2018).

Because of the long-term and informal acquisition of digital competencies, it seems reasonable to design a study as the next research project that measures the level of development at regular intervals over the period of an entire vocational training (2-3 years). The different starting levels as well as the individual developments would have to be examined more closely. Figure 7.1 shows that a future long-term study could build on the results of study 4. Since the required competencies can also be acquired at work and at home, an assessment should also be considered. However, a complete monitoring of learning gains, especially through private online actions, is practically impossible and usually not even desirable (Ifenthaler & Schumacher, 2016).

The next logical step would be to involve the companies. For this purpose, the training companies and their corporate instructors should be integrated into the study design in order to be able to understand, in addition to the contents of the lessons in vocational schools, what the vocational students have worked on and learned during their working hours. Since digital competencies should best be measured in a “problem-oriented, technology-rich and long-term settings where technology is used in a meaningful context, and various technological tools are used in integrated ways” (Ilomäki et al., 2016, p. 671), the linking of assessment in the company and in the school-based Learning Factory 4.0 makes sense. But it should be carried out over a longer period of time than in study 4, e.g. over the entire training period. In analogy to study 4, the following research questions arise for a future longitudinal study:

- How do multidisciplinary digital competencies develop in the long term through the systematic use of Learning Factories 4.0 in teaching?
- How do general technical competencies develop in the long term through the systematic use of Learning Factories 4.0 in teaching?

As Figure 7.1 shows, such a long-term study could integrate several different research designs. In the next section a methodological proposal is presented for how instruments of such a longitudinal study could be further developed.

7.3.3 Video Study and Item-Response Theory for Further Assessment of Competence Development

In order to determine the quantity of learning at a Learning Factory 4.0, a video study with a low-inference coding method could complement the study (Kurtz et al., 2020; Murray, 1983). Another investigation must also be conducted to determine in which steps and with which quality the learning processes were carried out at the Learning Factory 4.0. To detect this, corresponding sequences would have to be analysed with highly inferential coding. Using highly-inferential assessments, well-trained raters can interpret the videoed actions and thus determine their learning quality (Clausen et al., 2003; Kurtz et al., 2020). Thus, through the complementary videography and the subsequent highly inferential assessment, correlations between the respective performance and development factors in Learning Factory 4.0 lessons could be determined (Clausen et al., 2003). A mix of both inferential coding methods would certainly be very revealing. Consequently, the following research questions could explore the quality of Learning Factory 4.0 integration in Vocational School Teaching:

- How are the components of the Learning Factories integrated into the vocational teaching process?
- Which types of action-oriented learning are used at a Learning Factory 4.0 in vocational schools?
- What effect do different types of action-oriented learning at a Learning Factory 4.0 in vocational schools have on the corresponding competence development?

Based on the observed quality of learning within the Learning Factories 4.0, the quantitative survey instruments from Study 3 and 4 should be modified. Although the instruments used in the studies were each piloted in small samples and build on each other, the instrument development is far from complete. In the empirical studies of this thesis, the respective items were designed in the fictitious scenarios as realistically as possible based on work situations. Due to the very heterogeneous performance levels in (technical) dual vocational training, this would have to be considered when designing the future questionnaire. To draw conclusions from a longitudinal study in repeated measures design it is therefore recommended to apply item-response theory (IRT) (Gorter et al., 2015). An adapted instrument should therefore integrate the advantages of IRT in order to measure task difficulties as well as personal characteristics on the same scale (Hartig & Frey, 2013). By using IRT, more informative statements could be made about the latent variables of multidisciplinary digital competencies than about aggregated sum-scores, which “ignore differences between response patterns leading to equal sum-scores” (Gorter et al., 2015, p. 2). This allows more precise assessments to be made of the level of competence achieved by each individual. In doing so, the sample size must be considered. Depending on the complexity of the model to be recorded, a minimum of 100 (Linacre, 1994) – 200 (Stocking & Lord, 1983) participants is assumed. But the better the IRT assumptions are met by the corresponding data, the smaller the necessary sample size (Edelen & Reeve, 2007). During the test runs for study 4, qualified professionals were always consulted for their opinion on the all items, and these were then adapted accordingly. Therefore, the pool of subject-specific tasks was designed by the involved teachers and finally selected for the individual test dates. The extent to which the resulting items had the same level of difficulty over the three measurement points is therefore based on their subjective judgement. This limitation could also be addressed by IRT (Meyers et al., 2009; Stocking & Lord, 1983). A resulting adapted questionnaire should be evaluated and discussed further by corporate instructors for a subsequent study. Based on these considerations and the research questions in the previous sections, the following research questions arise for the use of item-response theory in the measurement of competencies:

- What items and test characteristics does the item-response theory provide for the construction and validation of an objective and externally assessed test of multidisciplinary digital but also general technical competencies of vocational students?
- What effects do different performance levels at the beginning or socio-economic variables have on competence development in the longitudinal study?
- Do different occupational groups develop their competencies to different degrees through teaching with Learning Factory 4.0?

7.3.4 Utilization of Learning Analytics to Assess Individuals’ Competence Development in Real Time in the Context of Learning with the Learning Factory 4.0

On the foundation of the information generated by digitized, horizontally and vertically interconnected production machines and products, a certain degree of handling of the related production management and control systems is required, because MES and ERP software enable and control the batch size 1 production of Industry 4.0 (Wermann et al., 2019). At the top of the automation pyramid (Gronau, 2020) sits the ERP system, which contains the business processes in procurement, production, sales, human resources and accounting in modules (Wilbers, 2017). Accordingly, ERP systems are also of great importance for teaching at commercial vocational schools and have been integrated in a didactically prepared form in teaching for quite some time (Hommel, 2017; Pongratz, 2012). An intermediary function is performed by the MES, which passes on the interface of information transfer by cyber-physical systems within production to ERP systems, monitors production and, if necessary, influences it. MES is largely integrated in technical vocational teaching (Hörner et al., 2016). To ensure that the automation pyramid and networked production runs smoothly, the two systems are closely linked (Mosler, 2017; Veile et al., 2019). This linkage could be based on an adapted Learning Management System to achieve an increase in learning outcomes and self-efficacy (Choi et al., 2007). By systematically integrating such a (cloud-based) learning management system into haptic instruction, "hybrid Learning Landscapes" are created which combine the strengths of hands-on learning with those of learning in a digital context (Pittich & Tenberg, 2020, p. 17). Such a hybrid learning landscape integrates ERP and MES in an authentic, didactic and modular content-based way, and is based on data generated by sensors and measurements of the cyber-physical systems in the Learning Factory (Tvenge & Martinsen, 2018).

As shown in Figure 7.1, based on the idea of assessing multidisciplinary digital competencies not (only) through self-assessment, but also through specific tasks, Learning Analytics could also be used in a long-term study. Evaluating the learning data obtained in such an instructional environment according to the Learning Analytics approach would be a promising project, especially if a corresponding "digital twin" of the real Learning Factory 4.0 is integrated online in this instructional design (Elbestawi et al., 2018; Tvenge & Martinsen, 2018). The concept of Learning Analytics is based on the use of static and dynamic information to optimize learning processes (through real-time support) as well as learning environments (Ifenthaler, 2015). Therefore, data generated from working with the Learning Factory 4.0 or performing tasks in the Learning Management System (Tvenge & Martinsen, 2018), combined with their characteristics, behaviour and performance, can lead to redesigning the instructional design and offering individual support (Elbestawi et al., 2018; Ifenthaler & Widanapathirana, 2014). Learning Analytics in the context of teaching Industry 4.0 in vocational schools could foster the quality of teaching and training (Ifenthaler, Gibson, et al., 2018) and the motivation to learn (Schumacher & Ifenthaler, 2018), and self-regulated learning (Schumacher, 2019) could be increased. Furthermore, Learning Analytics could support corporate instructors and vocational school teachers with assessments (Ifenthaler, Greiff, et al., 2018). If such an adaptive learning management system would not only involve the vocational schools but also the respective companies, competence development could be better understood and supported (Ifenthaler, Greiff, et al., 2018). Furthermore, a systematic and didactically sophisticated but flexible approach (Tvenge & Martinsen, 2018) would probably strengthen the cooperation between vocational schools and companies (Pittich & Tenberg, 2020).

If big data is a basis for Industry 4.0 Production (Elbestawi et al., 2018), but also for Learning Analytics (Ifenthaler, 2015), it would be logical to create synergies between these two areas. To approach this new field of research it would be advisable to start with the following questions:

- Which possibilities do vocational schools have to integrate adaptive learning systems into learning with Learning Factories 4.0?
- What are the perspectives of the stakeholders involved on utilizing Learning Analytics to foster competence development in Learning Factories 4.0?
- How does a system need to be designed in order to be practicable for both partners and to promote competence in Learning Factories 4.0?
- Which advantages could the integration of Learning Analytics have for competence development through Learning Factories 4.0 at vocational schools?
- What is required to involve the dual vocational training partners in connecting the Learning Factory 4.0 with Learning Analytics?

7.4 Conclusion

The development of all kinds of digital competencies is a lifelong task for technical vocational students in order to adapt to the development of technologies and the labour market (van Laar et al., 2017). But they will also need multidisciplinary digital competencies in addition to the technical ones, as they will work in (partly) smart factories after their training. The research on respective competencies is very diverse. Nevertheless, there is a need to establish concepts of competencies in the field of vocational school teachers and technical vocational students. Research on Learning Factories 4.0 in the university sector has also been growing for years, which is shown in the publication by Abele et al. (2019). But there remains a need for research, especially in the empirical assessment of competencies over longer periods of time.

The same cannot be said about the research on Learning Factories 4.0 at vocational schools. The scarce scientific literature on this topic can be supplemented by publications concerning the Learning Factories 4.0 at universities. But the findings from these studies should be used with caution, since the degree of independent learning is higher at universities than at vocational schools. Research here is still in its explorative phase and there are still many open questions facing several challenges, such as the identification of critical factors of learning success, didactic best-practice examples, cooperation opportunities with research, companies and other vocational schools, general empirical evidence and a scientific discourse that has emerged from the university context. This thesis provided initial empirical results and pointed the way for further research projects on using Learning Factories 4.0 to prepare technical vocational students for Industry 4.0.

This thesis is based on a theoretically derived and explorative model of multidisciplinary digital competencies for technical vocational students. These were analysed empirically on a pilot basis with pre-service vocational school teachers and finally with technical vocational students in a teaching unit with Learning Factories 4.0. This thesis' four studies could help the stakeholders of the German dual vocational education and training system to design corresponding teaching units at Learning Factories 4.0 in such a way that relevant technical competencies as well as multidisciplinary digital competencies can be promoted and measured in the classroom. Based on the limitations of this thesis, possible future research projects are suggested in order to generate scientific evidence so that technical vocational students are professionally prepared for working in an interconnected work environment. After all, this thesis aims to contribute to the science-based further development of the dual vocational training in Industry 4.0.

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Curriculum Vitae

Education:

2016	Master of Science, Economic and Business Education, University of Mannheim, Germany
2015	Erasmus Semester, Logistics and International Management, Warsaw School of Economics, Poland
2014	Bachelor of Science, Economic and Business Education, University of Mannheim, Germany

Teaching activities:

Since 2016	Statistical Methods (Undergraduate level – German, fall)
	Educational Management (Undergraduate level – German, spring)
	Supervising bachelor theses

Memberships:

AERA, AECT, BWP, EARLI

Appendix

Interview (semi-structured) Guideline (study 1)

Einleitung	*Demographie*	*Beruf & Unternehmen*	*Industrie 4.0*	*Ist-Kompetenzen*	*Soll-Kompetenzen*	*Lernortkooperation*

Guten Tag, Herr/Frau...,

Vielen Dank, dass Sie sich die Zeit nehmen mir bei dieser Erhebung zu helfen!

Bevor wir anfangen, möchte ich mich kurz vorstellen. Mein Name ist Michael Roll und ich arbeite an der Universität Mannheim am Lehrstuhl von Prof. Dr. Ifenthaler für Technologiebasiertes Instruktionsdesign.

Dort schreibe ich meine Doktorarbeit über digitale Handlungskompetenzen und deren Verschiebungen durch instruktionale Implementationen in der Industrie 4.0. Momentan bin ich am Anfang dieser Arbeit und deswegen möchte ich durch diese Interviewreihe erfahren, was denn die Ausbilder/-Innen für eine Vorstellung davon haben, inwiefern Industrie 4.0 Neues von ihren Auszubildenden in der Zukunft verlangt. Das langfristige Ziel meiner Forschung soll es sein, durch die gewonnenen Erkenntnisse ein Modell an Kompetenzen in der Praxis des dualen Ausbildungssystems zu erproben.

Dafür möchte ich ein differenzierteres und praxisnäheres Bild von überfachlichen digitalen Handlungskompetenzen in Ausbildungsbetrieben kreieren, als es momentan in der Forschung existiert.

Deswegen habe ich mir für das folgende Interview folgende Gliederung überlegt:

Ich werde Ihnen zuerst ein paar **demographische Fragen** stellen und anschließend ausführlicher auf ihre **aktuelle berufliche Tätigkeit**, sowie ihr Unternehmen zu sprechen kommen. Ich werde ein paar allgemeinere Fragen zum **Thema Industrie 4.0** in ihrem Unternehmen stellen. Dann werde ich nach den **aktuellen** und den **zukünftigen erforderlichen digitalen Handlungskompetenzen** fragen. Abschließend möchte ich dann wissen, wie Sie in ihrer Firma Lernen am Arbeitsplatz im Zuge der Industrie 4.0 und Lernortkooperation mit den jeweiligen Berufsschulen durchsetzen.

Wenn Sie einverstanden sind, würde ich gerne das Gespräch mit dem Tonband protokollieren, allein schon deshalb, damit ich später nicht nur auf mein Gedächtnis angewiesen bin und den tatsächlichen und genauen Gesprächsverlauf nachvollziehen kann. Natürlich werde ich das Tonbandprotokoll nach den geltenden Datenschutzgesetzen behandeln und dementsprechend keine Daten weitergeben oder veröffentlichen, die mit Ihnen als Person, oder ihrem Unternehmen in Verbindung gebracht werden können. Bei der Verschriftlichung der Tonbandaufnahme sorge ich für die Anonymisierung des Interviews, sodass sämtliche Rückschlüsse auf ihre Person wegfallen werden.

Damit die vielen verschiedenen Interviews gleichermaßen strukturiert ablaufen und ich nichts vergesse, habe ich mir diesen Interviewfragebogen erstellt {**ZEIGEN**!}. Das heißt aber nicht, dass ich alle diese Fragen nacheinander und schematisch einfach abhaken werde. Meistens ist es nämlich so, dass wir vom Leitfaden abweichen werden, um bestimmte Aspekte, die besonders interessant sind, ausführlicher zu besprechen. Insofern dient mir der Leitfaden einfach zur Orientierung innerhalb unseres Gespräches. Falls Sie mit manchen Fragen nichts anfangen können, oder diese nicht beantworten wollen, geben Sie mir bitte gleich nach der Fragenstellung Bescheid.

Bevor ich zu den Fragen komme, möchte ich Sie nochmal darauf hinweisen, dass mich besonders Ihre subjektive Sichtweiße auf die Problematiken interessiert und nicht wie es gerade bspw. in den Medien dargestellt wird oder von ihrer Firma erwünscht wäre. Es gibt also kein „Richtig“ oder „Falsch“ beim Beantworten der folgenden Fragen. Falls Sie über eine Antwort erstmals nachdenken müssen, können Sie das natürlich gerne auch laut. Auch wenn es nur scheinbar unwichtige Gedankengänge sind.

Sind sie mit der Aufzeichnung des folgenden Gespräches einverstanden?

Einleitung	*Demographie*	*Beruf & Unternehmen*	*Industrie 4.0*	*Ist-Kompetenzen*	*Soll-Kompetenzen*	*Lernortkooperation*

Bevor wir mit dem eigentlichen Interview beginnen, habe ich also erstmals noch ein paar Fragen zu Ihrer Person.

1) Wie alt sind Sie?
2) Geschlecht: (NICHT FRAGEN!)
3) Welchen Familienstand haben Sie derzeit?
4) Wie sieht Ihr beruflicher Werdegang aus?
   a) Wann haben Sie ihren letzten schulischen Abschluss absolviert?
   b) Welcher Abschluss war das?
   c) Können Sie mir bitte ihren beruflichen Werdegang vom Schulabschluss bis zum Eintritt bei XY grob skizzieren?
      - Berufsausbildung/Studium
      - Sonstige Qualifikationen, Fortbildungen
      - Unterbrechungen / Abbrüche
   d) Wie lange arbeiten sie bereits bei XY?
   e) Wie sah Ihre berufliche Entwicklung innerhalb des Unternehmens aus?

Einleitung	*Demographie*	*Beruf & Unternehmen*	*Industrie 4.0*	*Ist-Kompetenzen*	*Soll-Kompetenzen*	*Lernortkooperation*

Bislang haben wir über Ihren beruflichen Werdegang gesprochen. Kommen wir nun zu Ihrer aktuellen Tätigkeit bei XY.

Arbeitsinhalt:

5) Wie lautet ihre korrekte aktuelle Berufsbezeichnung?
6) Was sind ihre Tätigkeiten / Verantwortlichkeiten bei XY?
   a) Was sind dabei Ihre Kern- und was Ihre Nebenaufgaben im Alltäglichen?

Unternehmen:

Die folgenden Fragen dienen der Einordnung ihres Unternehmens.

7) Wie viele Mitarbeiter hat XY?
   a) Wie viele Auszubildende bilden sie zurzeit aus?
8) Welchen Jahresumsatz hatten Sie 2016?
9) Zu welcher Branche ist XY zuzuordnen?

Einleitung	*Demographie*	*Beruf & Unternehmen*	*Industrie 4.0*	*Ist-Kompetenzen*	*Soll-Kompetenzen*	*Lernortkooperation*

Nun kommen wir zu allgemeinen Fragen über die Industrie 4.0 und die kurz- oder langfristigen Absichten ihres Unternehmens Industrie 4.0 Maßnahmen zu implementieren.

10) Was ist ihre Vorstellung von Industrie 4.0?
11) Hat ihr Unternehmen bereits begonnen Industrie 4.0 in Ihre Produktion zu integrieren?
    a) Oder Planen Sie Industrie 4.0 Applikationen in den nächsten 1-5 Jahren zu implementieren?
    b) Wann planen Sie damit zu beginnen?
12) Ist XY Teil einer Supply Chain, in der der größte Endabnehmer schon Industrie 4.0 Applikationen verwendet?

Einleitung	*Demographie*	*Beruf & Unternehmen*	*Industrie 4.0*	*Ist-Kompetenzen*	*Soll-Kompetenzen*	*Lernortkooperation*

Kommen wir nun zu den aktuellen Kompetenzen, die gewerbliche Auszubildende aufgrund der bisherigen Digitalisierung mit sich bringen müssen. Ich werde Ihnen erst mal eine Auswahl an Kompetenzen vorlesen, und Sie sagen mir, ob diese zutreffen, oder nicht. Anschließend weißen Sie mich bitte auf Vergessenes hin.

13) Wie schätzen Sie die momentane Kompetenz ihrer gewerblichen Auszubildender hinsichtlich ihres Umgangs mit Digitalität (im Berufsleben) ein?
    Die Skala geht von -5 bis 5, wobei -5 das Schlechteste und 5 das Beste ist.

14) Über welche Fertigkeiten verfügt ein gewerblicher Auszubildender, wenn er digital kompetent ist? (Falls nichts kommt: Folgende optionale Leitfragen nehmen!)
    a) Wie beurteilen Sie die Motivation mit der ihre gewerbliche Auszubildende an digitale Herausforderungen herangehen?
    b) Wie schätzen Sie die Kompetenzen ein, Informationen zu finden, zu organisieren, zu bewerten?
    c) Können/Müssen gewerbliche Auszubildende bei XY,
        (i) digitale Inhalte generieren?
        (ii) selbständiges Programmieren?
    d) Meinen Sie, dass ihre gewerblichen Auszubildenden sich aus Sicherheitsaspekten betrachtet, adäquat im digitalen Kontext bewegen können?
    e) Wie beurteilen Sie das Level der Problemlösekompetenz ihrer gewerblichen Auszubildenden? Gerade wenn es um Probleme oder Aufgaben im digitalen Kontext geht.
    f) Welche weiteren Anforderungen sind momentan der Status Quo bei ihren Mitarbeitern?
15) Welche Kompetenzen bringen die gewerblichen Auszubildende von sich aus mit und ...
    a) welche werden in der Schule,
    b) und welche am Arbeitsplatz entwickelt?

Einleitung	*Demographie*	*Beruf & Unternehmen*	*Industrie 4.0*	*Ist-Kompetenzen*	*Soll-Kompetenzen*	*Lernortkooperation*

Kommen wir nun zu den <u>zukünftigen</u> Kompetenzen, die gewerbliche Auszubildende aufgrund von Implementation durch Industrie 4.0 Maßnahmen mit sich bringen müssen.

16) Falls nichts kommt: Ich werde Ihnen erst mal eine Auswahl an Kompetenzen vorlesen, und Sie sagen mir, ob diese zutreffen, oder nicht. Anschließend weißen Sie mich bitte auf Vergessenes hin.

17) Wie sehr meinen Sie werden sich generell die digitalen Kompetenzen von gewerblichen Auszubildenden im Zuge der Industrie 4.0 Implementationen ändern (müssen)?

Die Skala geht von -5 bis 5, wobei -5 das Schlechteste und 5 das Beste ist.

18) Über welche Fertigkeiten muss ein gewerblicher Auszubildender verfügen um digital kompetent in Zeiten von Industrie 4.0 (/ nach einer Implementation) zu sein?

Falls nichts kommt:

a) Wie beurteilen Sie die Motivation mit der ihre gewerblichen Auszubildenden an die digitalen Herausforderungen herangehen werden müssen?

b) Wie schätzen Sie die Kompetenzen ein, sich Informationen zu finden, zu organisieren, zu bewerten? Werden sich diese im Zuge einer Industrie 4.0 ändern?

c) Müssen gewerblichen Auszubildende in Zukunft digitale Inhalte generieren?

d) Wäre selbständiges Programmieren erforderlich?

e) Aus anderen Systemen oder theoretischen Inhalten integrieren?

f) Das die Herausforderungen an die IT Sicherheit und an (generell alle) Mitarbeiter wohl steigen werden ist denkbar. Meinen Sie, dass sich ihre gewerblichen Auszubildenden, aus (IT-) Sicherheitsaspekten betrachtet, adäquat im digitalen Kontext bewegen können?

g) Wird die Industrie 4.0 die Problemlösekompetenz von gewerblichen Auszubildende eher weiter herausfordern oder wird sich diese reduzieren? Und warum? Was für Problemsituationen könnten das beispielhaft sein?

19) Welche weiteren digitalen Kompetenzen oder Anforderungen sollten gewerbliche Auszubildende aufgrund der Industrie 4.0 zukünftig mit sich bringen?

20) Welche digitalen Kompetenzen sollten gewerbliche Auszubildende von sich aus schon mitbringen /erlernen und ...

a) welche werden in der Schule,

b) und welche am Arbeitsplatz entwickelt?

21) Meinen Sie, dass durch die Industrie 4.0 Ausbildungspläne an verschobene Kompetenzen angepasst werden müssen?

Die Skala geht von -5 bis 5, wobei -5 das Schlechteste und 5 das Beste ist.

Einleitung	*Demographie*	*Beruf & Unternehmen*	*Industrie 4.0*	*Ist-Kompetenzen*	*Soll-Kompetenzen*	*Lernortkooperation*

Der letzte Aspekt der mich interessiert ist das Lernen am Arbeitsplatz bzw. in der Berufsschule. Also die lernortübergreifende integrierte Kompetenzentwicklung.

22) Erzählen Sie mal: Wie fördern Sie gewünschte digitale Kompetenzen am Arbeitsplatz?

a) Nehmen Sie beim „Lernen am Arbeitsplatz“ Rücksicht auf aktuellen Lehrplänen der Ausbildung?

b) Verfügen Sie über ein Mentoring, Coaching oder ähnliches kommunikationsbasierendes Lernprogramm?

c) Gibt es für die Lernenden Möglichkeiten ihr Gelerntes oder Erarbeitetes zu reflektieren?

23) Wie wirkt sich die steigende Unternehmensvernetzung auch auf kooperierende Bildungseinrichtungen aus?

24) Wie könnten Sie sich in Zukunft ein Erlernen von digitalen Handlungskompetenzen am Arbeitsplatz vorstellen?

25) Wie ist es um die Kooperation mit den Berufsschulen bestellt?

Vielen Dank für das Gespräch und Ihre Antworten!

Interview (semi-structured) Guideline (study 2)

Guten Tag, Herr/Frau...,

Vielen Dank, dass Sie sich die Zeit nehmen mir bei dieser Erhebung zu helfen!

Bevor wir anfangen, möchte ich mich kurz vorstellen. Mein Name ist Michael Roll und ich arbeite an der Universität Mannheim am Lehrstuhl von Prof. Dr. Ifenthaler für Technologiebasiertes Instruktionsdesign.

Dort schreibe ich meine Doktorarbeit über digitale Handlungskompetenzen und deren Verschiebungen durch instruktionale Implementationen in der Industrie 4.0. In einer ersten Studie hat mich interessiert was denn die Ausbilder/-Innen für eine Vorstellung davon haben, inwiefern Industrie 4.0 Neues von ihren Auszubildenden in der Zukunft verlangt. Nun möchte ich selbiges von gewerblichen Berufsschullehrkräften erfahren. Das langfristige Ziel meiner Forschung soll es sein, durch die gewonnenen Erkenntnisse ein Modell an Kompetenzen in der Praxis des dualen Ausbildungssystems zu erproben.

Dafür möchte ich ein differenzierteres und praxisnäheres Bild von überfachlichen digitalen Handlungskompetenzen in Berufsschulen kreieren, als es momentan in der Forschung existiert.

Deswegen habe ich mir für das folgende Interview folgende Gliederung überlegt:

Ich werde zuerst nach **demographischen Angaben** fragen und werde anschließend ein paar allgemeinere Fragen zum **Thema Industrie 4.0** in ihrer Schule stellen. Dann werde ich nach den **zukünftigen erforderlichen digitalen Handlungskompetenzen** fragen. Abschließend möchte ich dann wissen, wie Sie in ihrer Schule diese Kompetenzen durch den Einsatz von Lernfabriken 4.0 fördern können und wie es im Zuge der Industrie 4.0 um die Lernortkooperation mit den jeweiligen Ausbildungsbetrieben bestellt ist.

Wenn Sie einverstanden sind, würde ich gerne das Gespräch mit dem Tonband protokollieren, allein schon deshalb, damit ich später nicht nur auf mein Gedächtnis angewiesen bin und den tatsächlichen und genauen Gesprächsverlauf nachvollziehen kann. Natürlich werde ich das Tonbandprotokoll nach den geltenden Datenschutzgesetzen behandeln und dementsprechend keine Daten weitergeben oder veröffentlichen, die mit Ihnen als Person, oder ihrer Berufsschule in Verbindung gebracht werden können. Bei der Verschriftlichung der Tonbandaufnahme sorge ich für die Anonymisierung des Interviews, sodass sämtliche Rückschlüsse auf ihre Person wegfallen werden.

Damit die vielen verschiedenen Interviews gleichermaßen strukturiert ablaufen und ich nichts vergesse, habe ich mir diesen Interviewfragebogen erstellt {**ZEIGEN**!}. Das heißt aber nicht, dass ich alle diese Fragen nacheinander und schematisch einfach abhaken werde. Meistens ist es nämlich so, dass wir vom Leitfaden abweichen werden, um bestimmte Aspekte, die besonders interessant sind, ausführlicher zu besprechen. Insofern dient mir der Leitfaden einfach zur Orientierung innerhalb unseres Gespräches. Falls Sie mit manchen Fragen nichts anfangen können, oder diese nicht beantworten wollen, geben Sie mir bitte gleich nach der Fragenstellung Bescheid.

Bevor ich zu den Fragen komme, möchte ich Sie nochmal darauf hinweisen, dass mich besonders Ihre subjektive Sichtweiße auf die Problematiken interessiert und nicht wie es gerade bspw. in den Medien dargestellt wird oder von ihrer Schulleitung erwünscht wäre. Es gibt also kein „Richtig“ oder „Falsch“ beim Beantworten der folgenden Fragen. Falls Sie über eine Antwort erstmals nachdenken müssen, können Sie das natürlich gerne auch laut. Auch wenn es nur scheinbar unwichtige Gedankengänge sind.

Sind sie mit der Aufzeichnung des folgenden Gespräches einverstanden?

Bevor wir mit dem eigentlichen Interview beginnen, habe ich also erstmals noch ein paar Fragen zu Ihrer Person.

1) Wie alt sind Sie?
2) Geschlecht: (NICHT FRAGEN!)
3) Welchen Familienstand haben Sie derzeit?
4) Wie sieht Ihr beruflicher Werdegang aus?
   a) Wann haben Sie ihren letzten schulischen Abschluss absolviert?
   b) Welcher Abschluss war das?
   c) Können Sie mir bitte ihren beruflichen Werdegang vom Schulabschluss bis zur jetzigen Tätigkeit als Berufsschullehrer kurz skizzieren?
      (i) Berufsausbildung/Studium
      (ii) Sonstige Qualifikationen, Fortbildungen
      (iii) Unterbrechungen / Abbrüche

Allgemeine Fragen zur Digitalisierung und Berufsausbildung in Ihrer Berufsschule

5) Welche Bildungsgänge bilden Sie in Ihrer BS aus?
6) Wie viele Schüler sind in diesem Schuljahr in diesen Bildungsgängen in ihrer BS angemeldet?
   d) Werden die Klassen alleine oder in Kombination mit anderen Ausbildungsberufen unterrichtet?

   Falls ja (jetzt oder später) die Frage stellen: Wird der Unterricht in der Lernfabrik entsprechend gemeinsam durchgeführt?

   e) Heutzutage sprechen viele über Digitalisierung im Arbeitsleben und Industrie 4.0 – welche Bedeutung haben diese Begriffe für Ihre Arbeit und Ihre Berufsschule?
   f) Spielt das Thema Industrie 4.0 für Sie auch in der schulischen Ausbildung eine Rolle?

   Falls ja: Wo sehen Sie Anknüpfungspunkte für Ihre Schulart?

   Falls nein: Wurde über eine systematische Integration schon Schulintern gesprochen?
7) Welche Inhalte oder Kompetenzen sollten im Zusammenhang mit der Industrie 4.0 Ihrer Meinung nach intensiver vermittelt werden?

Falls nichts kommt:

   a) Wie beurteilen Sie die Motivation mit dem gewerblichen Auszubildenden an die digitalen Herausforderungen herangehen werden müssen?
   b) Wie schätzen Sie die Kompetenzen ein, sich Informationen zu finden, zu organisieren, zu bewerten? Werden sich diese im Zuge einer Industrie 4.0 ändern?
   c) Müssen gewerblichen Auszubildende in Zukunft digitale Inhalte generieren?
   d) Wäre selbständiges Programmieren erforderlich?
   e) Aus anderen Systemen oder theoretischen Inhalten integrieren?
   f) Das die Herausforderungen an die IT Sicherheit und an (generell alle) Mitarbeiter wohl steigen werden ist denkbar. Meinen Sie, dass sich die gewerblichen Auszubildenden, aus (IT-) Sicherheitsaspekten betrachtet, adäquat im digitalen Kontext bewegen können?
   g) Etc.

Allgemeine Fragen zur Lernfabrik 4.0 an Ihrer Berufsschule.

8) Was für eine Lernfabrik 4.0 haben Sie an Ihrer Schule im Einsatz?

    a. Festo Gesamtanlage, Teamtechnik, Grundlagenlabore, etc.
9) Wer ist der Ansprechpartner? / Was ist Ihre Rolle im Lernfabrik-Team?
10) Wie war die (didaktische & technische) Einführung der Lernfabrik 4.0?
11) Wie zuverlässig funktioniert die Lernfabrik (im Unterricht)?
12) Wie ist der Stand der didaktischen Konzeptentwicklung?
    a. Gibt es Unterstützungsbedarf?
    b. Wie könnte man die Schule unterstützen, damit die Lernfabrik 4.0 besser funktioniert / in den Alltag eingebunden wird?
13) Welche Unterrichtsmethoden bieten hinsichtlich der Lernfabrik 4.0 an?
    a. Wie wird die Lernfabrik 4.0 momentan hauptsächlich genutzt? (Anschauungsobjekt?)
14) Reichen die zur Verfügung gestellten zeitlichen Ressourcen aus?
    a. Was wäre eine adäquate Deputatsstundenanzahl, die ihre Schule (zusätzlich?) benötigen würde um die Lernfabrik 4.0 optimal nutzen zu können?
    b. Für was würden diese Deputatsstunden vermutlich am meisten eingesetzt werden?
15) Wie regelmäßig nutzen Sie mit den gewerblichen Schülern die Lernfabrik 4.0?
16) Welche Erfahrungen wurden dabei gemacht?
    a. Auf Schülerseite
    b. Auf Lehrerseite (auch gerne Erfahrungen von Kollegen)
17) Welche Kompetenzen könn(t)en Ihrer Meinung nach an Lernfabriken 4.0 besser entwickelt werden als ohne Lernfabrik 4.0?

Falls nichts kommt: Auf Antworten von Frage 7, bzw. Ergebnisse Studie 1 verweisen.

18) Haben Sie den Eindruck, dass eine Lernfabrik 4.0 die Prozesse aus den Ausbildungsbetrieben abbildet?
    a. Falls ja: Welche?
    b. Falls nein: Warum nicht?

Allgemeine Fragen zur Lernortkooperation Ihrer Berufsschule mit Unternehmen.

19) Wie ist es aus Ihrer Sicht um die Lernortkooperation mit den jeweiligen Betrieben bestellt?
20) Besteht Ihrerseits grundsätzlich ein Interesse oder Bedarf an stärkerer Kooperation zwischen den dualen Partnern der beruflichen Ausbildung?
21) Sehen Sie Möglichkeiten die Lernfabriken 4.0 als einen zentralen Bestandteil der Lernortkooperation auszubauen?

Vielen Dank für das Gespräch und Ihre Antworten!

Questionnaire SAMDC (study 3)

Sehr geehrte Damen und Herren,

In dieser VPN Stunde geht es um Fähigkeiten und Fertigkeiten, die wichtig sind um digitale Handlungskompetenz zu besitzen. Dabei meint „digitale Handlungskompetenz" wie Menschen, in beruflichen, gesellschaftlichen und privaten Situationen mit digitalen Technologien umgehen. Die folgenden Fragen und Aussagen beziehen sich auf den beruflichen und privaten Umgang mit digitalen Technologien. Mit Ihrer Teilnahme an der Untersuchung unterstützen Sie die Entwicklung zukünftiger digitaler Lehr- und Lernszenarien für Schulen und Unternehmen im Ausbildungskontext. Wir bitten Sie, die Aufgaben bzw. Fragen nach bestem Wissen und Gewissen zu bearbeiten.

Untersuchungsablauf

Im ersten Teil der Studie werden Sie Selbsteinschätzungsfragen beantworten. Für diese ersten Hälfte der Studie werden Sie ca. 20 Minuten benötigen. Im zweiten Teil werden innerhalb eines fiktiven Szenarios offene Fragen gestellt. Dieser Teil kann ca. 20-40 Minuten dauern. Die Studie muss in einer Sitzung abgeschlossen werden. Bitte beantworten Sie alle Fragen und folgen Sie den Anweisungen auf den jeweiligen Seiten der Onlinebefragung. Bitte bestätigen Sie die Eingabe Ihrer Antworten mit Hilfe der Schaltflächen (… weiter) und benutzen Sie nicht die Browserfunktion um vor- bzw. zurückzublättern. Das Ende der Onlinebefragung wird Ihnen auf einer Abschlussseite bestätigt.

Datenschutz

Alle erhobenen Angaben werden streng vertraulich behandelt und die Anforderungen des Datenschutzes werden eingehalten. Eine Weitergabe der Daten an Dritte erfolgt nicht. Falls Sie Interesse an der Fragestellung oder den Ergebnissen dieser Untersuchung haben oder wenn sonstige Fragen auftreten, wenden Sie sich bitte an die Versuchsleitung.

Herzlichen Dank für Ihre Teilnahme!

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Teil (1)

1. *Attitude towards digitization*

Inwiefern stimmen Sie zu, dass folgende Aussagen auf Sie zutreffen?

1= Trifft überhaupt nicht zu, 2= Trifft überwiegend nicht zu, 3 = Weder noch, 4 = Trifft überwiegend zu, 5 = Trifft voll und ganz zu

1.1 Es ist wichtig für mich digital zu arbeiten

1.2 Ich nutze gerne das Internet.

1.3 Die zunehmende Digitalisierung empfinde ich als positiv.

1.4 Mir macht das Arbeiten mit digital vernetzten Technologien Spaß.

1.5 Es bereitet mir mehr Freude an und mit Computern zu arbeiten, als ohne.

1.6 Digitale Technologien vereinfachen meine Arbeit.

1.7 Ich werde später einen Vorteil haben, wenn ich mich mit digitalen Technologien gut auskenne.

1.8 Ich nutze digitale Technologien im privaten Alltag, weil sie nützlich sind.

1.9 Wenn weniger Mitmenschen digitale Technologien nutzen würden, würde ich diese ebenfalls freiwillig weniger nutzen wollen.

1.10 Ich nutze digitale Technologien, weil es von mir in meinem Alltag verlangt wird.

2. *Handling of digital devices*

Inwiefern stimmen Sie zu, dass folgende Aussagen auf Sie zutreffen?

1= Trifft überhaupt nicht zu, 2= Trifft überwiegend nicht zu, 3 = Weder noch, 4 = Trifft überwiegend zu, 5 = Trifft voll und ganz zu

2.1 Ich kann mehrere, unterschiedliche Tastenkombinationen anwenden.

2.2 Ich kann gut Bild- und Videobearbeitungsprogramme anwenden.

2.3 Ich verstehe einfache Programmcodes

2.4 Ich kann Dateien ins Internet selbst hoch- bzw. von dort runterladen.

2.5 Ich bin gut darin Dokumente zu erstellen und zu bearbeiten.

2.6 Ich finde mich in einer Datenbank zurecht.

2.7 Ich kann eine Webseite erstellen oder bearbeiten.

2.8 Ich nehme selbst Einstellungen an meinen digitalen Geräten vor um diese nach meinem Wunsch zu optimieren

2.9 Ich kann eigene Makros für Word oder Excel schreiben.

2.10 Ich kann meistens Unterstützung leisten, falls jemand Probleme mit seinem Computer hat.

3. *Information Literacy*

Inwiefern stimmen Sie zu, dass folgende Aussagen auf Sie zutreffen?

1= Trifft überhaupt nicht zu, 2= Trifft überwiegend nicht zu, 3 = Weder noch, 4 = Trifft überwiegend zu, 5 = Trifft voll und ganz zu

3.1 Ich weiß wo ich im Internet suchen muss um an entsprechend valide Informationen zu kommen.

3.2 Ich wende unterschiedliche Suchstrategien an, wenn ich im Internet nach Informationen suche.

3.3 Auf Webseiten suche ich meist lange, bis die gesuchte Information gefunden habe.

3.4 Normalerweise schaue ich mehr als die ersten drei vorgeschlagenen Suchergebnisse an.

3.5 Ich weiß, wie ich meine Suchanfragen im Internet formulieren muss, um die geeignetsten Treffer zu erhalten.

3.6 Ich organisiere meine Dateien auf meinem Computer in Ordnern und Unterordnern.

3.7 Durch meine Dateienstruktur fällt es mir leicht, gesuchte Informationen auf meinem Computer wieder zu finden.

3.8 Ich ordne runtergeladene Dateien sofort in ein einer Ordnerstruktur an.

3.9 Ich bräuchte externe Hilfe beim Strukturieren von Dateien und Informationen.

3.10 Ich kann Informationen, die ich im Internet gefunden habe, für mich so organisieren, dass ich diese auch nach längerem zeitlichem Abstand schnell wiederfinde.

3.11 Ich bewerte Informationen hinsichtlich ihrer Nützlichkeit im entsprechenden Kontext.

3.12 Ich prüfe Webseiten auf ihre Vertrauenswürdigkeit.

3.13 Ich überprüfe gefundene Aussagen im Internet auf deren Richtigkeit.

3.14 Ich denke meist über die Richtigkeit von neuen Informationen nach, bevor ich diese weiterleite.

3.15 Ich wähle bei Internetrecherchen immer das glaubwürdigste und nicht das schnellste Ergebnis.

4. *Application of digital security*

Inwiefern stimmen Sie zu, dass folgende Aussagen auf Sie zutreffen?

1= Trifft überhaupt nicht zu, 2= Trifft überwiegend nicht zu, 3 = Weder noch, 4 = Trifft überwiegend zu, 5 = Trifft voll und ganz zu

4.1 Ich kenne Techniken, um sichere Passwörter zu erstellen.

4.2 Ich erkenne, ob eine Webseite eventuell schädlich sein könnte.

4.3 Ich kenne mich mit Verschlüsselungstechniken aus (z.B. End-to-End)

4.4 Ich kenne Methoden um mich vor Identitätsdiebstahl im Internet zu schützen.

4.5 Ich kenne Methoden mein Smartphone möglichst gut vor dem Zugang Dritter zu schützen.

4.6 Ich verstehe, was datenbezogene Sicherheitsrisiken bei der Anwendung von Smartphones sein können.

4.7 Ich verstehe wie Dritte auf meine Daten legal zugreifen könnten.

4.8 Ich kann einer anderen Person erklären was mit „Datenschutz“ gemeint ist.

4.9 Ich kann mir vorstellen, wie Dritte (Firmen, Regierungen, etc.) meine Daten nutzen könnten.

4.10 Ich kann ganz gut selbst einordnen, wie gut meine Geräte vor dem Zugriff Dritter geschützt sind.

4.11 Ich installiere gezielt Sicherheitsmaßnahmen um meine Geräte zu schützen.

4.12 Ich kontrolliere meine Sicherheitseinstellungen im Kontext regelmäßig.

4.13 Wenn ich mit sensiblen Informationen agiere, achte ich immer auf einen ausreichenden Datenschutz.

4.14 Ich wende Strategien an, die mich vor einem Identitätsdiebstahl im Internet schützen sollen.

4.15 Ich führe regelmäßig BackUps meiner Dateien durch.

5. Copyright

Inwiefern stimmen Sie zu, dass folgende Aussagen auf Sie zutreffen?

1= Trifft überhaupt nicht zu, 2= Trifft überwiegend nicht zu, 3 = Weder noch, 4 = Trifft überwiegend zu, 5 = Trifft voll und ganz zu

5.1 Ich kann beim Umgang mit Materialien aus dem Internet Copyright-Richtlinien anwenden.

5.2 Ich muss Informationen, die ich aus dem Internet habe, bei öffentlichen Präsentationen nicht kennzeichnen.

5.3 Ich verweise bei verwendeten Materialien aus dem Internet immer entsprechend auf das entsprechende ©.

5.4 Ich kann ermitteln, ob ich ein Bild aus dem Internet nutzen darf.

5.5 Ich kann alle Bilder im Internet auch zu kommerziellen Zwecken weiter nutzen.

6. Collaboration

Inwiefern stimmen Sie zu, dass folgende Aussagen auf Sie zutreffen?

1= Trifft überhaupt nicht zu, 2= Trifft überwiegend nicht zu, 3 = Weder noch, 4 = Trifft überwiegend zu, 5 = Trifft voll und ganz zu

6.1 Ich kann beurteilen, ob meine Kommunikationsnachrichten im jeweiligen Kontext angemessen formuliert sind.

6.2 Ich kann mir vorstellen ausschließlich online in einem Team zu arbeiten um ein Projekt zu Ende zu bringen.

6.3 Ich kann beurteilen wann ich welches Kommunikationsmittel (z.B. Whatsapp, Email oder Telefonat) und gegenüber wem einsetzen kann.

6.4 Bei einer Gruppenarbeit kommuniziere ich gerne online.

6.5 Ich fühle mich wohl beim Kommunizieren über Videodienste (wie Zoom, Facetime, etc.).

7. Problem solving

Inwiefern stimmen Sie zu, dass folgende Aussagen auf Sie zutreffen?

1= Trifft überhaupt nicht zu, 2= Trifft überwiegend nicht zu, 3 = Weder noch, 4 = Trifft überwiegend zu, 5 = Trifft voll und ganz zu

7.1 Wenn alltägliche Computer-Probleme auftreten, versuche ich diese alleine zu lösen.

7.2 Ich löse kleinere IT-Probleme gerne selbst und ohne jemanden deswegen zu kontaktieren.

7.3 Das Lösen digitaler Probleme stellt mich nicht vor große Herausforderungen.

7.4 Ich kann Probleme im digitalen Kontext meist ganz gut alleine lösen.

7.5 Wenn ich ein Problem mit digitalen Technologien habe, überlege ich direkt wie ich das Problem in Zukunft vermeiden kann.

7.6 Ich suche immer nach einzelnen Komponenten eines größeren Problems um dieses schrittweiße zu lösen.

7.7 Bei komplexen Problemen erarbeite ich zuerst eine Strategie um sie zu lösen.

7.8 Wenn innerhalb einer Aufgabe Probleme spontan auftreten, kann ich auf diese eingehen, ohne das eigentliche Ziel aus den Augen zu verlieren.

7.9 Zum Lösen von komplizierten Sachverhalten greife ich bewusst auf Techniken, wie Brainstorming, Mindmapping, etc. zurück.

7.10 Ich schätze meine Fähigkeit komplexere IT-bezogene Probleme zu lösen, als sehr gut ein.

8. Self-reflection

Inwiefern stimmen Sie zu, dass folgende Aussagen auf Sie zutreffen?

1= Trifft überhaupt nicht zu, 2= Trifft überwiegend nicht zu, 3 = Weder noch, 4 = Trifft überwiegend zu, 5 = Trifft voll und ganz zu

8.1 Ich beurteile meine erreichten Fortschritte, in Bezug auf gestellte Aufgaben, selbst.

8.2 Ich bewerte meistens die einzelnen Schritte beim Problemlösen unmittelbar danach.

8.3 Ich prüfe meine Arbeitsergebnisse genau nach.

8.4 Ich vergleiche kritisch das von ein von mir erstelltes Produkt mit dem bestmöglichen erstellbaren Produkt.

8.5 Das ich meine Arbeit selbst bewerte, ist wichtig für mich

8.6 Mir fehlt häufig der Blick über den Tellerrand.

8.7 Ich prüfe oft nach, ob ich noch Wissenslücken aufweise.

8.8 Es ist wichtig sich selbst und seine Leistungen eigenständig zu bewerten, um sich zu verbessern.

8.9 Ich kann mich sehr gut selbst einschätzen.

8.10 Ich kann einschätzen was meine Stärken und was meine Schwächen im digitalen Kontext sein könnten.

9. Demographische Angaben

Zum Abschluss bitten wir um einige persönliche Angaben

9.1 Alter?

9.2 Geschlecht? Weiblich (1) / Männlich (2) / Divers (3)

9.3 Bachelor oder Master? Bachelor (1) / Master (2)

9.4 Haben Sie vor ihrem Studium eine berufliche Ausbildung abgeschlossen? Ja (1) / Nein (2)

9.5 Mit welcher Note haben Sie ihre Hochschulzugangsberechtigung erworben?

9.6 In welchem Hochschulsemester befinden Sie sich?

9.7 Was ist ihr momentaner Notendurchschnitt?

9.8 Möchten Sie später in den Schuldienst gehen? Ja (1) / Nein (2) / Weiß ich noch nicht (3)

9.9 Welches Nebenfach haben Sie gewählt?

9.10 Wie viele digitale Technologien nutzen Sie privat?

9.11 Wie viele digitale Technologien nutzen Sie im Studium?

9.12 Wie viele digitale Technologien nutzen Sie beruflich?

Questionnaire QAMDC (study 3)

Stellen Sie sich folgende fiktive Situation vor:

Sie sind kaufmännischer Mitarbeiter eines kleinen mittelständischen Produktionsunternehmen. Ihr Einsatzbereich ist, aufgrund der geringen Größe des Unternehmens, vielseitig. So erledigen Sie öfters Aufgaben aus Einkauf, Personal und Marketing. Eines Tages kommt Ihre Vorgesetzte (Frau Mayer-Schmidt) morgens um 09:00 Uhr zu Ihnen an den Arbeitsplatz und bittet Sie ihr bis morgen 12:30 Uhr eine Präsentation über: "*Industrie 4.0: Welche Rolle können RFID in MES-Systemen spielen?*" bereitzustellen. Frau Mayer-Schmidt betont, dass diese Aufgabe höchste Priorität genießt und bittet Sie zudem neben der reinen visuellen Darstellung auch zusätzliche Informationen übersichtlich auf einem Handout darzustellen. Mithilfe der Präsentation und der anschließenden Diskussion möchte die Vorgesetzte im Vorstand diskutieren ob es lohnenswert sein könnte die Produktion entsprechend auf den neuesten Industrie 4.0 Standard umzurüsten.

Im Folgenden werden Ihnen zu diesem Szenario Fragen gestellt, die Sie bitte reflektiert und in möglichst ganzen Sätzen beantworten. Beschreiben Sie dabei stets wie Sie vorgehen würden und antworten Sie so detailliert wie möglich.

1. Beschreiben Sie allgemein ihr Vorgehen, von der Informationsgewinnung bis hin zur Vorbereitung auf die Präsentation.
2. Beschreiben Sie das Vorgehen ihrer Internetrecherche chronologisch.
    a. Mit welchen Stichworten bekommen Sie welche Ergebnisse?
    b. Wie und warum passen Sie daraufhin die Suche an?
3. Nach welchen Kriterien beurteilen Sie, ob den gefundenen Informationen problemlos getraut werden kann?
4. Wie würden Sie die im Internet gefundenen Informationen in ihre vorhandene Ordnerstruktur Computer einordnen?

Sie stoßen auf mehrere Internetquellen, die Ihnen auch die Möglichkeit anbieten verschiedene Dateiformate runterzuladen und daraus dann die Informationen zu entnehmen.

5. Welche und wie viele Sicherheitsmaßnahmen kennen Sie um ihren PC for Malware (Schadhafter Software) durch solche Dateien zu schützen?
6. Was verstehen Sie unter gesichertem dem Schützen ihres PCs vor solcher schadhaften Software?

Bei Aufgaben im Arbeitsalltag kommt immer ein gewisser Zeitdruckhinzu. Diesen verspüren Sie aufgrund der besonderen Aufgabe nun besonders.

7. Wie würden Sie dabei digitale Sicherheitseinstellungen handhaben?

In der Mittagspause lassen Sie den Computer neu starten, da ein Microsoft-Update erforderlich war. Danach haben Sie keinen Zugriff mehr auf das Internet.

8. Wie gehen Sie schrittweiße vor um das das Problem zu lokalisieren und zu beheben? (Die Firma verfügt über keine eigene IT-Abteilung und Sie können erst in 2 Stunden jemanden um Hilfe bitten!)

Nach dem die grundlegende Recherche abgeschlossen ist, überlegen Sie sich nun das weitere Vorgehen. Fest steht, Sie wollen bei Frau Mayer-Schmidt glänzen und zeigen, wie digital kompetent Sie sind. Dabei verlassen Sie sich auf ihre Stärken:

9. Welche Softwareanwendungen beherrschen Sie besonders gut, die vielleicht ihre Kollegen nicht so gut können und die Sie generell im Laufe dieser Aufgabe benutzen?
10. Was ist, aus ihrer Sicht, die komplexeste Software, die Sie auch beherrschen, die hier von Relevanz sein könnte?
    a. Was würden Sie innerhalb dieser Software erstellen/programmieren/visualisieren?
11. Wie könnte Copyright das Verwenden von Text-, Bild- und Tonmaterialien für Ihre Präsentation beeinflussen?

Sie schreiben einem Kollegen, den Sie nicht sehr gut kennen und in einer anderen Firma arbeitet, dass Sie bei der Recherche Hilfe benötigen.

12. Wie würde der Nachrichtenstil aussehen?
    a. Welchen Online-Kommunikationsweg würden Sie wählen?

Sie wollen bei Ihrer Vorgesetzten Pluspunkte sammeln und Informationen nicht nur aufbereiten, sondern gleich auch Ideen für einen Firmeninternen Einsatz bereitstellen. Wissen aber noch nicht genau wo und wie. Dennoch wagen Sie sich an dieses komplexe Problem:

13. Beschreiben Sie ihre Methode um eine entsprechende Strategie zu finden wie Sie diese komplexe Aufgabe lösen wollen. Nennen Sie dabei jeden Schritt.

Coding Guideline QAMDC (study 3)

Item	Skala	Kriterien	Beispiele
Beschreiben Sie allgemein ihr Vorgehen, von der Informationsgewinnung bis hin zur Vorbereitung auf die Präsentation.	Sehr gute Problemlösekompetenz (Trifft voll zu)	• Übersicht mithilfe von Techniken verschaffen • Eigenes Vorwissen bewusst abfragen • Gründliche Analyse des Problems (Online, Offline). • Einzelne Schritte des PL-Prozesses werden klar dargestellt • Guter Austausch mit anderen Personen (Als letztes) • Eigenständige Problemlösung	*"Brainstorming; Schreibe mir auf einer Mindmap alles auf, was ich zu dem Thema weiß. Dann google ich anhand dieser Informationen um das die Themen zu vertiefen. Ich erstelle mir einen kleinen Meilenstein-Plan bis zur Präsentation.“*
	Gute Problemlösekompetenz (Trifft eher zu)	• Übersicht verschaffen • Informationen zu Problem sammeln • Analyse des Problems • Eigenständige Problemlösung	*„Ich verschaffe mir eine Übersicht und versuche die Aufgabe in einzelne Schritte zu zerlegen.“*
	weder gut noch schlecht (Teils-Teils)	• 0815 Antwort / Erwartbarer Durchschnitt • Problemstellung reformulieren • Online über mögliche Hilfen informieren	*„Ich lesen mich kurz über das Thema ein, stelle mir Fragen dazu und lege los“*
	eher schlecht (Trifft eher nicht zu)	• Problem wird nicht angegangen. • Nachdem Problem analysiert wurde, wird es an andere weitergeben • Problemlösung basiert nur auf (Experten-)Wissen von externen Personen	*„Frage bei Kollegen nach und schaue wie andere sowas gelöst haben.“*

	Schlechte/Keine Problemlösekompetenz (Trifft nicht zu)	• Problem ignorieren und versuchen darum herum zu arbeiten • Aufgeben • Hoffen, dass sich das Problem von alleine löst... • Leeres Feld	
Beschreiben Sie das Vorgehen ihrer Internetrecherche chronologisch. a. Mit welchen Stichworten bekommen Sie welche Ergebnisse? b. Wie und warum passen Sie daraufhin die Suche an?	Sehr gute Informationssuche (Trifft voll zu)	• Einbezug verschiedener Suchmaschinen • Literaturverzeichnisse werden miteinbezogen (Schneeballmethodik) • Datenbanken werden genutzt (Bibliotheken) • Suchtechniken werden genutzt (AND, OR …) • Variation der Suchbegriffe	*„Die Begriffe Digitalisierung und Industrie 4.0 in Google, Google Scholar oder wissenschaftlichen Datenbanken (Ebsco, Primo o.ä.) eingeben und nach einschlägigen Artikeln suchen und von dort aus nach weiteren Schlagwörtern suchen (Schneeballmethodik)“*
	Gute Informationssuche (Trifft eher zu)	• Einbezug verschiedener Suchmaschinen • Literaturverzeichnisse werden miteinbezogen (Schneeballmethodik) • sehr vielfältige Variation der Suchbegriffe	*„Ich würde die Kombinationen: „Auswirkungen Digitalisierung“, „Industrie 4.0“, „Risiken Digitalisierung“, „Risiken Industrie 4.0“, „Chancen Industrie 4.0“ als für den ersten Anlauf am aussichtsreichsten halten und daraufhin weitergooglen.“*
	Durchschnittliche Informationssuche (weder noch)	• Einbezug verschiedener Suchmaschinen • 0815 Antwort / Erwartbarer Durchschnitt • Variation der Suchbegriffe	*„Ich würde die Begriffe "Digitalisierung Auswirkungen Arbeit" und "Industrie 4.0 Auswirkungen Arbeit" eingeben.“*
	Eher schlechte Informationssuche (Trifft eher	• Einbezug von nur einer Suchmaschine • Suchbegriff wird nur gesamt gesucht (Keine Variation)	*„Ich würde nach Industrie 4.0 googeln“*

	schlechte Informationssu-che (Trifft nicht zu	• Es wird nur oberflächlich ge-sucht. • Die gewählte Suche basiert nicht auf fundierten Quellen, sondern kann editiert werden (Wiki) • Leeres Feld	*„Industrie 4.0 bei Wikipe-dia“*
Nach welchen Kriterien beurteilen Sie, ob den gefundenen Informationen problemlos getraut werden kann?	Sehr gute Evaluation (Trifft voll zu)	• Überprüfung der Vertrauens-würdigkeit der Informationen auf anderen Seiten • Bekanntheitsgrad/Ruf der veröffentlichenden Seite wird miteinbezogen • Literaturangaben werden auf Konsistenz geprüft • Wenn es möglich ist werden wissenschaftlichen Quellen ge-nutzt	*„Ich vergleiche die Infor-mationen mit weiteren ge-fundenen Informationen. Außerdem sehe ich mir die Autoren an und schaue, ob es sich um wis-senschaftliche Texte han-delt.“*
	Gute Evaluation (Trifft eher zu)	• Überprüfung der Vertrauens-würdigkeit der Seite • Bekanntheitsgrad/Ruf der veröffentlichenden Seite wird miteinbezogen • Kontrolle der Informationen über zusätzliche Recherche • seriöse Zeitungen werden als vertrauenswürdig eingestuft	*„Wenn ich beispielsweiße Zeitungen oder Nachrich-ten (Spiegel, Tagesschau, BBC) als Grundlage nehme, vergleiche ich de-ren Berichterstattung mit-einander. Da im Internet selten etwas wirklich ob-jektiv geschrieben ist.“*
	weder gute noch schlechte Evaluation (Teils-Teils)	• 0815 Antwort • generell Zeitungsquellen •Informationsquelle wird auf Fehler überprüft • Veröffentlichende Seite wird untersucht • Keine weiterführende Re-cherche zur Thematik	*„Ich schaue auf welcher Seite ich die Informatio-nen gefunden habe. Ver-trauenswürdige Seiten, welche explizit sich auf meine Zielgruppe bezie-hen und schon von ande-ren Seiten vielleicht schon als Quelle vorgeschlagen worden sind."*
	Schlechte Evaluation (Trifft eher nicht zu)	• Auswertung der Informatio-nen nicht ausreichend • Keine weiterführende Re-cherche zur Thematik	*„Bekanntheit der Seite"* *"Meist sieht man die Pro-fessionalität der Seite an."*

	Keine Evaluation (Trifft nicht zu)	• Es findet keine rationale Auswertung der gewonnenen Informationen statt • Keine Überprüfung der Vertrauenswürdigkeit der Seite, der die Informationen entnommen wurden. • Leeres Feld	*„Ich beurteile nach Gefühl, ob sich das seriös liest...“*
Wie würden Sie die im Internet gefundenen Informationen in ihre vorhandene Ordnerstruktur Computer einordnen?	sehr gute Strukturierung (Trifft voll zu)	• Informationen werden nach Kategorien zugeordnet • Oberbegriffe werden sortiert und Kategorien zugeordnet • Literaturverzeichnis wird nach diesen Kategorien erzeugt und gefüllt • "Strukturbaum" wird ersichtlich mit Ober und Unterordnern /Kategorien • Aktivieren des Vorwissens durch Zuordnung in bestehende Ordnerstruktur	*„Ich würde sie kategorisieren, eine Tabelle mit den Ergebnissen anlegen, versuchen, Oberbegriffe zu finden und nach Definitionen suchen.“*
	gute Strukturierung (Trifft eher zu)	• Nicht ganz so detaillierte Kategorisierung der Informationen • Oberbegriffe werden sortiert und Kategorien zugeordnet • Aktivieren des Vorwissens durch Zuordnung in bestehende Ordnerstruktur	*„Ich würde die Informationen nach Quellen und/oder nach Vor- und Nachteilen strukturieren.“*
	weder gut noch schlecht (Teils-Teils)	• 0815 Antwort / Erwartbarer Durchschnitt • Kategorisierung der Informationen • Struktur vorhanden, aber nicht übersichtlich	*„Nach Themenbereichen“* *„Ich würde sie nach Seiten strukturieren, welche bekannt sind, bzw. seriös aussehen.“*
	weniger gute Strukturierung (Trifft eher nicht zu)	• Informationen werden gesichtet und grob geordnet / ohne Struktur • Eher oberflächliche Strukturierung	*„Durchlesen und zusammenfassen, Inhalte einfacher erzählen können“*

	Keine/schlechte Strukturierung (Trifft nicht zu)	• Informationen werden ohne Struktur gespeichert • Es werden keine besonderen Maßnahmen zur Strukturierung genutzt. (Ordner, Tabelle, Überschriften, Roter Faden) • Leeres Feld	*"Ich packe die Informationen sofort in die entsprechende PowerPoint Folien."*
Welche und wie viele Sicherheitsmaßnahmen kennen Sie um ihren PC for Malware (Schadhafter Software) durch solche Dateien zu schützen?	Sehr gute Kenntnisse von Datensicherheit (Trifft voll zu)	• Viele Maßnahmen für Datensicherheit sind vollständig bewusst (Zutritts-, Zugangs-, Zugriffs-, Weitergabe-, Eingabe-, Auftrags-, Verfügbarkeitskontrolle) • Trennung Privat und Arbeitsbereiche • Passive und aktive Mechanismen sind bekannt (bspw. Antivirenprogramm (=Passiv) und Prüfen von ZipDateien (Aktiv) • Aktives „Achten", wo und wie man sich im Netz bewegt und was (für Formate) man wo runterlädt • Regelmäßige (Sicherheits-)Updates durchführen	*"Zunächst ist auf die Quelle zu achten, Ist die Internetseite vertrauenerweckend. Dann prüfe ich das Dateiformat. Ist es mir bekannt bzw. schlüssig in Bezug auf die gewollten Dateien. Gerne wird schafhafte Software in .exe oder .dmg Datei auf den Computer geschleust, dies sind ausführende Dateien, hier kann direkt angenommen werden, dass solch ein Dateiformat nicht zweckdienlich der Information von Text, Bildinformationen ist. Gängige Formate sind .jpeg, .gif. png Office Formate oder pdfs. Zudem gibt es Sicherheitssoftware, die die gedownloadeten Dateien überprüfen (McAfee, Kaspersky uvm.) Nicht vertrauenswürdiges Material lade ich erst gar nicht runter."*
	Gute Kenntnisse von Datensicherheit (Trifft eher zu)	• Mehrere Mechanismen sind bekannt • Passive und aktive Mechanismen sind bekannt (bspw. Antivirenprogramm (=Passiv) und Prüfen von ZipDateien (Aktiv) • Aktives drauf achten, wo und wie man sich im Netz bewegt und was (für Formate) man wo runterlädt	*"Ich weiß, dass man eine Firewall irgendwo downloaden kann, die den Computer gut davor schützt, ich weiß jedoch nicht genau wo. Ansonsten kenne ich verschiedene Antivirensysteme, wie Avira oder McAfee. "*

	weder gut noch schlecht (Teils-Teils)	• Mechanismus ist bekannt • Aktives drauf achten, wo und wie man sich im Netz bewegt und was (für Formate) man wo runterlädt	*"Ich wüsste nicht warum ich mehr Maßnahmen als ein einfaches Virenschutzprogramm brauche. Mehr nutze ich nicht und mehr sind mir auch nicht bekannt."*
	Eher schlechte Kenntnisse von Datensicherheit (Trifft eher	• Mechanismen sind nur unzureichend genannt • Maßnahmen für Datensicherheit sind nicht bekannt.	*"kostenloses AntiVir"*
	Keine Kenntnisse von Datensicherheit (Trifft nicht zu)	• Datensicherheit wird nicht eingesehen • Datensicherheit ist nicht bekannt und wird als verschwendete Zeit gesehen • Nur auf Bauchgefühl achten. • Leeres Feld	*"Ich kenne leider keine Sicherheitsmaßnahmen. Ich vertraue den Einstellungen, die von vorneherein auf mein Macbook installiert wurden."*
Was verstehen Sie unter gesichertem dem Schützen ihres PCs vor solcher schadhaften Software?	Sehr gutes Verständnis von Datensicherheit (Trifft voll zu)	• Viele Maßnahmen für Datensicherheit sind vollständig bewusst (Zutritts-, Zugangs-, Zugriffs-, Weitergabe-, Eingabe-, Auftrags-, Verfügbarkeitskontrolle) • Trennung Privat und Arbeitsbereiche • Passive und aktive Mechanismen sind bekannt (bspw. Antivirenprogramm (=Passiv) und Prüfen von ZipDateien (Aktiv) • Aktives drauf achten, wo und wie man sich im Netz bewegt und was (für Formate) man wo runterlädt • sichere Passwörter und regelmäßig aktualisieren	*"Wichtig ist es regelmäßige Updates des PCs durchzuführen, dass dieser aktuell bleibt. Dann mindestens einmal in der Woche das Antivirenprogramm über den PC laufen lassen. Und niemals Programme von unseriösen Quellen runterladen. Weder im privaten noch auf der Arbeit auf „unseriösen“ Seiten surfen."*

	Gutes Verständnis von Datensicherheit (Trifft eher zu)	• Mehrere Mechanismen sind bekannt • Passive und aktive Mechanismen sind bekannt (bspw. Antivirenprogramm (=Passiv) und Prüfen von ZipDateien (Aktiv) • Aktives drauf achten, wo und wie man sich im Netz bewegt und was (für Formate) man wo runterlädt	*"Es gibt bestimmte Seiten bzw. Suchbegriffe die einen denk ich recht schnell mit schadhafter Software beladen. Diese Seiten versuche ich tendenziell zu vermeiden. Ansonsten lade ich nichts von einer Seite runter bei der nicht das grüne Schloss vor dem Link steht. Aber Firewall ist eh immer an."*
	weder gut noch schlecht (Teils-Teils)	• Sicherheitsmechanismen sind bekannt • Aktives drauf achten, wo und wie man sich im Netz bewegt und was (für Formate) man wo runterlädt • sichere Passwörter regelmäßig zu aktualisieren	*"Immer überall abmelden, kein gleiches Passwort für mehrere Seiten nutzen. Downloads prüfen."*
	Eher schlechtes Verständnis von Datensicherheit	• Mechanismen sind nur unzureichend genannt • Maßnahmen für Datensicherheit sind nicht bekannt.	*"Ich verstehe darunter, dass der PC durch diese einen gewissen Schutz hat."*
	Kein Verständnis von Datensicherheit (Trifft nicht zu)	• Datensicherheit wird nicht eingesehen • Datensicherheit ist nicht bekannt und wird als verschwendete Zeit gesehen • Nur auf Bauchgefühl achten. • Leeres Feld	*„Nichts Spezielles. Mein Mac ist ja durch IOS geschützt vor Viren.“*

Wie gehen Sie schrittweiße vor um das das Problem zu lokalisieren und zu beheben? (Die Firma verfügt über keine eigene IT-Abteilung und Sie können erst in 2 Stunden jemanden um Hilfe bitten!)	Sehr gute Problemlösekompetenz (Trifft voll zu)	• Übersicht verschaffen • Eigenständiges Problem lösen • Informationen zu Problem sammeln • Gründliche Analyse des Problems (Online, Offline). • Guter Austausch mit anderen Personen (Als letztes) • Strukturierte Vorgehensweiße	*"- ich versuche zuerst mich vom Netzwerk zu trennen und mich anschließend wieder einzuloggen* *- ich starte den Computer noch einmal neu* *- ich frage andere Kollegen, ob es ihnen ähnlich geht* *- wenn ja, haben mehrere Leute keinen Zugriff und es scheint ein größeres Netzwerkproblem zu sein* *- wenn nein, versuche ich mit einem anderen Gerät zu googeln, woran es liegen könnte"*
	Gute Problemlösekompetenz (Trifft eher zu)	• Übersicht verschaffen • Informationen zu Problem sammeln • Eigenständiges Problemlösen • Analyse des Problems	*"ich würde zunächst auf Ursachenforschung gehen und versuchen das Problem zu identifizieren. Der Problemlösungsassistent von Microsoft könnte mir dabei helfen. Wenn ich nicht alleine weiterkomme würde ich einen Kollegen um Hilfe bitten."*
	weder gut noch schlecht (Teils-Teils)	• Problemstellung formulieren • Online über mögliche Hilfen informieren • Problemlösung nur mithilfe eigener Ideen. • Alternativen werden genutzt.	*„Problem googeln"*

	eher schlechte Problemlösekompetenz (Trifft eher nicht zu)	• Problem wird nicht angegangen. • Nachdem Problem analysiert wurde, an andere weitergeben • (Experten-)Wissen von Personen hinzuholen	*" ich würde vielleicht probieren ob das Wlan abgestellt wurde und wenn dies der Fall sein sollte es wieder anmachen, dann sollte ich wieder Zugriff auf das Internet haben. wenn dies aber nicht das Problem sein sollte, dann bin ich leider überfragt und würde mich dann an die Sachen halten die ich bereit schon rausgefunden hatte bevor ich dann endlich jemanden fragen kann der sich damit vielleicht besser auskennt als ich"*
	Schlechte/Keine Problemlösekompetenz (Trifft nicht zu)	• Problem ignorieren und versuchen darum herum zu arbeiten • Aufgeben • Hoffen, dass sich das Problem von alleine löst... • Leeres Feld	*"Ich frage einen Fachmann, da ich keine Ahnung von Technik habe..."*
Welche Softwareanwendungen beherrschen Sie besonders gut, die vielleicht ihre Kollegen nicht so gut können und die Sie generell im Laufe dieser Aufgabe benutzen?	Sehr gute Softwareanwendung (Trifft voll zu)	• Sehr sicheres Antworten und komplizierte Software (Excel) • Softwareanwendung erfordert Programmieren • "Excel +" • Kombinationen aus vielen Anwendungen	*"Ich beherrsche PowerPoint sehr gut, da ich während meiner Ausbildung mehrere Präsentationen erstellen und präsentieren musste. Mit Word und Excel kann ich auch gut umgehen jedoch fehlen mir Kenntnisse in Bereichen wie Makroprogrammierung oder ganz speziellen Einstellungen in Word. Ich habe außerdem gute Grundkenntnisse in SAP (mehrere Module)."* *"Ich erstelle eigene HTML Seiten"*

	Gute Software-anwendung (Trifft eher zu)	• Gute Kenntnisse mit Umgang von Programmen • "PowerPoint" • Nennung mehrerer Softwar-eanwendungen	*"Ich kann ganz passabel mit Word, PowerPoint und Excel umgehen."*
	weder noch	• 0815 Antwort / Erwartbarer Durchschnitt • Social Media wird als hilf-reich erachtet • "Word"	*"Ich bin gut in Word & Social Media"*
	Eher keine gute Softwareanwen-dungen (Trifft e-her nicht zu)	• Weniger als 0815 Antwort • Unsicherheit bezüglich der Softwareanwendungen wird ersichtlich • Fokus auf Social Media	*"Ich beherrsche Word ganz in Ordnung. Bei Excel und Power-Point fühle ich aber sehr mich unwohl"*
	Schlechte Software-anwendung (Trifft nicht zu)	• Computer wird wie eine Black Box behandelt (Info in – Info out) • Zusammenhänge nicht klar ("sehr geringe Selbsteinschät-zung") • "Keine", "Paint"	*"Ich glaube, in meinem Bekanntenkreis bin ich diejenige, die sich am we-nigsten mit Softwares aus-kennt..."* *"RFID"*
Was ist, aus ihrer Sicht, die komplexeste Software, die Sie auch beherrschen, die hier von Relevanz sein könnte? c. Was würden Sie innerhalb dieser Software erstellen/programmieren/visualisieren?	Sehr gute Software-anwendung (Trifft voll zu)	• Sehr sicheres Antworten und komplizierte Software (kom-plexer als Excel) • Softwareanwendung erfordert Programmieren • Kombinationen aus vielen Anwendungen	*"Generell kann ich ganz solide mit SQL, C++ und R arbeiten. Vielleicht kann ich das hier ja integ-rieren“*
	Gute Soft-warean-wendung (Trifft eher zu)	• Gute Kenntnisse mit Umgang von Programmen • „höheres“ aber noch Stan-dardprogramm bspw. "Excel"	*"Microsoft Access"* *"Adobe Photoshop kann ich ganz gut anwenden"*
	weder noch	• 0815 Antwort / Erwartbarer Durchschnitt • MS Office Produkte • "PowerPoint"	*"PowerPoint und Word sind schon sehr komplex, diese kann ich aber gut anwenden und würde na-türlich beide hier nutzen wollen. (ppt für Präsenta-tion. Word für Handout."*

	Eher keine gute Softwareanwendungen (Trifft eher nicht zu)	• Weniger als 0815 Antwort • Unsicherheit bezüglich der Softwareanwendungen wird ersichtlich • Fokus auf Social Media	*"Ich beherrsche MS Pakete nur sehr begrenzt"*
	Schlechte Softwareanwendung (Trifft nicht zu)	• Computer wird wie eine Black Box behandelt (Info in – Info out) • Zusammenhänge nicht klar ("sehr geringe Selbsteinschätzung") • "Keine", "Paint"	*"Ich beherrsche keine komplexere Software"* *„Instagram kann ich Bilder und Stories sehr gut erstellen."*
Wie könnte Copyright das Verwenden von Text-, Bild- und Tonmaterialien für Ihre Präsentation beeinflussen?	Sehr gutes Wissen über Copyright (Trifft voll zu)	• Bewusstsein, was Copyright ist und welche Daten im Internet unter das Copyright fallen • Rechte von Urhebern sind vollständig bekannt. • Konsequenzen von Copyright Verletzungen • Datumsangabe bei Webseiten Nennung • Verweis auf Gesetzeslage	*„Im kommerziellen Bereich spielen die Lizenzen von verwendeten Materialien eine große Rolle, dabei ist darauf zu achten, dass diese entweder für den gewollten Zweck freigegeben sind bzw. über eine sog. CC-Lizenz verfügen und somit zur freien Verfügung stehen. Dann ist ebenfalls zu unterscheiden, ob die Materialien für die eigene Präsentation genutzt werden dürfen und ob sie darüber hinaus auch an dritte als Handout weitergegeben werden dürfen. Hier ist häufig auch die Nutzung von Bildmaterialien eingeschränkt. Sie können Teile für Präsentationen nutzen, diese aber nicht als Handout vervielfältigen und weitergeben."*

	Gutes Wissen über Copyright (Trifft eher zu)	• differenziertes Wissen, wie mit Copyright umgegangen wird • Rechte von Urhebern sind bekannt. • Korrektes Nutzen von Copyright-Daten • Wissen über Urheberrechte. • Überprüfung der Seriosität der Quelle wird mitgenannt	*„Ich muss die Quellen nennen, von welchen ich meine Informationen bezogen habe. Ich darf den Text nicht kopieren ohne zu zitieren. Ich darf keine extern bezogenen Dinge als mein eigens geistliches Eigentum verwenden“*
	weder noch	• 0815 Antwort / Erwartbarer Durchschnitt • Rechte von Urhebern sind teilweise bekannt • Einsilbige Antworten	*"Mit dem Copyright Zeichen wirkt die Präsentation viel besser als ohne denn somit kann man sofort erkennen das deine Quellen im Internet sicher sind."*
	Eher kein Wissen (Trifft eher nicht zu)	• Betonung eher auf den negativen Aspekten wie Zeitfressend und "mit hohem Aufwand verbunden" • Kein vollständig korrekter Umgang mit Copyright • Kaum Wissen, was unter das Copyright fällt	*"Durch das Belegen mit Quellen wirkt sich Copyright sehr zeitfressend aus"* *"Copyright macht die Arbeit schwerer"* *"Viele Materialien darf ich dann überhaupt nicht verwenden"*
	Kein Wissen von Copyright (Trifft nicht zu)	• Copyright ist nicht bekannt • Bedenkenlose Nutzung von urheberrechtlichen Daten ohne Angabe von Quellen.	*„Copyright beeinflusst bisher gar nicht das Verwenden von Text-, Bild- und Tonmaterialien für diese Präsentation.“*

Wie würde der Nachrichtenstil aussehen? d. Welchen Online-Kommunikationsweg würden Sie wählen?	Sehr gute Kollaborationskompetenz (Trifft voll zu)	• Sehr gute Zusammenarbeit mit Kollegen und Mitmenschen • Offenheit bzgl. Kritik • Kommunikationsregeln werden sicher angewandt • Verschiedene Kanäle zur Kollaboration werden natürlich aufgeführt • Email wird als Kommunikationsmittel präferiert • Auf Umgangston wird wertgelegt	*„Es kommt auf den Grad der Bekanntschaft an, ob WhatsApp, SMS, oder hier vielleicht am besten per Mail: Sehr geehrter Herr Maier, für meine Recherche bezüglich der Präsentation über ... Dabei bin ich folgendes gestoßen... Liege ich richtig in der Annahme, dass Desweiteren hätte ich gerne Ihre Unterstützung in folgenden Punkten: ...* *Mit freundlichen Grüßen, xy.“*
	gute Kollaboration (Trifft eher zu)	• Gute Zusammenarbeit mit Kollegen und Mitmenschen • Offenheit bzgl. Kritik • Kommunikationsregeln werden sicher angewandt • Verschiedene Kanäle zur Kollaboration werden genutzt. • Email wird als Kommunikationsmittel präferiert	*"Über den Account der Geschäftsmail. Die Mail würde geschäftliche Standards (Höfliche Anrede, Signatur, ...) enthalten. Kurz den Fall schilden und fragen, ob die Möglichkeit einer Unterstützung bestehe."*
	weder gut noch schlecht (Teils-Teils)	• 0815 Antwort / Erwartbarer Durchschnitt • Nur ein oder kein Kanal zur Kommunikation wird genutzt. • Kommunikation mit Kollegen und Mitmenschen findet statt. • Kommunikation weist Lücken auf und kann dadurch nicht sinnvoll genutzt werden	*„Email schreiben“*
	Eher schlechte Kollaboration (Trifft eher nicht zu)	• Kritik wird nicht als Möglichkeit der Verbesserung angesehen • Kein sinnvolles Nutzen der Kommunikation • Social Media wird als Kommunikationsmittel präferiert	*"Anrufen und fragen ob er Zeit hat mir zu helfen.* *Falls ich ihn nicht erreiche: Whatsapp"*

	Keine Kollaborationskompetenz (Trifft nicht zu)	• Kommunikation wird vermieden. • Social Media wird als Kommunikationsmittel präferiert • Kritik wird nicht angenommen	*"mit dem Smartphone"*
Beschreiben Sie ihre Methode um eine entsprechende Strategie zu finden wie Sie diese komplexe Aufgabe lösen wollen. Nennen Sie dabei jeden Schritt.	Sehr gute gehobene Problemlösefähigkeit (Trifft voll zu)	• Übersicht verschaffen • Informationen zu Problem sammeln • Gründliche Analyse des Problems (Online, Offline). • Guter Austausch mit anderen Personen / Expertenwissen zurate ziehen	*"1.Mindmap erstellen* *2.Informationen sammeln* *3.Genauen Plan aufstellen* *4.Evtl Team zusammenstellen* *5.Plan abarbeiten* *6.Präsentation vorbereiten* *7.Vorgesetzten zeigen "*
	Gute gehobene Problemlösekompetenz (Trifft eher zu)	• Übersicht verschaffen • Informationen zu Problem sammeln • Analyse des Problems • Expertenwissen zurate ziehen	*"Um das auf das Unternehmen anwenden zu können, müsste ich die Bereiche, welche von der Idee profitieren könnten, ausfindig machen und gleichzeitig deren aktuellen Stand hinsichtlich dieses Themas analysieren. Danach erarbeite ich eine Strategie wie ich die vorgestellten Inhalte auf die einzelnen Bereiche anwenden kann."*
	weder gute noch schlechte Problemlösekompetenz (Teils-Teils)	• Problemstellung formulieren • Online über mögliche Hilfen informieren • Problemlösung nur mithilfe eigener Ideen.	*"Ich recherchiere im Internet, ob jemand anderes sowas ähnliches schon Mal gemacht hat und lasse mich davon inspirieren. Überdies bereite ich eine Präsentation zur Veranschaulichung meiner Ergebnisse vor."*

	eher keine gehobene Problemlösekompetenz (Trifft eher nicht zu)	• Alternativen werden genutzt. • Problem wird nicht angegangen. • Nachdem Problem analysiert wurde, an andere weitergeben • Es sind keine tiefergehende Lösungsschemata zu erkennen.	*"Ich erstelle eine Präsentation die sehr gut visuell bearbeitet ist und in der Präsentation erkläre und beschreibe ich alle meinen Ideen"*
	Keine/Schlechte gehobene Problemlösekompetenz (Trifft nicht zu)	• Problem ignorieren und versuchen darum herum zu arbeiten • Aufgeben • Durch Überheblichkeit versuchen, das Problem zu lösen, den falschen, viel zu komplizierten Ansatz wählen	*"Auf die Schnelle würde mir persönlich nichts dazu einfallen, wie ich Strategie entwickeln könnte um diese Aufgabe zu lösen."*

Questionnaire at time point 0 (Pre-test; study 4)

Sehr geehrte Damen und Herren,

Vielen Dank, dass Sie sich an der Unterrichtserprobung im Rahmen des Projektes *LoK4.0* beteiligen. *LoK4.0* möchte die Entwicklung von didaktischen Konzepten zur lernförderlichen Nutzung von Lernfabriken 4.0 und zur Stärkung der Lernortkooperation untersuchen. Die Universität Mannheim arbeitet dabei mit Südwestmetall und dem Institut der deutschen Wirtschaft Köln zusammen. Der Forschungszweck der folgenden Untersuchungsreihe besteht darin die digitalen Handlungs- und unterrichtsrelevante-, technische Kompetenzentwicklung durch den unterschiedlichen Einsatz von Lernfabriken 4.0 zu erfassen.

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Stellen Sie sich nun folgende Situation vor:

Sie sind Mitarbeiter eines kleinen mittelständischen Produktionsunternehmen (nicht ihre tatsächliche Firma!).

Eines Tages kommt Ihre Vorgesetzte (Frau Brunner) morgens um 09:00 Uhr zu Ihnen an den Arbeitsplatz und bittet Sie ihr bis morgen 12:30 Uhr eine Präsentation über: "*Sensoren in der Industrie 4.0: Welche Rolle spielen Sensoren in einer Smartfactory?*" bereitzustellen. Frau Brunner betont, dass diese Aufgabe höchste Priorität genießt und bittet Sie zudem neben der reinen visuellen Darstellung auch zusätzliche Informationen übersichtlich auf einem Handout darzustellen. Mithilfe der Präsentation und der anschließenden Diskussion möchte die Vorgesetzte im Vorstand diskutieren ob es lohnenswert sein könnte die Produktion entsprechend auf den neuesten Industrie 4.0 Standard umzurüsten.

Im Folgenden werden Ihnen zu diesem Szenario Fragen gestellt, die Sie bitte reflektiert und in möglichst ganzen Sätzen beantworten. Beschreiben Sie dabei stets wie Sie vorgehen würden und antworten Sie so detailliert wie möglich.

Frau Brunner gibt Ihnen dabei die folgenden Fragen mit, die Sie gerne von Ihnen beantwortet haben möchte:

Wie gehen Sie vor, wenn Sie einen Ihnen bislang unbekannten Sensor an eine Steuerung anschließen wollen?	
Welche Sensoren kennen Sie, mit denen Sie berührungslos den Abstand zu einem Objekt erfassen können?	
Beschreiben Sie von einem der oben genannten Sensoren das Funktionsprinzip in Stichpunkten.	
Über welche Signalarten könnte der Abstandswert vom Sensor zur SPS übertragen werden?	
Beschreiben Sie die Funktionsweise eines optischen Näherungsschalters.	
Nennen Sie zwei Chancen, die die 4. industrielle Revolution bietet.	
Was ist das EVA Prinzip?	

Fragen zur digitalen Handlungskompetenz

Nennen Sie alle Software(Anwendungen), die Sie für die Aufgabe von Fr. Brunner besonders gut können und nutzen wollen.	
Was ist die komplizierteste Industrie 4.0 bezogene Sache, die Sie mit Software bearbeiten können und welche Software wäre das?	
Wo und wie suchen Sie nach Informationen über Industrie 4.0 und Smartfactories im Internet? Auf was müssen Sie achten bei Informationen aus dem Internet?	
Nach welchen Kriterien bewerten Sie, ob gefundene Informationen aus dem Internet problemlos getraut werden können?	
Wie müssen Sie auf das Copyright bei dieser Aufgabe aufpassen?	
Wie ordnen Sie auf einem PC die gefundenen Informationen an?	
Bei der Recherche stoßen Sie Schnell auf Gefahrenhinweise hinsichtlich der Schnittstellen in der Industrie 4.0. Wie sollte man sich selbst im Internet vor Gefahren (Spam, Viren, Malware, etc.) schützen?	
Aber wie schützen Sie sich aber wirklich im Internet?	
Und vor was sollte man beispielsweiße die Smartfactory (im Internet) schützen?	

Sie kommen nicht so wirklich weiter, weil Sie nicht genauer wissen worauf Fr. Brummer bei einer Präsentation achtet. Sie beschließen sie zu kontaktieren. Auf was müssen Sie achten, wenn man schriftlich und digital (bspw. WhatsApp, Email, etc.) mit einem (vorgesetzten) Kollegen aus der Firma kommuniziert?	
Nach einer Mittagspause lassen Sie einen Computer neu starten, da ein Microsoft-Update erforderlich war. Danach haben Sie keinen Zugriff mehr auf das Internet. Wie gehen Sie schrittweiße vor um das Problem zu lösen und zu beheben?	

Questionnaire at time point 1 (study 4)

Sehr geehrte Damen und Herren,

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Frau Brunner gibt Ihnen dabei die folgenden Fragen mit, die Sie gerne von Ihnen beantwortet haben möchte:

Nennen Sie die Vor- und Nachteile eines GMR-Sensors gegenüber einem Reedkontakt	
Welche Werkstoffe kann ein kapazitiver Näherungsschalter erfassen?	
Sie müssen einen Ihnen bislang unbekannten Sensor an eine Steuerung anschließen. Erklären Sie schrittweise ihr Vorgehen.	
Beschreiben Sie das EVA Prinzip	
Nennen Sie zwei Voraussetzungen für eine Smartfactory.	
Bei der Inbetriebnahme einer Anlage stellen Sie fest, dass eine Abstandsmessung nicht korrekt funktioniert. Beschreiben Sie ihr Vorgehen in Stichpunkten.	

Fragen zur digitalen Handlungskompetenz:

Welche Software beherrschen Sie so gut, dass Sie glauben Sie sind darin besser als die meisten Ihrer Kollegen? (Sie können auch mehrere Möglichkeiten nennen.)	
Bei der Erstellung der Präsentation für Frau Brunner wollen Sie Bilder aus dem Internet verwenden. Wie spielt hier das Copyright eine Rolle?	
Welche(n) Suchbegriff(e) würden Sie wählen, wenn Sie für die Aufgabe von Fr. Brunner anfangen würden zu googeln?	
Wie strukturieren Sie auf einem PC die gefundenen Informationen?	
Sie haben nun mehrere Informations-Quellen gefunden. Was unterscheidet gute von schlechten Quellen im Internet?	
Durch die Vernetzung der Industrie 4.0 verbinden sich viele Geräte miteinander und mit dem Internet. Das birgt auch für ihr Unternehmen viele Gefahren. Welche könnten das sein?	
Wie schützen Sie sich selbst im Internet?	
Sie fragen über Social Media um Hilfe um die Aufgabe zu lösen. Was könnten die Gefahren von Snapchat oder Whatsapp Nutzung sein?	
Auf was sollten Sie bei der Zusammenarbeit durch digitale Technologien achten?	
Was ist die beste Lösungsstrategie, wenn bei Ihnen in der Firma irgendein unbekanntes technisches Problem auftritt?	

Bitte vergeben Sie Nummern, was Sie nacheinander machen würden und beginnen Sie mit 1: - Ich frage um Hilfe - Ich schaue mir an was funktioniert und was nicht - Ich google das Problem - Ich schaue, ob ich mit meinem Wissen, das Problem selbst lösen kann - Ich probiere verschiedene Möglichkeiten aus - Sonstiges:_____________________________	

Questionnaire at time point 2 (study 4)

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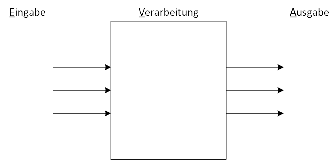
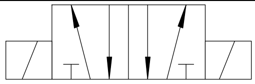
Welcher Unterscheid im Aufbau besteht zwischen einer Reflexionslichtschranke und einer Einweglichtschranke?	
Welche Werkstoffe kann ein kapazitiver Näherungsschalter erfassen?	
Der Begriff EVA-Prinzip steht für Eingabe-Verarbeitung-Ausgabe-Prinzip. Geben Sie für jede Komponente ein Beispiel.	
Beschreiben Sie die Funktionsweise dieses pneumatischen Ventils.	
Erklären Sie. Was ist eine Smartfactory?	
Bei der Inbetriebnahme einer Anlage stellen Sie fest, dass eine Abstandsmessung nicht korrekt funktioniert. Beschreiben Sie ihr Vorgehen in Stichpunkten.	

Fragen zur digitalen Handlungskompetenz:

Für die Präsentation nutzen Sie PowerPoint, Word und Excel. Was ist das komplizierteste, was Sie mit diesen drei Softwares machen können?	
Warum müssen Sie dabei die Quellen aus dem Internet angeben?	
Beschreiben Sie Ihre Suchstrategie im Internet, wenn Sie die Aufgabe von Fr. Brunner erledigen möchten.	
Wie ordnen Sie für sich die gefundenen Informationen?	
Welchen Quellen würden Sie dabei eher **nicht** vertrauen?	
Wieso sollten Sie (nicht nur bei dieser Aufgabe) im Internet auf Datenschutz achten?	
Welche Maßnahmen kann man ergreifen um sein Handy oder den PC sicherer zu machen? Nennen Sie alles was Ihnen einfällt.	
Was machen Sie davon wirklich damit ihr Name oder ihre Daten im Internet nicht missbraucht werden können?	
Sie schreiben nun Frau Brunner ein paar Rückfragen. Auf was sollte man achten, wenn man seinem Chef/ seiner Chefin schreibt?	
Können Sie kurz beschreiben, welche einzelnen Schritte Sie nutzen um ein (technisches) Problem zu lösen?	

Coding Guideline (study 4)

Note: This Coding Guideline was only created for the multidisciplinary questions. The subject-related tasks were evaluated by the participating teachers according to their normal exam standards.

Items			Scale	Criteria	Examples
T0	T1	T2			
Nennen Sie alle Software(Anwendungen), die Sie für die Aufgabe von Fr. Brunner besonders gut können und nutzen wollen.	Welche Software beherrschen Sie so gut, dass Sie glauben Sie sind darin besser als die meisten Ihrer Kollegen? (Sie können auch mehrere Möglichkeiten nennen.)	Für die Präsentation nutzen Sie PowerPoint, Word und Excel. Was ist das komplizierteste, was Sie mit diesen drei Softwares machen können?	Positiv (3)	• Programmieren spielt eine Rolle • Mindestens 2 Programme werden genannt (Kein Social Media) • (fach)spezifische Programme	*"DAWs (ProTools), PowerPoint (Keynote), Pages"* *“Ich kann CAD/CAM programmieren, und Word, Excel, PowerPoint, Keynote, Pages"*
			Weder noch (2)	• 0815 Antwort / Erwartbarer Durchschnitt • Social Media überwiegt	*„YouTube, Instagram, Word“* *„Excel“*
			Negativ (1)	• Es wird nur Social Media genannt • Sehr oberflächliche Antwort	*„Facebook / Instagram“*
			Keine Antwort (0)	• Computer / Software werden wie eine Black-Box behandelt • Keine Antwort	
Wo und wie suchen Sie nach Informationen über Industrie 4.0 und Smartfactories im Internet?	Welche(n) Suchbegriff(e) würden Sie wählen, wenn Sie für die Aufgabe von Fr. Brunner anfangen würden zu googlen?	Beschreiben Sie Ihre Suchstrategie im Internet, wenn Sie die Aufgabe von Fr. Brunner erledigen möchten.	Positiv (3)	• Beschreibung auf was geachtet werden muss bei der Suche • Variation der Suchbegriffe • Es wird nicht gleich das erste Ergebnis genommen	*„zuverlässige Quellen im Internet suchen. Zur Not mit mehreren Begriffen. Pros + Contras raussuchen.“* *„Grundskepsis wahren“*
			Weder noch (2)	• Gedankenloses Urvertrauen in bspw. Wikipedia • 0815 Antwort / Erwartbarer Durchschnitt	*„Google, „Industrie 4.0“ eingeben, Wikipedia lesen.“*

			Negativ (1)	• Nur Nennung der Suchmaschine • Nur Suchbegriff wird genannt	*„Auf Rechtschreibung“* *„Einfach Industrie 4.0 googeln*
			Keine Antwort (0)	• Keine Antwort / Leeres Feld	
Wie ordnen Sie auf einem PC die gefundenen Informationen an?	Wie strukturieren Sie auf einem PC die gefundenen Informationen?	Wie ordnen Sie für sich die gefundenen Informationen?	Positiv (3)	• Thematische Strukturen • Oberbegriffe werden sortiert und Informationen Kategorien zugeordnet • Genaue (Ordner-) Struktur wird beschrieben	*„Thematisch. Also mit verschiedenen thematischen Ordnern. Dann eventuelle nach Namen oder Datum. Das kommt dann darauf an.“*
			Weder noch (2)	• 0815 Antwort / Erwartbarer Durchschnitt • Keine Kategorisierung, aber Struktur erkennbar	*„Ordner, mit Unterordnern“*
			Negativ (1)	• Speicherung ohne Kategorisierung	*„Über Anordnen „nach Datum geordnet“*
			Keine Antwort (0)	• Keine Antwort • Keine Strukturierung	*„Gar nicht“*
Nach welchen Kriterien bewerten Sie, ob gefundene Informationen aus dem Internet problemlos getraut werden können?	Sie haben nun mehrere Informations-Quellen gefunden. Was unterscheidet gute von schlechten Quellen im Internet?	Welchen Quellen würden Sie dabei eher **nicht** vertrauen?	Positiv (3)	• Überprüfung der Vertrauenswürdigkeit der Seiten • Kontrolle der gewonnenen Informationen • Veröffentlichende Seite wird untersucht	*„Quellenangaben / Verfasser überprüfen und Inhalte stichwortartig googlen.“* *„Ich vergleiche die Informationen mit bspw. Schulbüchern“*
			Weder noch (2)	• 0815 Antwort • Man verlässt sich nur auf Bekanntheitsgrad der Seiten •	*„Wenn die Seite seriös wirkt, keine Rechtschreibfehler hat und man die Seite kennt“*

			Negativ (1)	• Auswertung der Informationen nicht ausreichend • Keine inhaltliche Bewertung der Informationen	*„Antivirus wird mich vor falschen Informationen warnen“* *„Fehlerfreie Grammatik der Seite“*
			Keine Antwort (0)	• Informationen werden ohne Bewertung übernommen. • Keine Antwort	*„Ich vertraue“* *„Nach Gefühl“*
Wie müssen Sie auf das Copyright bei dieser Aufgabe aufpassen?	Bei der Erstellung der Präsentation für Frau Brunner wollen Sie Bilder aus dem Internet verwenden. Wie spielt hier das Copyright eine Rolle?	Warum müssen Sie dabei die Quellen aus dem Internet angeben?	Positiv (3)	• Bewusstsein, was Copyright ist und was darunterfällt, kann erkannt werden • Rechte von Urhebern sind bekannt • Korrektes Anwenden von Copyright	*"Copyright schützt denjenigen, der das Recht besitzt, ein Werk wirtschaftlich zu verwerten. Das Copyright ist dem deutschen Urheberrecht ähnlich, allerdings setzt es einen anderen Fokus. Das Urheberrecht nämlich schützt den Urheber als Schöpfer eines Werkes."*
			Weder noch (2)	• 0815 Antwort / Erwartbarer Durchschnitt • Mehrere korrekte Stichworte zu Copyright	*„rechtlich geschützte(s) Programme/Gut“*
			Negativ (1)	• Rudimentäres Verständnis was Copyright sein könnte • Unvollständige, einsilbige Antworten	*„Kopierverbot“*
			Keine Antwort (0)	• Copyright ist nicht bekannt. • Komplett falsche Antwort • Leeres Feld	*„Bedenkenlose Nutzung von Inhalten“*

Bei der Recherche stoßen Sie Schnell auf Gefahrenhinweise hinsichtlich der Schnittstellen in der Industrie 4.0. Wie sollte man sich selbst im Internet vor Gefahren (Spam, Viren, Malware, etc.) schützen?	Durch die Vernetzung der Industrie 4.0 verbinden sich viele Geräte miteinander und mit dem Internet. Das birgt auch für ihr Unternehmen viele Gefahren. Welche könnten das sein?	Wieso sollten Sie (nicht nur bei dieser Aufgabe) im Internet auf Datenschutz achten?	Positiv (3)	• Gefahr durch Vernetzung ist bekannt • Maßnahmen zur Datensicherheit sind bekannt	*"Schutz vor Datenmissbrauch"* *"Viren, Werbung, Falschinformationen, Hacker"*
			Weder noch (2)	• 0815 Antwort / Erwartbarer Durchschnitt • (Mehrere) Antworten, die nicht unbedingt sinnstiftend sind • Min. eine Antwort in Bezug auf die Gefährdung	*„Werbung“* *„Viren“*
			Negativ (1)	• Nennung eines bloßen Stichworts	*„Werbung“*
			Keine Antwort (0)	• Sinn für Gefährdung fehlt • Leeres Feld	„-„
Aber wie schützen Sie sich aber wirklich im Internet?	Wie schützen Sie sich selbst im Internet?	Was machen Sie davon wirklich damit ihr Name oder ihre Daten im Internet nicht missbraucht werden können?	Positiv (3)	• Gefahr für die eigenen Daten ist bekannt • Maßnahmen zur Datensicherheit sind bekannt •	*„Passwörter und Firewall up2date halten, nicht auf alles Klicken“*
			Weder noch (2)	• 0815 Antwort / Erwartbarer Durchschnitt • (Mehrere) Antworten, die nicht unbedingt sinnstiftend sind • Min. eine Antwort in Bezug auf die Gefährdung	*"Virenschutz, Adblocker, "*
			Negativ (1)	• Nennung eines bloßen Stichworts	*„Adblocker“*

			Keine Antwort (0)	• Sinn für Gefährdung fehlt • Leeres Feld	
Und vor was sollte man beispielsweiße die Smartfactory (im Internet) schützen?	Sie fragen über Social Media um Hilfe um die Aufgabe zu lösen. Was könnten die Gefahren von Snapchat oder Whatsapp Nutzung sein?	Welche Maßnahmen kann man ergreifen um sein Handy oder den PC sicherer zu machen? Nennen Sie alles was Ihnen einfällt.	Positiv (3)	• Gefahr für die eigenen Daten ist bekannt • Maßnahmen zur Datensicherheit sind bekannt • Wissen vor Gefahren ist vorhanden.	*„Um keine Spuren zu hinterlassen wäre der Tor-Browser super. Sonst halt aufpassen (unterschiedliche Passwörter), dass man nirgends leichtfertig seine Daten an Anbieter oder Dritte gibt.“*
			Weder noch (2)	• 0815 Antwort / Erwartbarer Durchschnitt • (Mehrere) Antworten, die nicht unbedingt sinnstiftend sind • Min. eine Antwort in Bezug auf die Gefährdung	*„Man verliert schnell die Macht über geteilte Fotos“*
			Negativ (1)	• Nennung eines bloßen Stichworts	*„Fremden“*
			Keine Antwort (0)	• Sinn für Gefährdung fehlt • Leeres Feld	
Sie kommen nicht so wirklich weiter, weil Sie nicht genauer wissen worauf Fr. Brummer bei einer Präsentation achtet. Sie be-	Auf was sollten Sie bei der Zusammenarbeit durch digitale Technologien achten?	Sie schreiben nun Frau Brunner ein paar Rückfragen. Auf was sollte man achten, wenn man seinem Chef/ seiner Chefin	Positiv (3)	• Kommunikations“regeln“ werden genannt • Unterschiedliche Kommunikationskanäle werden genannt • Es wird zwischen privater und geschäftlicher Kollaboration getrennt	*"richtige Grammatik, Richtige Ansprache, serös, Zielführend und freundlich"* *"Seriös und nicht wie mit Freunden schreiben"*
			Weder noch (2)	• 0815 / Erwartbarer Durchschnitt • Mehrere Nennungen	*"Keine Firmengeheimnisse über Whatsapp kommunizieren"*

			Negativ (1)	• Kaum sinnvolle Regelnennungen (oder nur oberflächlich) • Ein Stichwort	*"Auswahl der richtigen (seriösen) Emojis"*
			Keine Antwort (0)	• Es sind einem keine Regeln bewusst • Leeres Feld	*"Nichts Besonderes"*
Nach einer Mittagspause lassen Sie einen Computer neu starten, da ein Microsoft-Update erforderlich war. Danach haben Sie keinen Zugriff mehr auf das Internet. Wie gehen Sie schrittweiße vor um das Problem zu lösen und zu beheben?	Was ist die beste Lösungsstrategie, wenn bei Ihnen in der Firma irgendein unbekanntes technisches Problem auftritt?	Können Sie kurz beschreiben, welche einzelnen Schritte Sie nutzen um ein (technisches) Problem zu lösen?	Positiv (3)	• Einzelne Schritte werden in logischer Reihenfolge genannt • Zuerst Analyse des Problems • Schrittweise Fehlersuche • Expertenrat als letzter Schritt • Eigenständigkeit wird sichtbar	*„Kurzfristig: Problemdiagnose starten, Internetrouter neu starten, zur Not Update rückgängig machen; Langfristig: Auf ein zuverlässiges Betriebssystem umstellen (NICHT Windows)“* *„"Schauen wo der Fehler liegt. Internetprobleme können oft in Einstellungen selbst einrichten, oder wenn Adminrechte nicht vorliegen entsprechend der IT Bescheid geben.“*
			Weder noch (2)	• Einzelne Schritte nicht klar abgrenzbar • Schritte nicht in logischer Reihenfolge •	*„Suche nach Problem an anderem Gerät“*
			Negativ (1)	• Es wird nicht probiert das Problem zu lösen, sondern sofort nach Hilfe gerufen • Keine Schrittweise Problemlösung	*"Nach Hilfe rufen"* *"IT Anrufen"* *„Meinen Papa anrufen“*
			Keine Antwort (0)	• Problem wird ignoriert •	*"Nichts Besonderes"*