The Promotion of Technology-Based Analytical Problem-Solving Skills (aPSS) Based on the Cognitive Apprenticeship Approach and Through Adaptive Tutorial Feedback

Stefan Christian Ferner, University of Hamburg, Germany
Christopher Andre Klupak, University of Hamburg, Germany
Felix Walker, University of Hamburg, Germany

The Asian Conference on Education & International Development 2023
Official Conference Proceedings

Abstract
The need to promote the aPSS of trainees in the technical-commercial sector results from various reasons. On the one hand, the digitalisation and automation of industrial production processes has led to increased demands on future maintenance staff. On the other hand, at the end of the dual initial training of electronics technicians for automation technology, there was a discrepancy between the curricular requirements and the actual existing competences. This results in a need for support, which is to be countered in the sub-study of the TechKom research project. The aim of the project is to investigate the influence of adaptive tutorial feedback (ATF) and cognitive modelling on the development of aPSS. ATF is understood to be information and assistance that adapts to the learning need situationally and provides only what is actually needed. Based on the need for support and the aim of the project, the following hypothesis is investigated: Trainees who only have access to the video for cognitive modelling in the "modelling" phase acquire less aPSS than trainees who receive ATF in the computer simulation while working on problems. To acquire aPSS, an automation system was digitally simulated. The trainees use the simulation of an industrial automation plant to carry out strategy-guided troubleshooting. Learning videos (CA approach) and the ATF were implemented within the digital automation system. In the further course, the first results about the influence of the adaptive-tutorial feedback will be presented.

Keywords: Analytical Problem-Solving Skills, Adaptive Tutorial Feedback, Cognitive Apprenticeship-Approach, Computer-Based Environment, Simulated Industrial Automation System

Introduction

1) Theoretical preliminary overview

a) Excursus: Industry 4.0 and VET research in Germany

With the arrival of Industry 4.0 in the 2010s came a plethora of expectations, promises, benefits and technologies, but also increased demands on workers in the industrial sector. Internet of things, Smart Factory, Intelligence Sensors, Artificial Intelligence (AI) or Virtual/Augmented Reality (VR/AR) are just a few examples that are listed as key technologies in Industry 4.0 and pick up on the previously mentioned concepts (Kamarul Bahrin, Othman, Nor Azli, & Talib, 2016, p. 138; Wichmann, Eisenbart, & Gericke, 2019, p. 2131).

Technological changes in the industrial sector have led to the emergence of new professions, the revision of existing professions or the need to retrain workers (Schäfer, Link, & Walker, 2020, pp. 131–132).

In recent years, due to technological and educational policy developments in Germany, there have been many efforts to investigate and empirically confirm a competence model for the training occupation of electronics technician for automation technology (Schäfer & Walker, 2018, p. 68), as the vocational training sector in particular has received little attention to date (Beck, Landenberger, & Oser, 2016, pp. 9–10).

Within the nationwide research initiative ASCOT[1], the sub-project KOKO EA[2] was integrated, which investigated and validated the competence structure of electronics technicians for automation technology (Walker et al., 2016, 160, 162-163). This showed that the professional competences are made up of two sub-competences (Expert knowledge and problem-solving skills, see Figure 1).

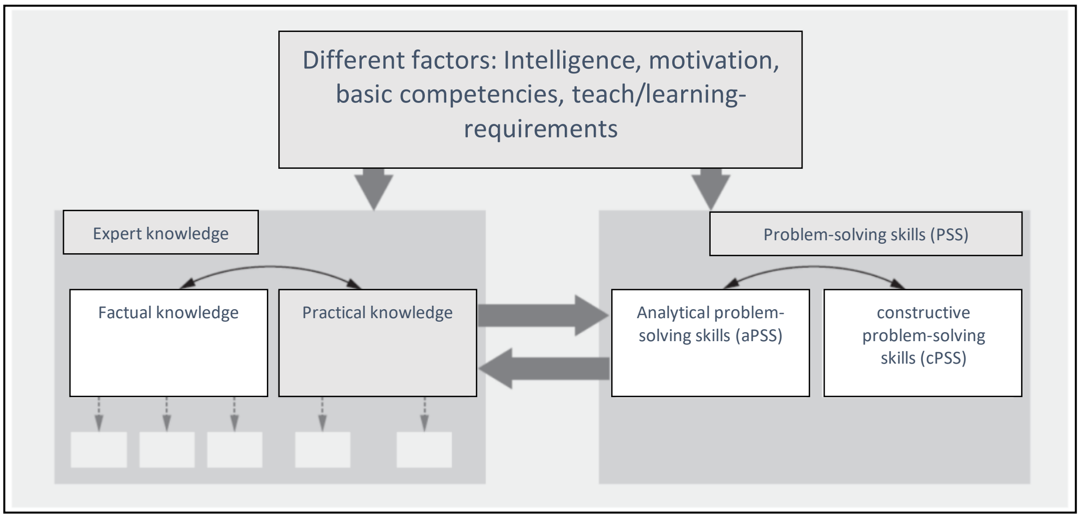

Figure 1: Competence model of professional knowledge (Walker et al., 2016, p. 142)

---

[1] Technology-based Assessment of Skills and Competences in Vocacional Education and Training (Research project from 2011-2015 in Germany).
[2] Competency measurement and modeling for electronics technicians for automation technology.

In addition, the sub-competences addressed can be further differentiated: The factual knowledge and the practical knowledge form the expert knowledge and the analytical and constructive problem-solving skills form the superordinate problem-solving competence. Studies conducted in the KOKO EA project also showed that the participants had weaknesses in the aPSS, as one third of the participating trainees did not have the curricular requirements and thus there was a discrepancy between the expected and the actual competences (Walker et al., 2016, p. 163).

Since the study conducted is specifically concerned with researching and promoting analytical problem-solving competence, no further differentiation of the competence model is made, and the focus is placed on the PSS term. PSS is understood as the application of expert knowledge in problematic action situations (Walker, Link, & Nickolaus, 2015, p. 224). With this understanding it follows that the expert knowledge is to be regarded as a prerequisite for successful troubleshooting or the software-side expansion of a programmable logic controller (PLC). Thus, troubleshooting represents the aPSS and the concrete use of knowledge about PLCs - e.g. programming a PLC program - represents the constructive sub-dimension. The assumption that expert knowledge must be available to be able to deal with a problematic situation was confirmed by the high influence of specialist knowledge in the areas of automation technology (AT)/PLC on fault diagnosis (Walker et al., 2016, p. 163). Furthermore, it was shown that the analytical and constructive PSS can not only be explained based on expert knowledge but can also be assumed as independent dimensions with a correlation value *r* of 0.58 (Walker et al., 2016, p. 163).

With the confirmation of the competence model presented above as well as the analytical problem-solving competence standing on its own and the special need for support located in it, the follow-up project TechKom[3] resulted, which is embedded in the nationwide transfer initiative ASCOT+[4].

b) Training in computer-based learning environment: Troubleshooting in simulation systems

To reduce the deficits in aPSS and to address the complexity of error cases, a web-based simulated industrial automation system (SIAS) was developed with which trainees can process various error cases and practice troubleshooting on automation systems. Furthermore, it was shown that a simulation system can also be used to promote analytical problem-solving skills (Walker et al., 2016, p. 159).

The error cases implemented in the simulation system cover the areas of mechanics, electrical engineering and PLC to realistically represent professional reality. A real system (see Figure 2), which produces a cube from two individual metal pieces in an error-free environment, served as the basis for development.

[3] Technology-based assessment and promotion of competences.
[4] Follow-up project of the ASCOT project.

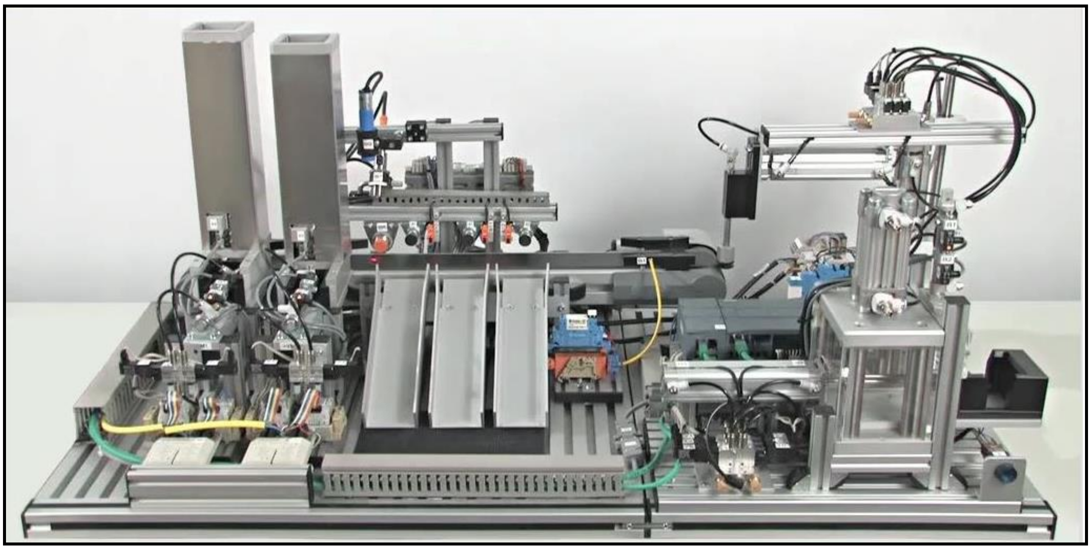

Figure 2: Real model from industrial automation system (Own illustration)

Generally, error diagnosis is understood as the process of identifying and interpreting situations that differ from the nominal situation. For the project, this means that the simulation system deviates from its nominal state in the individual error cases and the subjects must make a diagnosis of the actual situation. The need for training in problem-solving skills is not only evident in the findings on curricular discrepancies. In the past two decades, a number of studies have shown that trainees were inadequately prepared with regard to fault diagnosis in electrical and metal engineering fields (Matthes, Schmidt, Kybart, & Spangenberger, 2021, p. 32). In particular, the studies by Walker, Link, Mohr and Schäfer (2018), Abele, Walker and Nickolaus (2014) and Becker (2009) have shown that there is a need to promote error diagnosis skills in the form of training.

The web-based simulation system used can be seen in the figure below.

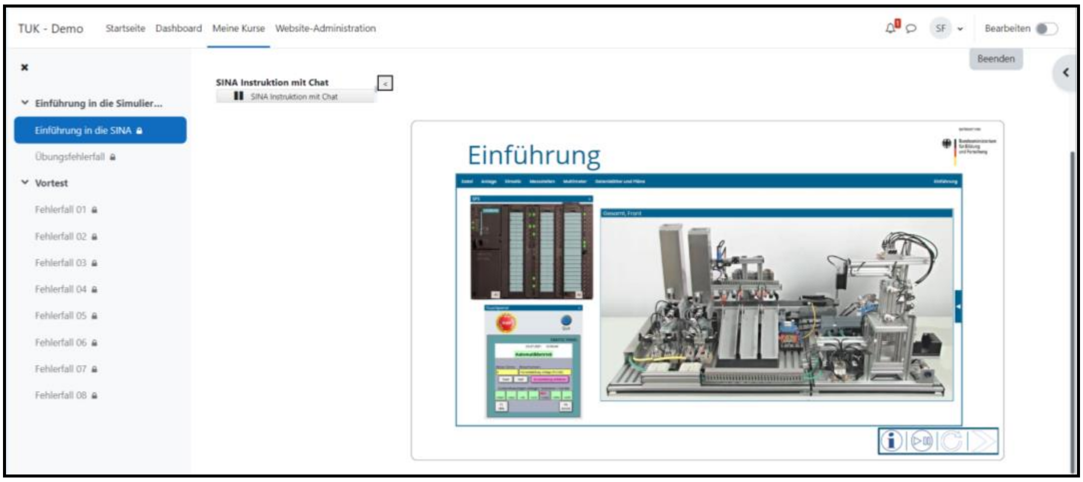

Figure 3: Implemented web-based SIAS - Introduction in LMS (Own illustration)

c) Adaptive tutorial Feedback (ATF)

In addition to the error cases, adaptive tutorial feedback (ATF) is implemented. The study uses the feedback concept according to Narciss (2006). Narciss understands the term feedback to mean information that is intended to help learners solve a task correctly, which is why Narciss also speaks of informative feedback. Informative feedback can be combined with adaptive learning environments, which are teaching systems that adapt to the needs of the learners (Marschner, 2011). The ATF follows from the combination of informative feedback and adaptive learning environments. The ATF was chosen because previous research showed that feedback has a positive impact on student achievement (Butler, Godbole, & Marsh, 2013; Hattie, 2009). In addition, Sweller, van Merrienboer and Paas (1998) found that the working memory is less stressed when information is provided according to the situation. Finally, the results of Schaper, Hochholdinger and Sonntag (2004) should be mentioned, in which the effectiveness of ATF was tested and confirmed.

ATF is presented in the form of a chat. Here, the participants who are assigned to the experimental group (EG) receive written information from the maintenance manager about the source of the error (see Figure 4).

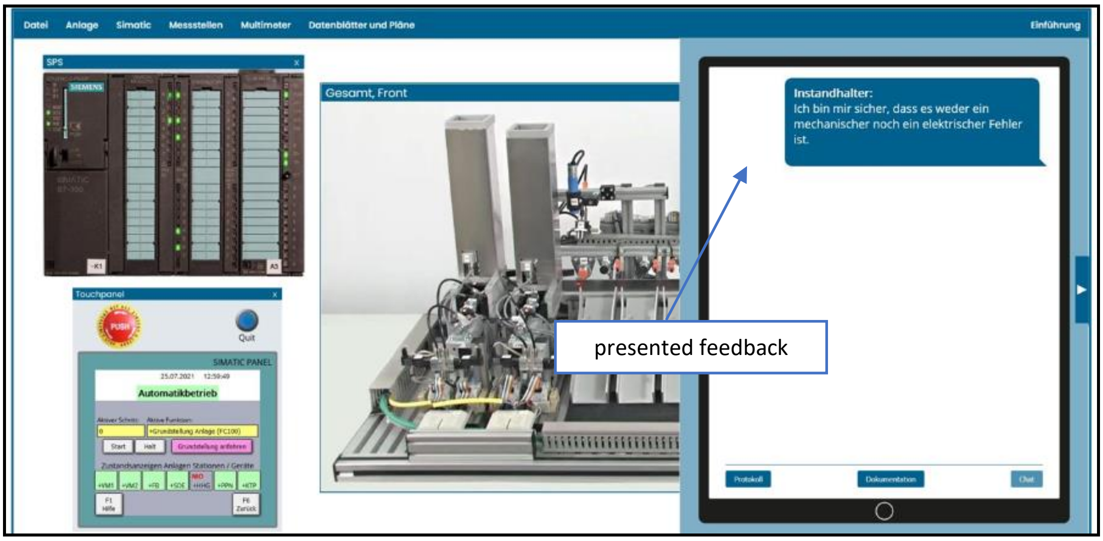

Figure 4: Implemented ATF in LMS.
Here: Presented feedback "I am sure it is neither a mechanical nor an electrical error case."
(Own illustration)

For the design of the ATF, the design principles according to Narciss (2006) were used. For example, the subjects are given the opportunity to think about the possible cause of the error after the help has been given (see Figure 4). In addition, the ATF is only displayed via the chat function when a counter, which is active in the background of the browser, recognizes the necessity. In addition, the help is provided in a gradation that leads the subjects to the source of the error in a more and more targeted manner with a correspondingly high processing time. In this way, the application of the help is always brought to the fore.

d) Troubleshooting strategies according to the Cognitive Apprenticeship-Approach (CAA)

In the study, solution videos were integrated according to the cognitive apprenticeship-approach (CAA) of Collins, Brown and Newman (1989). Here, an expert demonstrates a procedure to pass on the expert knowledge to learners, who are supposed to acquire the practical knowledge and apply it independently. Within the teaching method (six phases in total), the expert recedes more and more into the background, so that the learner independently carries out the demonstrated approach. These solution videos are intended to bridge the gap between expert knowledge and the application of this knowledge to problems, which is not always successful, especially with learners (Collins et al., 1989, p. 454). The

CAA is associated with improved performance in diagnostic competence in a wide range of disciplines, including medicine (e.g. Gräsel & Mandl, 1993), nursing (e.g. Küng, Staudacher, & Panfil, 2018) and technology (e.g. Gschwendtner & Geißel, 2020). Furthermore, long-term competence acquisition, individual support and clear lesson structuring have been documented.

At the beginning of the study, video-based support was provided in the modelling phase. The expert introduced the concept of the simulated industrial plant to help build the mental model. Subsequently, the participants worked on a practice task ('practice error case') within the computer-based learning environment. Within the practice error case, coaching is provided by the expert. Thus, the first two phases first show the procedure within the simulation system before feedback is given to the test persons. Subsequently, both in the pre-test and in the intervention phase, the existing error cases were worked on independently. After the cause of the error has been diagnosed, the error case is documented in the articulation phase within an error log. After the articulation of the fault, the above-mentioned expert comes to the fore again in the form of video-based support and describes the concrete procedure of fault diagnosis for the corresponding fault case.

All error cases follow the same procedure, which can be summarized as follows:

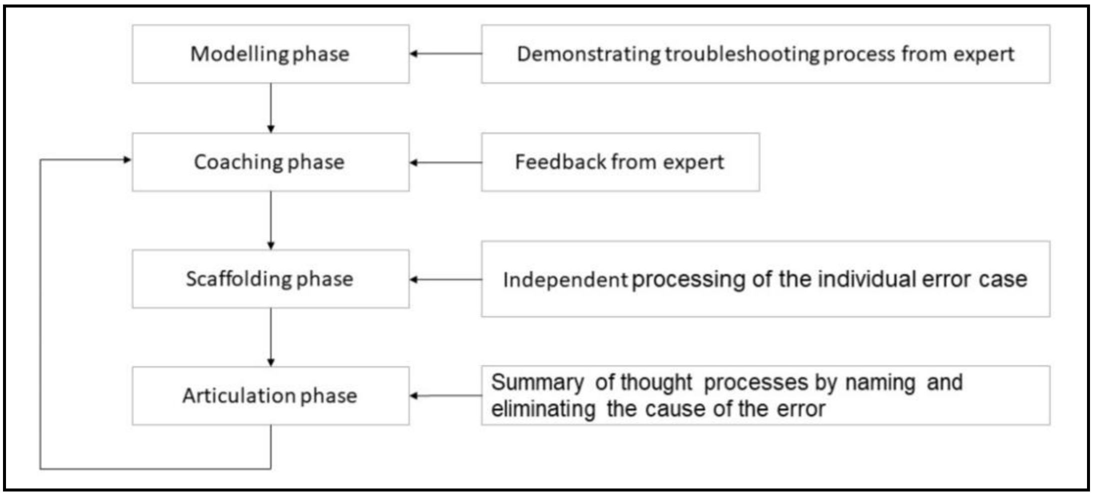

Figure 5: Cycle of the first four phases of the CAA.
Here: Implemented method in connection with troubleshooting in the LMS
(Own illustration).

In the study conducted, only the first four phases are used. The ATF is made available to the trainees during the scaffolding phase.

2) Study: Technology-based assessment and promotion of competences (TechKom) in electrical and metal-technical vocational education and training

The simulation system used was embedded in a Learning Management System (LMS). This had the advantage that trainees could access the system from anywhere and thus work on the error cases either in the company or from home. Furthermore, log files and the answers could be extracted by the LMS and its backend, so that the exact clicking behavior of the participants could be investigated in the future. Figure 6 shows the LMS.

Figure 6: Implemented web-based SIAS in LMS (Own Illustration)

a) Hypothesis

Trainees who only have access to the video for cognitive modelling in the "modelling" phase acquire less aPSS than trainees who receive ATF in the computer simulation while working on problems.

b) Research design

The study features a pretest-intervention-posttest Experimental-Control-Group design (see Figure 7). In Measuring time 1 (MT1, Pre-test), general test items and eight professional test items were first inquired among all participants in the form of error cases on the aPSS. Subsequently, the participants were divided into a Control Group (CG) and Experimental Group (EG) for the processing phase (intervention phase). After completion of the intervention phase, the participants received eight test items on the second day in Measuring time 2 (MT2, Post-test), which were identical to those from the Pre-test.

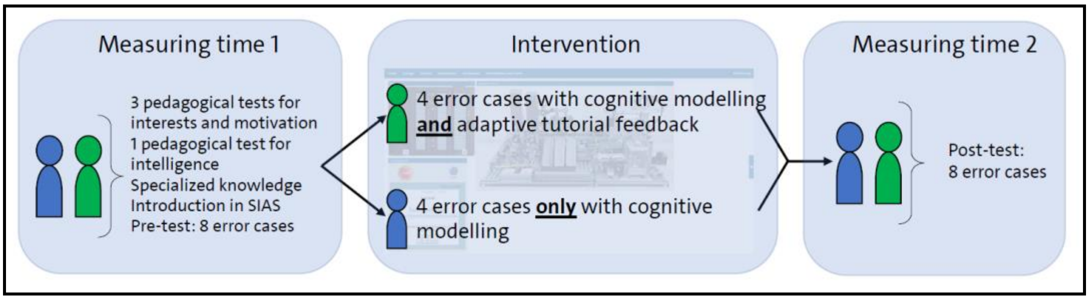

Figure 7: Research Design (Own illustration)

c) Method

The methodology behind the study is by means of hypothesis testing in a longitudinal CG-EG design. Hypothesis testing was conducted using a general analysis of variance (ANOVA) and a t-Test for independent groups.

To be able to test the hypothesis, two procedures of ANOVA were used: (1) the General Linear Model (GLM) with repeated measures and the Univariate Analysis of Variance (UAV). The first procedure was used to be able to include the temporal influence in the data analysis. The t-test was used to be able to analyze the mean value of both groups of the Pre- and Post-test.

Conclusion

1) Results

Of the total 102 trainees who participated, 97 subjects took the demographic test. Of these 97, 83 stated that they were male and 12 females. In addition, two respondents indicated neither / nor, which includes non-binary. The age range of the subjects was about 17 to 25 years and the average age was about 20 years and 5 months. Of the 97 subjects, 54 stated that they were training to become mechatronics technicians and the remaining 43 to become electronics technicians for automation technology. For the overall analysis, the IQ value of 91 tended to be below average.

a) t-Test of independent groups

In Table 1 you can see the group statistics.

Group Statistics

	Control- or Experimental-group (CG/EG)	N	Mean (MV)	Std. Deviation (SD)	Std. error mean
Total score SIAS – error cases Pre-test (MT1)	CG	51	4,16	2,461	,345
	EG	48	3,71	2,212	,319
Total score SIAS – error cases Post-test (MT2)	CG	50	5,36	2,848	,403
	EG	45	5,49	3,181	,474

Table 1: t-Test for independent random sample.
Here: Comparison from the achieved Mean of EG/CG in Pre- and Post-test

On the horizontal axis, the achieved points of the Pre-test (MT1) are plotted with the Post-test (MT2), while the groups CG and EG are found on the vertical axis. The *MV* reflects the average error cases solved in SIAS. A *MV* of 4.12 indicates that subjects assigned to the CG were able to achieve an average of four (rounded down) points in the MT1. In contrast, in EG only slightly less than four (*MV* = 3.76 points). The average *MV* was 3.95 points in the Pre-test and 5.42 points in the Post-test (MT2). If the *MV*'s of the two groups are compared between the MT1 and MT2, then it is noticeable that both groups were able to generate an increase in the average total points achieved. The largest increase can be found within the EG, which increased their *MV* by +1.73 points to 5.49. The CG increased their *MV* (= 5.36) by +1.24 points.

b) Analysis of variance (ANOVA)

b.1) General Linear Model (GLM) with repeated measures

After the group statistic, the ANOVA test was performed using the GLM with repeated measures. This was performed with the Within-Subjects Contrasts (see Table 2) and Between-Subject Effects (see Table 3).

Tests of Within-Subjects Contrasts

Maß: MASS_1

Source	Error_cases	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Error_cases	Linear	104,693	1	104,693	26,899	<,001	,224
Error_cases* Group (CG/EG)	Linear	2,882	1	2,882	,741	,392	,008
Error(Error_cases)	Linear	361,960	93	3,892			

Table 2: General Linear Model (GLM) with repeated measures. Here: Tests of Within-Subjects Contrasts

With a significance value of p < .001*** and thus highly significant, it shows that the repeated measures have a high influence on the data. Furthermore, the partial Eta-square (η2) indicates the effect size. With a value of $\eta 2$ = .224, which is above the threshold of .14 for large effects, it again shows a large effect of repeated measures on error detection. If the two values for the pairing Error_cases*Group (CG/EG) are analyzed, then it is noticeable that the significance (p = .392) increases significantly and the η2 (= .008) drops by a multiple. Thus, because of the exceeded significance threshold and the fallen effect size, the group membership does not take a statistically significant influence on the error diagnosis.

In another analysis, the influence of Between-Subjects Effects was examined. The analysis took fault finding as a constant variable and examined the statistical influence of group membership. Here, it can again be seen that repeated measures exerts a highly significant influence (p < .001*** and $\eta 2$ = .807 in Table 3) on the Post-test score obtained, while group membership again exerts no influence on the Post-test.

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	4151,899	1	4151,899	388,303	<,001	,807
Group (CG/EG)	,657	1	,657	,061	,805	,001
Error	994,396	93	10,692			

Table 3: General Linear Model (GLM) with repeated measures. Here: Tests of Between-Subjects Effects

b.2) Univariate Analysis of Variance (UAV)

Tests of Between-Subjects Effects

Dependent Variable: Total score SIAS – error cases Post-test

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	277,201[a]	10	27,720	4,114	<,001	,329
Intercept	213,948	1	213,948	31,754	<,001	,274
Group (CG/EG)	3,054	1	3,054	,453	,503	,005
Score_Pre-test	276,808	9	30,756	4,565	<,001	,328
Error	565,957	84	6,738			
Total	3635,000	95				
Corrected Total	843,158	94				

a. R Squared = ,329 (Adjusted R Squared = ,249)

Table 4: Univariate Analysis of Variance (UAV).
Here: Tests of Between-Subjects Effects

As in the previous presentations of results, the significance and the η2 are again considered (see Table 4). First, the corrected model is highly significant (p < .001***) and has a high effect size ($\eta 2$ = .329). Furthermore, significant statements can be made about the sources 'Score_Pre-test'. The Pre-test has a significant influence (p < .001***) on the total score achieved in the Post-test. Moreover, because of the partial eta-square, MT1 is shown to take a large effect size ($\eta 2$ = .328) on performance in the MT2.

2) Discussions

The mean values showed that there were differences between the groups of participants (CG vs EG). While in MT1 the CG was minimally 'better' (+.36) than the EG in *MV*, in MT2 it was the other way around. Thus, the EG took the minimally better results with a *MV* of 5.49 compared to the CG (*MV* = 5.36). The increase in the *MV* achieved in each case also shows that both groups were able to increase their performance in terms of error diagnosis. With the high increase in the score within the EG, it is evident that at first glance individuals with a poorer starting position were able to benefit particularly from training with the simulation system.

With the analysis of variance, a much broader interpretation and discussion of the test results is possible. First, it was shown that the repeated measures, in the form of the two error diagnoses performed, has a statistically highly significant influence on the test results obtained. In contrast, it was found that the group influence on the two tests performed was not statistically significant. Thus, it was shown that the repeated measures have a direct effect and the group membership has no direct effect on the results of the Pre- and Post-test. Based on these findings, further possible interpretations can be formulated. Due to the high effect of the repeated measures and the increase in performance of both groups of persons, the statement can be made that the CA-approach and the CBL in the form of the SIAS contribute to the increase in the problem-solving ability of trainees. Based on the non-significant effects in relation to group membership (CG without ATF; EG with ATF), the statement can be made that the ATF has a statistically non-significant influence on the test results of the participating trainees and thus the division into CG and EG is not statistically relevant for successful error diagnosis.

With the results and the associated discussion, the hypothesis that was established cannot be statistically confirmed. Nevertheless, a medium effect size was shown in an analysis of covariance between the group with the ATF and the points achieved in the post-test, which is not shown here, making further analysis of the data and a further survey with a broader sample necessary.

3) Limitations

There are some limitations to the results. First, the small number of participants should be mentioned, which does not allow any statistically reliable statements. Especially with the fact that the already small sample of 102 trainees was further divided by the CG-EG design and within the group allocation the group was further reduced by invalid statements. The loss of subjects was not only observed in the intervention phase, but also in the first measurement point in the general test parts. Here, a high loss of results was recorded in the intelligence test. The third limitation was the usability problems of the simulation system. Here, server problems, blockages by the firewall or the internet speed were significant limiting factors on the part of the technology. The last point to mention is that no analysis of the log data was made, but the answers were compared with an evaluation template. A log file analysis of the problem-solving process would additionally validate the results, as the subjects' log files can be used to check whether and to what extent the test persons responded to the ATF.

4) Outlook

To statistically validate the results, the main survey was launched in October 2022 and will be completed in May 2023. The aim of the main survey was to achieve a sample size of n = 300. In addition, we worked on the usability problems and reduced the number of error cases to be processed from eight to six. We have worked with partners from industry and the education sector. Because of the cooperation, there was a high level of interest in the research project and the simulation system on the part of the industry community. The broad use of the simulation system for other industrial areas (e.g. process and control engineering) and the added value of training systems in problem-solving were given as positive feedback to us. The trainees also reported back that the training was a good idea. In addition, further usability problems were addressed.

Finally, in the future, we will focus on log file analysis to be able to analyze the problem-solving behavior of the subjects more precisely.

References

Abele, S., Walker, F., & Nickolaus, R. (2014). Zeitökonomische und reliable Diagnostik beruflicher Problemlösekompetenzen bei Auszubildenden zum Kfz-Mechatroniker. *Zeitschrift Für Pädago-Gische Psychologie*, *28*, 167–179.

Beck, K., Landenberger, M., & Oser, F. (Eds.) (2016). *Wirtschaft - Beruf - Ethik: Vol. 32. Technologiebasierte Kompetenzmessung in der beruflichen Bildung. Ergebnisse aus der BMBF-Förderinitiative ASCOT*. Bielefeld: W. Bertelsmann Verlag.

Becker, M. (2009). Diagnose als Aufgabe in gewerblich-technischen Berufsfeldern. Lernen & lehren. *Lernen & Lehren*, *24*(95), 101–107.

Butler, A. C., Godbole, N., & Marsh, E. J. (2013). Explanation feedback is better than correct answer feedback for promoting transfer of learning. *Journal of Educational Psychology*, *105*(2), 290–298. https://doi.org/10.1037/a0031026

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. In L. B. Resnick (Ed.), *Knowing, learning, and instruction: essays in honor of Robert Glaser* (pp. 453–494). Hillsdale: Lawrence Erlbaum Associates.

Gräsel, C., & Mandl, H. (1993). Förderung des Erwerbs diagnostischer Strategien in fallbasierten Lernumgebungen. *Unterrichtswissenschaft*, *21*. https://doi.org/10.25656/01:8195

Gschwendtner, T., & Geißel, B. (Eds.) (2020). *Beiträge zur Technikdidaktik: Vol. 6. Einblicke in aktuelle Forschungsarbeiten der Technikdidaktik*. Berlin: Logos Verlag.

Hattie, J. (2009). *Visible learning: A synthesis of over 800 meta-analyses relating to achievement* (Reprinted.). London: Routledge.

Kamarul Bahrin, M. A., Othman, M. F., Nor Azli, N. H., & Talib, M. F. (2016). Industry 4.0: A review on industrial automation and robotic. *Jurnal Teknologi*, *78*(6-13), 137–143. https://doi.org/10.11113/jt.v78.9285

Küng, R., Staudacher, D., & Panfil, E.-M. (2018). Ein zentrales pädagogisches Modell für die Praxisausbildung: „Cognitive Apprenticeship". *PADUA*, *13*(2), 115–123. https://doi.org/10.1024/1861-6186/a000424

Marschner, J. (2011). *Adaptives Feedback zur Unterstützung des selbstregulierten Lernens durch Experimentieren* (Dissertation). Universität Duisburg-Essen, Essen.

Matthes, N., Schmidt, K., Kybart, M., & Spangenberger, P. (2021). Trainieren der Fehlerdiagnosekompetenz in der Ausbildung. Qualitative Studie mit Lehrenden im Bereich Metall- und Elektrotechnik. *Journal of Technical Education (JOTED)*, *9*(1), 32–53.

Narciss, S. (2006). *Informatives tutorielles Feedback. Entwicklungs- und Evaluationsprinzipien auf der Basis instruktionspsychologischer Erkenntnisse*. *Päädagogische Psychologie und Entwicklungspsychologie: Vol. 56*. Münster: Waxmann.

Schäfer, P., Link, N., & Walker, F. (2020). Assessing Professional Knowledge of Teachers at Vocational Schools—Using the Example of a Professional Development for Automation and Digitized Production. In E. Wuttke, J. Seifried, & H. M. Niegemann (Eds.), *Research in vocational education: volume 4. Vocational education and training in the age of digitization: Challenges and opportunities* (pp. 131–154). Opladen, Berlin, Toronto: Verlag Barbara Budrich.

Schäfer, P., & Walker, F. (2018). Problemlösen im Bereich der Automatisierungstechnik – Entwicklung und Evalua-tion eines Lehrerfortbildungskonzepts. *Journal of Technical Education (JOTED)*, *6*(4), 67–85.

Schaper, N., Hochholdinger, S., & Sonntag, K. (2004). Förderung des Transfers von Diagnosestrategien durch computergestütztes Training mit kognitiver Modellierung. *Zeitschrift Für Personalpsychologie*, *3*(2), 51–62. https://doi.org/10.1026/1617-6391.3.2.51

Sweller, J., van Merrienboer, J. J. G., & Paas, F. G. W. C. (1998). Cognitive Architecture and Instruc-tional Design. *Educational Psychology Review*, *10*(3), 251–296. https://doi.org/10.1023/A:1022193728205

Walker, F., Link, N., Mohr, F., & Schäfer, P. (2018). Entwicklung eines Fortbildungskonzepts: auf Basis des Ansatzes zum technologisch-pädagogischen Inhaltswissen zu Industrie 4.0. *Lernen & Lehren*, *33*(130), 53–59.

Walker, F., Link, N., & Nickolaus, R. (2015). Berufsfachliche Kompetenzstrukturen bei Elektronikern für Automatisierungstechnik am Ende der Berufsausbildung. *Zeitschrift Für Berufs- Und WIrtschaftspädagogik*, *111*(2), 222–241.

Walker, F., Link, N., van Waveren, L., Hedrich, M., Geißel, B., & Nickolaus, R. (2016). Berufsfachliche Kompetenzen von Elektronikern für Automatisierungstechnik – Kompetenzdimensionen, Messverfahren und erzielte Leistungen (KOKO EA). In K. Beck, M. Landenberger, & F. Oser (Eds.), *Wirtschaft - Beruf - Ethik: Vol. 32. Technologiebasierte Kompetenzmessung in der beruflichen Bildung. Ergebnisse aus der BMBF-Förderinitiative ASCOT* (pp. 139–169). Bielefeld: W. Bertelsmann Verlag.

Wichmann, R. L., Eisenbart, B., & Gericke, K. (2019). The Direction of Industry: A Literature Review on Industry 4.0. *Proceedings of the Design Society: International Conference on Engineering Design*, *1*(1), 2129–2138. https://doi.org/10.1017/dsi.2019.219

Contact email: stefan.ferner@uni-hamburg.de
christopher.andre.klupak@uni-hamburg.de
felix.walker@uni-hamburg.de