HOW TO MAKE 4C/ID VISIBLE? AN ONLINE PROFESSIONAL LEARNING ENVIRONMENT FOR MATHEMATICS TEACHERS ON DIAGNOSING AND SUPPORTING PROBLEM SOLVING

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The Four-Component Instructional Design Model (4C/ID) is a well-established and evidence-based framework for the design of professional development programs. However, there is still limited research on how learners actually use the instructional components offered by 4C/ID-based learning environments. To address this gap, we implemented a digital learning environment for mathematics teachers based on the 4C/ID model. A total of 303 pre-service and in-service mathematics teachers completed the intervention focusing on diagnosing students' mathematical problem-solving abilities and supporting them appropriately. We analysed learners' interactions with supportive information, their engagement with feedback, and their use of part-task practice. The findings suggest that many learners did not fully exploit the opportunities for self-regulated learning provided by the learning environment.

INTRODUCTION

The Four Component Instructional Design Model (4C/ID) provides a theory-informed structure for designing learning environments. The core idea is that four components of a learning environment – learning tasks, supportive information, procedural information, and part-task practice – can be designed to align with each other and, thus, ensure that learning can take place in and on authentic and complex situations (van Merriënboer & Kirschner, 2017). This makes the model particularly suitable for learning complex tasks that are usually presented fragmented and decontextualized – such as teaching mathematics (Kreutz et a., 2020): Mathematics teachers face major challenges in their everyday professional lives, as complex actions and skills are required (Drijvers, 2022) – which calls for holistic learning opportunities that mimic real-life challenges. To address this, a commonly agreed upon approach is to combine theory and practice during the learning process (Lipovsky & Rzejak, 2015). 4C/ID design principles may tackle the threat of cognitive overload in such learning opportunities.

A recent synthesis describes the effectiveness of 4C/ID-based interventions in various contexts such as education and teacher professional development (Neck et al. 2025). However, effects vary between studies and are not perfectly coherent within studies, which calls for empirical investigations regarding how learners utilize the learning opportunities offered by the four components of a 4C/ID-based intervention.

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To address this gap, we implemented a digital learning environment for mathematics teachers. The intervention provided automated formative feedback, allowed learners to skip content they had already mastered, and enabled them to actively select additional learning tasks based on their individual needs—developed using a 4C/ID approach (van Merriënboer & Kirschner, 2017). The aim of the study is therefore to investigate 4C/ID-based learning through learners' interactions with the learning environment when learning about how to diagnose and support students' mathematical problem-solving abilities.

The Learning Environment

The starting point for the learning environment is to implement problem-solving learning in secondary school mathematics lessons (Prediger et al., 2022; Rott, 2020). Problem-solving is a complex real-life task for teachers, who must respond adaptively to different student solutions. In the learning environment, teachers work through the example task of 'staircase numbers' (German: 'Treppenzahlen'). This serves as an example for other problem-solving tasks. It is particularly well-suited to this purpose because students can work on it at a level appropriate to them. It is based on the school version of Sylvester's theorem.

The ***learning tasks*** were based on the staircase numbers task. Teachers first familiarized themselves with the task by solving it themselves in an app and received information on problem solving in general and in mathematics in particular. They then proceeded to the main phase of the learning environment, diagnosing student solutions and providing appropriate support tailored to individual students' strengths and weaknesses. We therefore decided on four learning tasks (Tab. 1) and arranged the individual tasks within the learning tasks from easy to difficult. Teachers were repeatedly given vignettes with fictitious work statuses of the students.

At the beginning of each learning task, teachers receive ***supportive information*** in the form of an informational text. This text provides basic background knowledge that is necessary to complete the task. Its main function is to activate prior knowledge and link it to the new learning content. In total, four supportive information texts are provided, each tailored to one of the four learning tasks (Tab. 1). The supportive information remains accessible throughout the task and can be accessed again at any time. Learners decide for themselves whether, when, and for how long they want to use this support.

Throughout the learning process, teachers repeatedly receive ***procedural information*** in the form of supplementary information texts when new procedural knowledge is required. An example of such content is Sylvester's theorem. Access to this information is optional and requires an active decision of the teachers. In addition, teachers receive continuous feedback on their task performance. For multiple-choice tasks, feedback is provided in a binary right/wrong format, while open-ended tasks are accompanied by sample solutions or suggestions that illustrate the optimal answer. For

multiple-choice tasks, the learning environment implements an iterative processing cycle: teachers first select an answer, receive immediate feedback, and if the answer is incorrect, are presented with the relevant supporting information again before being asked to try the task again.

Table 1: The four learning tasks of the learning environment with the corresponding supportive information

Learning Task	What is done in the learning task?	Supportive Information
LT 1	Getting to know the learning environment and problem solving as a task in mathematics lessons	Why problem solving? Describes why problem solving is an important skill to learn and the need to teach problem-solving skills in mathematics lessons.
LT 2	Developing expectations	Expectations Describes which solutions and discoveries are possible based on the staircase numbers and what work can be expected from the learners.
LT 3	Assessing learners' progress (Diagnosis)	Diagnosis and support cycle: Introduction of the diagnosis and support cycle as a model for quickly assessing the progress of learners. The processing steps will differentiate between finding examples, sorting examples, making assumptions, and testing assumptions.
LT 4	Providing specific guidance for further work (Support)	Types of support: Various options and ways of supporting learners during the problem-solving process. We distinguish between five types of assistance: motivational assistance, feedback assistance, general strategic assistance, content-oriented strategic assistance, and content-related assistance.

When a high degree of automation is required, recurring aspects of the learning content are practiced as isolated subtasks; this process is called ***part-task practice*** in the 4C/ID

model. In some cases, teachers are offered optional additional tasks that complement the main task. This is particularly relevant for diagnosing students' learning progress. Here, teachers can then work on additional vignettes with student solutions.

The present study

The aim of the study is to make 4C/ID-based learning visible through the interaction of teachers with the learning environment.

First, based on the assumptions of the 4C/ID model, we assume that the correct implementation and effective use of the learning environment will lead to a gradual reduction in the consultation of supportive information. As learners work through the tasks and acquire subject knowledge, they should increasingly rely on their own knowledge and therefore refer to the information texts less frequently. This leads us to our first research question (RQ1): *Do teachers access supportive information less frequently as they work through the learning task?*

In order to make proper use of the learning environment, teachers must recognize and utilize essential new information, such as procedural information. This leads to the second research question (RQ2): *Do teachers recognize procedural information as necessary information and utilize it accordingly?*

According to the 4C/ID model, we assume that learners who receive negative feedback or are unable to solve the tasks are more likely to access supportive and procedural information and to take advantage of opportunities for additional learning tasks (part-task practice). The third research question therefore focuses on “low achievers” and asks (RQ3): *Do learners who answer tasks incorrectly make greater use of support resources or engage more frequently in additional learning tasks afterwards?*

An important skill when working in an online learning environment is the ability to receive and implement feedback. The fourth research question therefore asks (RQ4): *How do learners engage with feedback after incorrect responses, and does the duration of feedback viewing predict whether they subsequently correct their written explanations?*

METHOD

Sample

A total of $N = 303$ individuals participated in the study. The sample included 299 mathematics teacher education students enrolled in elementary, secondary, and special education programs at the University of Education Freiburg, as well as four practicing teachers who also participated in the online learning environment.

Procedure

The data was collected between January and June 2025. Completing the online learning environment takes approximately four hours. The study was conducted using the “LimeSurvey” platform. This made it possible to track learners' interactions with the

learning environment, such as how long help files were open for and when they were clicked on.

The course began with a short introduction to familiarize participants with the learning environment, followed by a pre-test assessing prior knowledge related to diagnostic and pedagogical support and motivational dispositions. Participants then engaged in the pedagogical intervention. After each learning task, interim assessments and self-reports on motivation, perceived relevance, and perceived goal attainment were collected. A post-test assessed diagnostic and support-related competencies, motivation, and learning-related attitudes.

The present contribution does not report pre- and post-test competency outcomes or motivational self-reports but focuses exclusively on process data derived from participants' interactions with the learning environment.

Material and Process Assessment

The main course material was developed as a series of vignettes regarding diagnosing students' mathematical problem-solving with a focus either on diagnosing students' abilities or giving the appropriate support to aid students.

In vignettes on diagnosing students' problem-solving abilities, teachers had to explain in a free-text response how the student's solution could be classified within a 'diagnosis and support' cycle (here: identifying examples, organizing examples, formulating hypotheses, or evaluating results). After submitting their response, learners received an exemplary correct solution which they had to compare to their own given solution in a self-regulated way. For each task, it was also recorded whether learners had accessed available supportive information.

In vignettes regarding giving appropriate support to students during mathematical problem solving, teachers were presented student solution strategies once again. In a multiple-choice task, participants were asked to select the most appropriate form of instructional support for each student or situation from five categories: motivational support; feedback-oriented support; general strategic support; content-related strategic support; and content-focused support. Here, after submitting their selection, learners received immediate feedback. Correct responses were followed by confirmatory feedback, while incorrect responses triggered explanatory feedback, which provided supportive information about the error and the underlying mathematical or pedagogical issue. Subsequently, learners were required to explain in a free-text response how such support could be implemented in practice. These responses were coded as either correct, if they meaningfully incorporated aspects of the preceding feedback, or incorrect if they did not reflect the feedback content. The analysis examined whether feedback was attended to, operationalised as the duration of feedback viewing, and subsequently applied in learners' responses.

RESULTS

Decreasing use of assistance during tasks (RQ1)

In line with the first research question, the frequency of help-seeking behaviour decreased throughout the learning tasks. In particular, the probability of learners accessing previously provided information after the initial introduction decreased significantly for all tasks examined. For the ‘Diagnosis and Support’ learning task in particular, the odds of consulting this information were significantly lower as learners progressed to later tasks within the learning environment.

Recognition of necessary novel information (RQ2)

In order to investigate whether learners identified and used the available learning aids as intended, their help-seeking behavior was analyzed at several points within the learning environment. An increase in requests for supporting information was observed, corresponding to the transition from the 'Diagnosis and Support' unit to the 'Supporting Students' unit within the 4C/ID learning sequence. This suggests that learners strategically accessed support when faced with a new learning task, reflecting adaptive behavior consistent with the 4C/ID principle of gradually reducing instruction.

However, not all participants exhibited this tendency. In Task 5, 184 out of 303 learners (approximately 60%) used the available support; in Task 10, this figure was 169 learners (approximately 56%). Importantly, Tasks 5 and 10 each followed a content-area transition (from Task 4 to 5 and from Task 9 to 10), where consulting the newly provided information may be particularly relevant. Notably, even in the initial learning task where access to a mandatory support element was necessary to progress, only 154 out of 303 participants (approximately 51%) utilised the support.

Utilizing additional learning opportunities (RQ3)

This analysis was taken out with the vignettes on diagnosing students’ problem-solving abilities. Within the learning environment, participants were repeatedly asked to diagnose the students' solution strategies based on a series of vignettes. Here, learners who answered incorrectly were expected to make greater use of the subsequent support options, such as additional learning tasks or further instructions. Against this background, the present analyses focus on whether learners actually responded to the feedback and made use of further support options.

First, we examined whether learners who answered the first task incorrectly were more likely to use the available support options when working on the next task. A Welch's t-test for two samples revealed no significant difference in task accuracy between learners who accessed support information ($M = 0.24$, $SD = 0.43$) and those who did not ($M = 0.30$, $SD = 0.46$), $t(286.1) = 1.25$, $p = .213$.

Secondly, we investigated whether learners who did not perform well on both tasks, and who were explicitly informed of their comparatively lower progress, were more

likely to complete optional tasks offered as additional learning opportunities. The results showed no significant difference in the total number of correct answers between learners who completed the additional tasks ($M = 0.37$, $SD = 0.48$) and those who did not ($M = 0.42$, $SD = 0.49$), $t(287.93) = 0.83$, $p = 0.406$.

Taken together, these results suggest that learners' use of formative assessment opportunities within the 4C/ID-based learning environment was not consistent with their performance levels.

Making use of feedback (RQ4)

This analysis was taken out with the vignettes regarding giving appropriate support to students during mathematical problem solving. To investigate whether time spent engaging with feedback after an initial incorrect response predicted subsequent improvement, each task instance (four per learner) was treated as an independent observation. A Welch's t-test was conducted to compare feedback viewing times between episodes in which learners later corrected their written explanations, and episodes in which no correction occurred. Feedback viewing time was defined as the interval between the presentation of the explanatory feedback and the learner clicking to proceed to the next screen.

On average, feedback engagement was longer for episodes that resulted in a corrected explanation ($M = 36.03$ s, $SD = 36.69$) than for episodes without correction ($M = 29.94$ s, $SD = 34.34$). This difference was statistically significant, $t(554.63) = -2.27$, $p = .024$, and corresponded to a small effect size, $d = 0.17$.

DISCUSSION

The results present an ambivalent picture regarding the use of the components prescribed by the 4C/ID model. On the one hand, access to supportive information decreases over the course of working on a learning task, which is fully consistent with expectations for learning environments designed according to the 4C/ID model. At the same time, however, supportive and procedural information were only partially used. These results suggest that although a significant proportion of teachers exhibited adaptive, 4C/ID-compliant help-seeking behavior, a considerable number did not take advantage of the available support, even when it was essential. The opportunities for self-regulation afforded by the model were therefore not fully utilized by learners.

From a mathematics education perspective, the findings highlight a central challenge in professional learning for teaching problem-solving: supporting teachers not only in acquiring diagnostic and instructional knowledge, but also in recognizing when and why such knowledge needs to be activated. Diagnosing students' problem-solving processes and providing adaptive support constitute highly situated, content-specific professional practices that require teachers to coordinate mathematical insight, pedagogical judgment, and responsiveness to students' thinking. While the 4C/ID-based environment successfully offered authentic representations of these practices,

the limited and performance-independent use of support resources suggests that many learners did not fully engage in this coordination process.

Surprisingly, low-performing learners made only limited use of the additional learning opportunities provided. Possible explanations include cognitive overload or inaccurate self-perceptions of their own performance. Furthermore, only a weak effect was observed in the use of feedback, which again fits the overall pattern of results indicating that opportunities for self-regulated learning were only minimally exploited.

A limitation of the present study is its exclusive focus on process data, without relating learners' interaction patterns to pre–post changes in diagnostic and instructional competencies. While this allows insights into how teachers engage with a 4C/ID-based learning environment, it does not yet inform which learning behaviours are associated with professional growth. Future research should therefore link process indicators—such as the use of supportive and procedural information, feedback engagement, and optional practice—to gains in diagnostic accuracy and quality of instructional support.

REFERENCES

Drijvers, P. (2022). Digital Technology in Mathematics Education: Past Performance and Future Pathways. In G. Pinkernell, F. Reinhold, F. Schacht, & D. Walter (Hrsg.), *Digitales Lehren und Lernen von Mathematik in der Schule* (S. 399–410). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-65281-7_17

Kreutz, J., Leuders, T., & Hellmann, K. (Eds.). (2020). *Professionsorientierung in der Lehrerbildung: Kompetenzorientiertes Lehren nach dem 4-Component-Instructional-Design-Modell*. Springer Fachmedien Wiesbaden. https://doi.org/10.1007/978-3-658-25046-1

Lipovsky, F., & Rzejak, D. (2015). Key features of effective professional development programmes for teachers. *Ricercazione, 7*, 27–51.

Neck, M., Leuders, T., & Reinhold, F. (2025). Implementing the four-component instructional design model in professional development programs: A systematic review with a focus on teachers. *Frontiers in Education, 10*. https://doi.org/10.3389/feduc.2025.1631375

Prediger, S., Quabeck, K., & Erath, K. (2022). Conceptualizing micro-adaptive teaching practices in content-specific ways: Case study on fractions. *Journal on Mathematics Education, 13*(1), 1–30. https://doi.org/10.22342/jme.v13i1.pp1-30

Rott, B. (2020). Teachers' Behaviors, Epistemological Beliefs, and Their Interplay in Lessons on the Topic of Problem Solving. *International Journal of Science and Mathematics Education, 18*(5), 903–924. https://doi.org/10.1007/s10763-019-09993-0

Van Merriënboer, J. J. G., & Kirschner, P. A. (2017). *Ten Steps to Complex Learning: A Systematic Approach to Four-Component Instructional Design* (3. Aufl.). Routledge. https://doi.org/10.4324/9781315113210