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General Problem-solving Skills Can be Enhanced by Short-time Use of Problem-Based Learning (PBL)

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Abstract

Future students are confronted with a complex world that demands the ability to solve problems in unstructured, undefined, and unfamiliar situations. The aim of the present study was to investigate the development of problem-solving skills through the implementation of Problem-Based Learning (PBL). While previous research has primarily focused on content-related and long-term measurements when examining the effects of PBL, this study took a different approach by exploring the general increase in problem-solving skills resulting from PBL. The sample consisted of 90 second-semester students who were assessed at three different time points using three subscales of the Wilde-Intelligenz-Test I & II: *analogies (AL), letter series (BR) and numerical series (ZN)*. The findings revealed a significant improvement in general problem-solving abilities within the PBL group. These results provide valuable insights into the impact of PBL on the development of general problem-solving skills, even within a domain-independent and short-term context. Lecturers are encouraged to consider implementing PBL in their study programs, as it equips graduates with the necessary skills to tackle the challenges of today's dynamic and constantly changing world.

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Introduction

Problem-solving has emerged as a crucial competency necessary to tackle today's challenges and prepare individuals for future employment opportunities. Higher Education recognizes problem-solving as an essential skill for graduates to succeed in their professional lives (Funke et al., 2018). Problem-solving can be defined as "an individual's capacity to engage in cognitive processing to understand and resolve problem situations where a method of solution is not immediately obvious. It includes the willingness to engage with such situations to achieve one's potential as a constructive and reflective citizen" (OECD, 2014, p. 30).

Torp and Sage (1998, 2002) emphasize the significant role of problem-solving in a rapidly changing world. In their opinion, this doesn't necessarily yield a one-size-fits-all solution for addressing every challenge. However, research underscores the significance and impact of this specific competence. As a generic skill, problem-solving has the potential to be trained on current problems and be transferred to future societal and occupational challenges. Lezak et al. (2012) describe this process of problem-solving as the ability to abstract a problem, think of alternatives and develop a concept of decision-making. For the development of this skill, past research identified PBL as an effective learning method (Strobel & van Barneveld, 2009). Graaf and Kolmos (2003) outlined the process of learning through PBL by highlighting four key aspects. According to this perspective, learning is stimulated by *problems* and developed by working on a *project* with a certain amount of *experience* in a specific *context.* PBL aligns with constructivist thinking, which places the responsibility on learners to identify and construct potential solutions to problems. As a student-centered method, PBL actively engages learners, fosters collaboration, and cultivates the ability to transfer knowledge to various situations. The primary cognitive processes involved in problem-solving, namely representing, planning, executing, and monitoring (Mayer, 2013) closely align with the aspects emphasized in PBL. This can be recognized by having a deeper look at the structure of the 7-step framework and its application in the PBL tutorials. The framework starts with a clarification of the PBL case. First, the students identify unknown content. This is followed by a collection of possible challenges or issues represented by the case. After this, the brainstorming section starts to discuss and collect any thoughts about relevant content of the case which focusses on the solution. The next step is to cluster the collected aspects, rate them in their relevance and impact on the problem-solving and finally the group decides how the problem is formulated with which the students are going to start their research. Afterwards, the phases of planning the solution, researching for relevant information and clustering the collected information with a close monitoring of the progress begins. This finally ends with a reiterating group discussion in the tutorials until the group agrees on having solved the case and formulated a good solution. This process – of course on a more detailed level – seems to be quite similar to the process of problem-solving. The original PBL method follows a 7-step framework (Konermann, 2016) that guides learners through the resolution of presented cases. As this study wants to present a way to measure the impact of PBL in an early period of learning, we decided to take the 7-step framework as it tightly guides learners through the process of case-based reasoning while practicing the PBL tutorials. Additionally, the 7-step method is supported by PBL tutors to assure a learning process without the need of huge prior knowledge which is widely not existing in this period of first-year bachelor students. It begins by clarifying unfamiliar content or terminologies, identifying relevant information including useful criteria compared to prior knowledge and initiating a brainstorming process. Learners engage in discussions to prioritize the resolution of the case and define a problem that must be solved to address the overarching issue. They then embark on the problem-solving process by conducting research, gathering information, comparing it to the given problem, and continuously monitoring their progress with a focus on potential solutions.

It is reasonable to assume that problem-solving abilities can be effectively trained through PBL due to its inherent characteristics and methodology. Through repeated exposure to different problems, learners become adept at employing various problem-solving techniques such as brainstorming, hypothesis testing, and logical reasoning. They learn to think creatively, generating innovative solutions and considering multiple perspectives. One key advantage of PBL is its emphasis on analytical skills. By presenting learners with authentic problems, PBL stimulates their ability to analyze situations, identify relevant information, and break down complex problems into manageable components. This process enhances their capacity to think critically, evaluate evidence, and make informed decisions—a crucial skill set applicable across a wide range of domains. By this, this pedagogical method is supposed to offer numerous benefits in addressing general problem-solving abilities and equipping individuals with the skills needed to navigate complex challenges effectively. By engaging in PBL, individuals acquire a repertoire of problem-solving strategies that can be transferred and applied to diverse situations, presumably contributing to their overall problem-solving capabilities. Finally, PBL provides learners with a realistic and contextualized learning experience. By immersing themselves in authentic problems, learners gain a deeper understanding of how concepts and theories are applied in practice. This contextualized learning enhances their ability to transfer knowledge from one domain to another, enabling them to tackle unfamiliar problems with confidence and adaptability.

So far, the evaluation of PBL has predominantly relied on assessing its impact using practical problems that closely resemble previously encountered issues (Albanese & Mitchell, 1993; Almulla, 2020; Berkson, 1993; Castillo-Megchun et al., 2021; Dochy et al., 2003; Kasim, 1999; Newman, 2003; Reznich & Werner, 2001; Sharma, 2015; Vernon & Blake, 1993). Where Albanese & Mitchell, Berkson, Castillo-Magchun et al., Kasim, Newman, Reznich & Werner and Vernon & Black mostly focus on healthcare related programs, Almulla, Dochy and Sharma focus more on the seniority of the learner and its period of study. Consequently, the effects have primarily been measured within the content and context that aligns with the original PBL environment or the learners progress in study. This approach presents challenges in determining whether the benefits extend to different problem types and contexts or if it enhances general problem-solving skills. Given that problem-solving can be considered a skill that transcends specific contexts, it is crucial to explore its transferability to various scenarios. In terms of assessment, the more abstract and dissimilar the context of measurement the more applicable the results should be to any other fields of application. Barnett & Stephen (2002) discussed the concept of learning from the perspective of the proximity or distance of a topic to its corresponding domain. This leads to different ways of understanding and transferring skills which are needed to develop and strengthen competencies in the specific domain. Further learning research divides by the transfer of skills which is the training of content across various fields (Barnett & Ceci, 2002) and relates to a central topic in cognitive psychology. Emphasizing learning that is closely aligned with the domain is crucial for ensuring a profound understanding. Additionally, decontextualizing the learning content is vital to maximize the effectiveness of competence transfer. One of the primary objectives of PBL is to cultivate domain-independent skills rather than skills that are limited to specific contexts. Therefore, relying solely on practical problems as assessment measures may not provide a comprehensive understanding of the impact of PBL. Additionally, most of PBL research is conducted during advanced study periods, typically occurring in higher semesters after the fourth or fifth semester. (Almulla, 2020; Barrows, 1980, 1996; Barrows & Tamblyn, 1980; Caplow et al., 1997; Castillo-Megchun et al., 2021; Davis & Harden, 1999). To ensure a broader assessment of PBL's impact it would be beneficial to also investigate PBL learning scenarios in earlier study periods, such as the first or second semester, to minimize reliance on prior knowledge.

While PBL is often utilized in later stages of the curriculum, its impact should be examined from a learner's perspective in various courses, not exclusively advanced ones. By adopting a more independent assessment method the impact and effectiveness of PBL on learning can be evaluated and provide individual feedback at any stage of the course, rather than solely in advanced courses. Additionally, some studies have employed measures such as scores from regular Secondary Education certificates (Thomas, 2000) as dependent variables to demonstrate the effectiveness of PBL. However, using average grades at the end of the school year as measures of PBL's impact does not adequately support individual facilitation within the specific course where PBL is implemented. The measurements are usually long ago and susceptible to confounding influences. Furthermore, the effects of PBL are often investigated from a long-term perspective (Yew & Goh, 2016), overlooking potential short-term interventions or adaptations that learners can utilize for their individual development and adjustments - an essential aspect of successful student-centered facilitation (Kolmos et al., 2008). Therefore, the present study adopted a different approach by examining the short-term impact of PBL on general thinking and problem-solving abilities. We employed various cognitive instruments within a domain-independent context and an early stage of the study to address the limitations of previous research and shed light on the missing short-term and transfer-related effects of PBL independent of prior knowledge in the respective field of study.

To summarize our argumentation which leads to our research design as well as our main research hypothesis, there are mainly three different aspects we want to address by our study design:

1. Field of study or subject which leads to a dependence on content
2. Method of measurement which leads to a dependence on context
3. Progress of learners in its study period which leads to a dependence on the prior knowledge or experience of the learners

In a crossover research-design we treated the learning methodology as the independent variable and the development of problem-solving abilities as the dependent variable. This leads to the main research hypothesis: The two different learning methodologies, a traditional course group (CG) and a Problem-Based Learning group (PBL) show a statistically significant difference in their development of problem-solving across the measured timepoints. This main hypothesis includes three inevitable premises and a fourth additional to be tested before determining the main hypothesis:

(1) No difference in the baseline measurement at timepoint t_0

(2) Significant difference between the two measurements of CG and PBL from timepoint t_0 to timepoint t_2 after the PBL intervention
(3) Pairwise comparison of the development of each group
(4) Interaction effect for timepoint and group

Method

Research design

A total of 168 first-year psychology students were randomly assigned to two groups. with the first group participating in a traditional tutorial led by a tutor, referred to as the "course group". The second group engaged in a PBL tutorial, led by the students themselves and structured according to the 7-Step-Method of PBL (Konermann, 2016; Maurer & Neuhold, 2012), and will be referred to as the "PBL group". To ensure both groups covered the same foundational content in Differential and Personality Psychology, PBL-oriented cases were developed for the PBL group while the course group received regular presentations with equivalent content for. In contrast to the PBL group, where students had to formulate the problem statement and utilize the traditional 7 Step Method of PBL, the course group was instructed by a tutor who presented and discussed the content from slides. To assess general problem-solving abilities, subscales of the Wilde-Intelligenz-Test (Version 1 and 2) were applied (Althoff & Jäger, 1994; Kersting et al., 2008). The research background of both the Wilde-Intelligenz-Test I (WIT1) and the Wilde-Intelligenz-Test II (WIT2) are based on Thurstone's (1938) model of Primary Mental Ability (PMA). The PMA model comprises seven primary factors: (1) Reasoning, (2) Space, (3) Number, (4) Verbal, (5) Memory, (6) Word Fluency and (7) Perceptual Speed (Kersting et al., 2008). The factor relevant for the current study is (1) Reasoning, which includes three subtests (1.1.) Analogy, (1.2) Processing, and (1.3) Numeral Series. Over time, Thurstone's model has been developed, modified and validated by various researchers. Jäger (1982), for example, focused on reasoning and introduced the *Modified Model of Mental Abilities (MMPMA)*. Jäger identified common factors in numeral and verbal series as explanatory factors of problem-solving. The reasoning factor, encompassing these different aspects, can be measured using their sum score to validly represent *Reasoning* (Jäger, 1982). As demonstrated earlier, problem-solving, as assessed by the WIT instrument, serves as a common criterion to measure problem-solving abilities. Initially, Jäger (1968) started to deal with common factors to represent the dimension of *reasoning*. This facet is usable to measure the cognitive performance in a way of deductive reasoning which is also described as complex problem-solving. As this is used for personnel selection processes (Kersting et al., 2008; Schmidt & Hunter, 2004) it is a robust and representative criterion (Wilhelm, 2004) for the present study and its purpose of measuring the problem-solving ability on an abstract, content independent level. The WIT provides two versions of tasks (Version A and B) to measure the groups at three different timepoints. This ensures that tasks are not repeated and minimizes learning effects. By employing a crossover design, we administered the subscales of *numerical*, *verbal* and *letter series* at three timepoints. The first assessment took place one week before the intervention, the second assessment occurred after two weeks, and the third assessment occurred after the final course but before the exam. At the second timepoint, the groups switched their learning methods. Each week consisted of three mandatory course sessions.

Participants and exclusions

The participants of this study were in their first-year psychology bachelor students enrolled at the Faculty of Applied Psychology of the SRH University of Applied Sciences in Heidelberg. Out of a potential sample size of N=168, a total of N=136 students participated at the first timepoint. For the second timepoint, the number of participants decreased to N=121 and at the third timepoint, there were N=111 students who took part in the study. The age range of the participants was between 18 to 25 with a mean age (M) of 20.85 and a standard deviation (SD) of 1.978. The gender distribution of the sample leaned towards females, with n = 81 (73 %) female participants and n = 30 (27 %) male participants.

Participation in the study was voluntary, and students received a total of seven test subject hours, which is a common requirement for psychology students during their study program, for their involvement in all three timepoints. The box plot method as a common method in social sciences was employed to identify outliers (Bortz & Schuster, 2016; Döring, 2022; Döring & Bortz, 2016), resulting in the exclusion of n=31 students from further analysis.

The following table gives an insight on our participant's characteristics.

Participants		Age		
		Mean (SD)	Min	Max
Gender	N (%)	20.85 (1.987)	18	27
Female	81 (73%)	20.62 (1.921)	18	27
Male	30 (27%)	21.47 (2.030)	18	27

Table 1. Overview of participants characteristics.

Materials

The participants were provided with all study materials in printed format. The testing instruments included information regarding data privacy and an informed consent form. The study received approval from the ethics committee of the SRH University Heidelberg and the Heidelberg University of Education. It was assured that neither of the groups experienced any systematic disadvantages during the study.

Variables

Three scales from the WIT1 and WIT2 were utilized to assess the construct of *formal logical thinking* also known as *reasonable thinking*. The WIT1 scales included *analogies (AL)*, *letter series (BR)* and *numerical series (ZN)*. The WIT2 scales comprised *analogies (AL)*, *numerical series (ZN)* and *transaction (AW), which* were representative of the problem-solving skill (Kersting et al., 2008). Both testing instruments involved completing various series within a given time frame and marking the correct answer from multiple choice options provided on the answer sheet.

In the *Analogies* subtest participants were presented with an equation that consisted of two given words on the left side (e.g. *Sheep* and *Wool*) and one word on the right side (e.g. *Bird*) with the second word missing. Below the equation, participants were provided with five answer options (a-e) and had to select the correct one. In this case, the correct answer would be *d) Feathers.*

The *Numerical Series* subtest involved a given series of six numbers (e.g. *2, 5, 8, 11, 14, 17, ?*). Participants had to identify the rule by which the numbers were generated and write down the correct upcoming number. In this case, as the rule means *add 3 to each number*, the correct answer would be *20.*

The Letter Series subtest presented participants with 10 randomly combined letters (e.g. *a h b h c h d h e h ? ?*) from which they had to deduce the underlying pattern. On the answer sheet, five options (1-5) were provided, and participants had to select the correct one. In this case, following the *correct sequence of the alphabet (a, b, c, …) with an h in between,* the correct answer would be *4) f h.*

The *Processing* subtest required participants to mentally visualize the folding of a figure. They were presented with 20 unfolded figures displaying different patterns such as black boxes, stripes, dots, or notches on the outside. On the right side, participants saw five proposed folded figures, of which four were not derived from the unfolded figure on the left side. Participants had to imagine how to fold the initial figure and mark the correct answer.

Procedures

Each group, consisting of approximately 12-15 participants, was accompanied into the testing room by an instructor who had received prior training from the authors. All groups were simultaneously tested in 12 separate rooms. Each testing session lasted for approximately one hour. Prior to the start of the assessment, materials including introductions, information regarding data privacy, and informed consent were already arranged on the tables. The test scales of the WIT1 and WIT2 each had predefined time limits for participants to complete each section. The instructors commenced each phase by informing the participants about the allocated time for completing the tasks. After the three sections, with durations of 7 minutes, 11 minutes, and 8 minutes and 30 seconds the participants were instructed to stop writing.

Statistical Analyses

To address the main hypothesis, the following analyses were applied. First, an independent t-test was conducted to ensure there were no differences in problem-solving abilities between the CG and the PG at baseline (t_0). The score of the baseline measurement served as the dependent variable, while the group the students started with was the independent variable. To test the first premise of our main hypothesis, a general linear modeling approach was used. Additionally, we used a paired t-test to examine the development between the two groups from t_0 to t_1, after the PBL intervention of each group. To investigate potential interactional effects, we conducted a repeated measures ANOVA considering timepoints and groups, as well as analyzing each subdimension individually, to identify the origin of the differences in problem-solving.

This analysis allowed us to examine the development of the PG group between t_0 and t_1, as well as the CG between t_1 and t_2, compared to the CG's development from t_0 to t_1 where there was no PBL intervention. (see Figure 1 for further details)

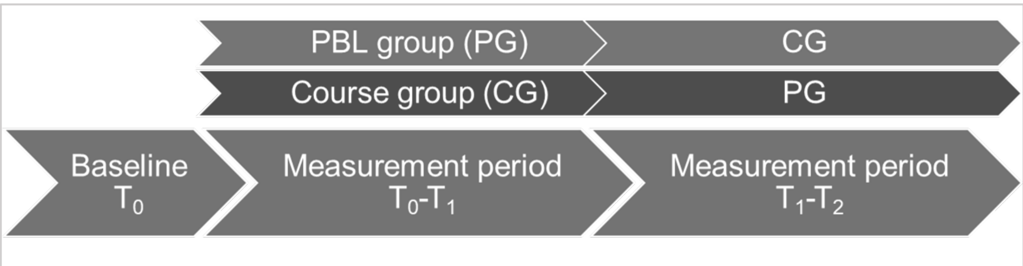

Figure 1. Cross-over design measurement periods.

Results

First, it was confirmed that both groups had a similar baseline performance (t_0) (CG: t(109) = 0.58, p = 0.567, M=325,17, SD=13.11 and PG: M=323,81, SD=11,67 (see also Figure 2)).

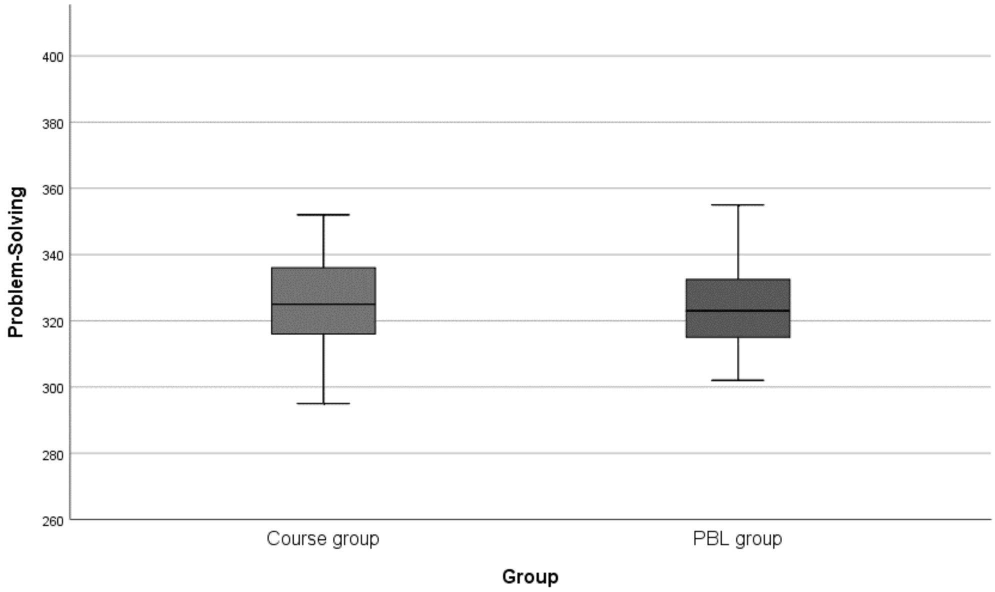

Figure 2. Baseline (t_0) measurement between CG and PG.

The second analysis aimed to compare the development of the intervention itself, measured at the selected timepoints, using the applied measurement instruments. The results revealed a significant difference in problem-solving skills. The sample consisted of N=80 students, and the findings indicated a statistically significant overall development between the different measurement timepoints with *F(1, 78) = 29,843, p < .001*. Based on these results, the second premise can be accepted. To test the third premise of the main hypothesis, a paired t-test was conducted for both groups and the two timepoints (see Figure 3 for details).

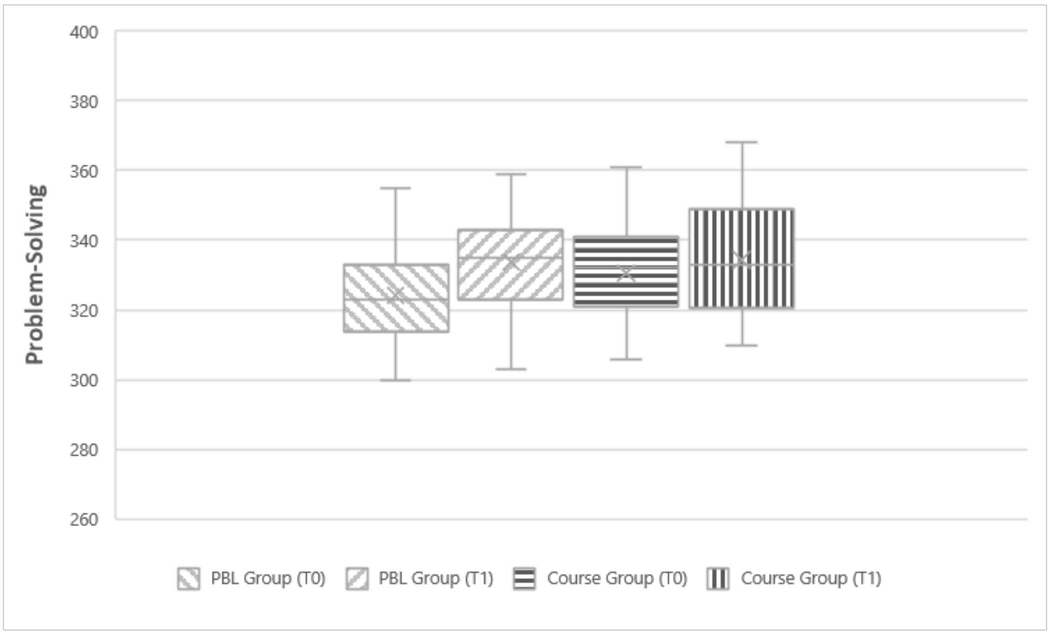

Figure 3. Comparing Deductive Reasoning between the two groups and timepoints.

The results demonstrate a significant development in the problem-solving skills of the PBL group, as observed from the scores before (M = 323.46, SD = 12.58) and after the intervention (M = 333.57, SD = 12.04). Specifically, a significant increase of 10.11 points (95%CI[-15.15, -5.08]) was observed when comparing the results between the first and the second timepoints. This difference was statistically significant, $t(34) = -4{,}08$, $p < .001$. In contrast to the course group before the treatment (M = 326.76, SD = 12.91) and after treatment (M = 327.24, SD = 20.90) there is a development of 0.49, 95%CI[-7.32, 6.34] which was not statistically significant, $t(44) = -0.14$, $p > .05$. With this result the third premise and therefor our inevitable premises for our main hypothesis can be accepted. Paired t-test for each subscale yielded more differentiated results. For *Analogies*, the course group (CG) did not show a significant difference between the timepoints with M = 106.43, SD = 8.14 before and M = 108.14, SD = 6.37 after the treatment with a development of 1.74, 95%CI[-4.60, 1.18] which was not statistically significant, $t(34) = -1{,}21$, $p = .234$. In opposite to this the PBL group (PG) showed a development of 5.25, 95%CI[-8.12, -2.38] 10.11, 95%CI[-15.15, -5.08] which was a statistically significant increase with $t(34) = -4{,}08$, $p < .001$.

In contrast to the control group, the PBL group (PG) demonstrated a statistically significant increase ($t(34) = -4.08$, $p < .001$) with a difference of 5.25 (95%CI [-8.12, -2.38]) compared to 10.11 (95%CI [-15.15, -5.08]) in the control group. None of the other scales showed statistically significant differences. The Letter Series CG exhibited a difference of 0.21 (95%CI [-4.64, 4.21]), $t(34) = -0.10$, $p = .922$ while the PG demonstrated a difference of 2.80 (95%CI [-7.47, 1.87]), $t(34) = -1.25$, $p =$

.225. Similarly, the Numerical Series CG displayed a change of 2.00 (95%CI [-7.00, 3.00]), $t(34) = -0.82$, $p = .419$, while the PG exhibited a change of 1.75 (95%CI [-8.46, 4.96]), $t(34) = -0.55$, $p = .591$. None of these differences were statistically significant.

Furthermore, the authors performed a repeated measures ANOVA as a fourth and mostly additional premise to compare the effect of the learning format on problem-solving.

The results show a significant difference between the two timepoints with Wilk's Lambda = 0.89 ($F(1,73) = 9.45$, $p = .003$ but no interaction between the timepoints and the groups with Wilk's Lambda = 1.00 ($F(1,73) = 0.01$, $p = .943$). Furthermore, the differences between the subscales were analyzed to identify if there are variations in the repeated measures concerning the subscales *Analogies*, *Letter Series* and *Numerical Series*. Also, for the subscales, no significant differences were found in relation to an interactional effect. This is supported by Wilk's Lambda values of 0.997 ($F(1,72) = 0.18$, $p = .669$) for Analogies, 1.00 ($F(1,72) = 0.10$, $p = .759$) for the subscale Letter Series, and 1.00 ($F(1,72) = 0.02$, $p = .892$) for Numerical Series.

Discussion

The present study and its results demonstrate that PBL can be effectively measured in short-term periods within a Higher Education learning environment. Additionally, we provide evidence that PBL leads to a general enhancement of problem-solving measurable via common standardized intelligence tests, more specifically the construct *reasoning* represented by one subdimension *Analogies* and irrespective of specific content. Another significant finding of the study is the ability to measure the impact of PBL using a domain-independent research design. The hypotheses were confirmed, revealing a new method of measuring effects by three aspects: (1) the short-term development of problem-solving skills, (2) the use of practical tasks as an independent variable to represent the impact of PBL, and (3) the applicability of this method in a context with fundamental learning content. Previous studies, such as Gallagher et al. (1992), Lohman & Finkelstein (2002), and Zumbach et al. (2004) have reported similar findings, demonstrating the effectiveness of PBL as a learning method. Although these studies were conducted in different contexts (primary/secondary education) or focused on longer timespans (more than one year), they also indicated improvements in problem-solving skills as observed in the present study. We conducted four premises to prove our hypothesis which were (1) to prove that there is no difference in the baseline measurement at timepoint t_0, to prove the (2) significant difference between the two measurements of CG and PBL from timepoint t_0 to timepoint t_2 after the PBL treatment and (3) that there is significant difference in the pairwise t-test for the PBL group as well as (4) an interaction effect between timepoint and group. Various studies have shifted their focus towards practical or professional skills, which can be seen as essential competencies analogous to problem-solving itself (e.g. Albanese & Mitchell, 1993; Berkson, 1993; Dochy et al., 2003; Gijbels et al., 2005; Kasim, 1999; Newman, 2003; Smits et al., 2002; Vernon & Blake, 1993). These studies have highlighted a significant enhancement in professional competence through the implementation of PBL. In this study, a different measurement approach was employed, and it identified a similar increase in problem-solving skills within a shorter timeframe compared to recent studies. Notably, we found, that the effects of PBL could also be observed through standardized intelligence tests, further validating the positive outcomes. These findings provide valuable insights for educators to effectively support and facilitate the learning process of individual learners. Typically, the impact of interventions is assessed over long-term periods (Yew & Goh, 2016), posing challenges in intervening and providing timely support to the learners. This finding has already been emphasized by Kolmos et al. (2008) who conducted research demonstrating the importance of individual facilitation in enhancing the problem-solving skills of students. Additionally, Koh et al. (2008) confirmed the positive impact of PBL on the development of professional skills, specifically in the field of medicine, using practical testing scenario as a measure.

Another aspect that can be linked to the effects of PBL is the self-regulation in learning and the utilization of planning and thinking strategies. Several studies, such as those conducted by Weber; and Zumbach (2007; 2003), have described the students' abilities to effectively handle large amounts of information. PBL appears to support the cognitive processes involved in identifying, understanding, sorting, and determining the crucial aspects of this information. This cognitive process bears a striking resemblance to the cognitive ability of problem-solving. The present study's results also demonstrate the impact of PBL on this particular facet of cognitive ability, further supporting its practical implications. Notably, the most significant finding is the effectiveness of a learning method practised within the realm of – in this case – basic psychological theories, models, and perspectives, often encountered in the early stages of various study programs. This learning approach leads to a significant enhancement in problem-solving skills, thus exerting a profound influence on students' cognitive growth. Especially analogies play a crucial role in problem-based learning. The use of analogies allows individuals to bridge the gap between unfamiliar or abstract ideas and more familiar or concrete ones, enabling them to make connections and gain deeper insights into the problem at hand. Thus, analogies serve as a powerful problem-solving method by harnessing the ability to recognize patterns, draw connections, and transfer knowledge from one domain to another When confronted with a complex problem, employing analogies allows individuals to approach the problem from a different perspective, tap into their existing knowledge, and unlock creative solutions (e.g. Gentner et al., 2003). The study also highlights this crucial role of analogies in the development of problem-solving skills as students engage in PBL practices.

Limitations

Following Berliner (2002) who described the challenges of educational research in a nutshell our design had similar restrictions we wanted to address. We combined a mostly laboratory study design with a real learning setting to prove the possibility of measuring its effectiveness and impact. This leads to a typical confrontation of internal and external validity. While we chose not to validate PBL with its usual assessments common in various fields of study, we instead opted to gauge its effectiveness through intelligence testing. Here, we focused on a short-term timeframe to exclude other external factors while allowing for the learners' experiences and development. However, it's a conventional yet acknowledged limitation inherent in educational research (Berliner, 2002). Another effect of our research design leads us to the impact of the carry-over effect in learners experience. Known from crossover designs (Piantadosi, 2013) as presented in our study, learners who are treated with PBL in the first section will not *forget* how the process of thinking works when they switch to the course group. This leads to the limitation with which we had to deal by accumulating the groups *before treatment* and *after treatment* of PBL to ensure its exclusiveness.

Through the implementation of the intelligence test, we opened a new field of measurement in the context of assessing the impact of PBL on problem-solving skills. This introduces an element of uncertainty regarding the availability of representative and comparable studies to validate the feasibility of these assessment tools. However, as one of the primary objectives of our study is to pioneer a novel approach to measuring the impact of PBL we acknowledge this limitation. To address this, we intensively supervised the research and testing procedure with more than 15 people such as scientific assistants, tutors and professors involved.

Furthermore, problem-solving is commonly conceptualized across three dimensions as described above. Our study, however, demonstrated its impact on only one of these three dimensions, thereby constraining our conclusion to the fully represented dimension of *reasoning* in our research design using the WIT 1 and WIT 2 intelligence tests. Importantly, we acknowledge that this is not a crucial limitation for us, given the strong correlation between the learning setting and the content presented to students during our experiment, which closely aligns with one of the subdimensions of *reasoning*. In our study, *Analogies* exhibited a significant impact of PBL, notably tied to the learning process within PBL tutorials. Here, students engage in case-based learning, wherein they identify analogies between the presented cases and literature, from which they may derive both problem formulations and solutions. By consistently employing this methodology, our suggestion is that learners predominantly refine the competence represented by *Reasoning, specifically* through the subdimension of *Analogies*. However, this learning process does not exert a comparable influence on the other subdimensions *Numerical Series* and *Verbal Series, resulting in a notable* difference within this single facet.

We were able to show a significant development by the utilization of paired t-tests. Further, we performed repeated measures ANOVA which is fairly discussed to be indispensable for interventional studies. In considering our sample size we want to admit that there is no numerical proof for the estimated interactional effect. We refer to the prior discussion where educational and mostly field studies have limitations with which we have to deal in practical settings, especially with research designs as we present in our study.

Conclusions

The present study contributes to a deeper understanding of how PBL can impact skills and knowledge in short-term periods. It introduces a method for assessing the individual's problem-solving skill level from a short-term perspective. In the realm of Higher Education, learning should focus on facilitating PBL as an impactful method for developing key skills in each individual student. While PBL has traditionally been associated with face-to-face-settings, recent developments in distance education and the aftermath of the Corona pandemic have highlighted the importance of integrating PBL into a wider range of educational contexts, such as blended learning, hybrid approaches, or fully online-scenarios. This expansion necessitates a focus on the social dimensions of PBL (Lozinski et al., 2017). Building upon the present research design, distance learning scenarios can be employed without compromising the valuable information concerning the individual learner's development in problem-solving skills. As emphasized by Torp and Sage; Torp and Sage (1998, 2002) educators must cultivate these skills within their learners to prepare them for future challenges and problem-solving tasks. With the ongoing and accelerating digitalization, simple tasks are increasingly automated by technology, leaving complex problems enriched with emotional and sensitive aspects that require human intervention. Whereas Zhao et al. (2022) already tried to examine the possibility of computers to deal with emotions, it still remains a complex combination of speech, facial expressions and gestures. In this field, human beings are more suitable to integrate this parallel information in communication processes. Compared to the definition of deductive reasoning and problem-solving skills in the field of cognitive psychology (Lezak et al., 2012), this shows a higher importance of research on how to enable learners to gain and facilitate this skill. Irwin et al. (2003) discussed the relationship between problem-solving skills and methods that help individuals navigate an interconnected and information-rich world. In their work, they referenced the significance of these skills for prevention, drawing from the contributions of Beck and Greenberg (1984).

Subsequent research by Beck & Alford (2014) further emphasized the utilization of these skills as to promote overall well-being and support the recovery process of individuals with mental health conditions.

Considering these aspects, PBL emerges as an impactful method that has already found application in the field of higher education. Future research should utilize these findings to provide educators with a method for assessing the development of problem-solving skills in their learners. This approach aligns with the goal of achieving a better alignment between the learners' skill sets, their individual developmental levels and the learning methods employed. The ultimate objective is to equip future graduates with a healthier skill set that prepares them to tackle the increasingly complex interdisciplinary and intercultural challenges of our ambiguous future world. In summary, the central tenet is to prioritize the training of learners' ability to navigate difficult situations, identify or develop relevant structures, and leverage analogies to solve problems in our dynamic and intricate world.

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