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Team-based learning (TBL): Each phase matters! An empirical study to explore the importance of each phase of TBL

Linda Roossien[a], Tobias B. B. Boerboom[a], Gerard W. G. Spaai[a] and Rien de Vos[b]

[a]Faculty of Medicine, Centre for Evidence Based Education, Amsterdam University Medical Centres, University of Amsterdam, Amsterdam, The Netherlands; [b]Faculty of Medicine, Institute for Education and Training, Amsterdam University Medical Centres, University of Amsterdam, Amsterdam, The Netherlands

ABSTRACT

Context: In Team Based Learning (TBL), it is, based on theory, assumed that knowledge development in each phase contributes to the subsequent phase and to learning performance. However, there is no empirical evidence for this assumption.

Aim: In order to find support for the relation between TBL and the underlying theory, we determined to what extent each phase of TBL is associated with the knowledge development in the next phase and with the total learning performance.

Methods: We measured the scientific concepts recalled by 56 second-year undergraduate medical students before TBL, after each of the three phases and after TBL. We used multivariate regression analysis to determine the statistical association between the phases as well as the total learning performance.

Results: Results showed that in each phase, students produced new concepts in addition to those previously recalled. Regression models showed statistically significant explained variance ranging from 0.19 to 0.26, between the three phases and the total learning performance.

Discussion: Each phase of the TBL is significantly associated with knowledge development in the subsequent phase and with the total learning performance, and therefore matters. This study contributes to the scientific underpinning of TBL and offers leads to more elaborate research and interventions to improve TBL.

KEYWORDS
Team-based learning; active learning; collaborative learning; cooperative learning; learning process

Introduction

In the past twenty years, medical education has experienced an increase in the use of teaching methods that stimulate and facilitate active learning and student engagement. Active learning can be defined as any instructional strategy that involves students in the learning process by requiring students to engage in meaningful learning activities and think about what they are doing (Bonwell and Eison 1991; Prince 2004; Mitchell et al. 2017; Hartikainen et al. 2019). In active learning students are not passive recipients of knowledge, but they are involved in higher order cognitive tasks that allow them to build knowledge in a meaningful way (Slavin and Chambers 1996; Van Blankenstein et al. 2011). Studies have shown that active learning improves learning outcomes (Slavin and Chambers 1996; Prince 2004; Freeman et al. 2014).

A method that facilitates and stimulates active learning is Team-Based Learning (TBL) (Michaelsen 2004). TBL is a cooperative and collaborative instructional strategy designed to deepen student's learning and to support the development of 5 to 7-member permanent groups into self-managed learning teams. This strategy is increasingly being applied in health science education because, in addition to deeper learning, it also stimulates the development of skills that are important for healthcare, such as clinical reasoning, problem solving, collaboration and communication (Haidet et al. 2008; Janssen et al. 2008; Parmelee 2008; Haidet et al. 2012; Burgess et al. 2014). TBL consists of structured series of learning activities for multiple teams of students divided into three phases, the preparation phase, the readiness assurance phase and the application phase, and concludes with peer evaluations (Michaelsen 2004; Michaelsen, Parmelee, et al. 2008).

Practice points

- This study contributes to the scientific underpinning of TBL and strengthens the relation between TBL and the underlying theory.
- Knowledge development in each phase of TBL is important for knowledge development in the subsequent phase and for the learning performance of TBL
- Interventions that benefit knowledge development in one of the three phases of TBL can lead to an improvement in the total learning performance of TBL.

CONTACT Linda Roossien l.roossien@amsterdamumc.nl Faculty of Medicine, Center for Evidence Based Education, Amsterdam University Medical Centres, University of Amsterdam, Meibergdreef 15, 1105 Amsterdam, AZ, The Netherlands
This article has been corrected with minor changes. These changes do not impact the academic content of the article.

The preparation phase is an individual study phase. In this phase, students obtain new information by completing programmed activities such as readings or e-learning assignments (Michaelsen 2004). These activities contain information on concepts and ideas students need to understand to be able to engage in problem solving in the subsequent phases.

In the readiness assurance phase students are made accountable for learned information from the preparation phase (Michaelsen et al. 2008a). In this phase, students take two tests, the individual readiness assurance test (iRAT) and the team readiness assurance test (tRAT) collectively referred to as the RATs. The RATs activate students' individual and collective knowledge and insights, test students' overall understanding of key concepts and enable the teacher to assess whether the students have a clear understanding of the key concepts (Michaelsen et al. 2008a). By using repeated retrieval, the RATs help reinforce students' memory of what they learned during the preclass study and increases retention of knowledge (Larsen et al. 2008; 2009; Schmidmaier et al. 2011).

In the application phase, students work in their teams to share and apply the learned information from the previous phases to solve problems, called application exercises (Birmingham and McCord 2004; Michaelsen, Parmelee, et al. 2008). These exercises, which are specifically designed to stimulate in-depth discussions, promote deeper understanding of the content of the course (Michaelsen et al. 2008b; Roberson and Franchini 2014). When discussing the answers, the teacher calls on students to justify their solutions and to criticize each other's solutions. Usually, the teacher discusses the best practice solutions at the end of the sessions. By engaging in these exercises and justifying their solutions, students involve in higher order cognitive tasks (Hernandez 2002; Michaelsen et al. 2008b; Van Blankenstein et al. 2011).

The structure of TBL, as described above, and its division into phases is based on the principles of the (social) constructivist learning theory (Hrynchak and Batty 2012). According to this learning theory, learning is a constructive, cumulative, self-directed, goal-oriented, situated, cooperative and individually distinct process of knowledge acquisition, meaning making and skills development (Phillips 1997; Mayer 1999). Since this learning theory posits that learning is a constructive and cumulative process, it can be assumed that each step or phase in this process contributes to the subsequent step or phase. TBL therefore assumes that knowledge development in each phase is important for the subsequent phase and for learning performance

Another instructional strategy that relies on social constructivist learning theory is Problem Based Learning (PBL) (Savery and Duffy 1995; Hendry et al. 1999; Hmelo-Silver and Eberbach 2012). PBL also consists of a series of learning activities divided into three phases according to a fixed structure and as with TBL, learning takes place in small groups (Dolmans et al. 2015). In 2011, Yew, Chng and Schmidt conducted a study on the knowledge development in each phase of Problem-Based Learning (PBL). This study has shown that learning in the phases of PBL is cumulative. The learning in each PBL phase is strongly influenced by the learning in the previous phase. This instructional strategy thus appears to reflect the underlying theory of constructivism.

Similar to PBL, TBL was developed bearing the aforementioned learning theory in mind. The effectiveness of TBL has been demonstrated by various studies through improved performance on end-course exams or assignments (McInerney and Dee Fink 2003; Fatmi et al. 2013; Emke et al. 2016; Liu and Beaujean 2017). While the idea that new learning builds on pre-existing knowledge may be widely accepted, in the context of TBL there is little published empirical evidence to support the assumption that knowledge development at each phase of TBL is important for the subsequent phase and for learning performance. If we could determine the impact of each phase of the TBL process on knowledge development in the next phase and total cognitive learning performance of TBL, this could enable more targeted interventions to improve this process and enhance learning performance.

Therefore, in this study we addressed the research question: To what extent is knowledge development in each phase of TBL associated with the knowledge development in the subsequent phase and with total learning performance of TBL? Based on the underlying theory of TBL, we expect that the knowledge development in each phase of TBL is associated with the knowledge development in the subsequent phase. We also expect that knowledge development in each phase is associated with TBL's total learning performance. Further, in the preparation phase, the conceptual basis is laid for knowledge development in the subsequent phases. We therefore expect that knowledge development in the preparation phase will be more strongly associated with TBL's total learning performance than knowledge development in the other phases.

Methods

Design

To answer the research question to what extent knowledge development in each phase of TBL is associated with knowledge development in the subsequent phase and with total learning performance of TBL, we conducted a prospective cohort study with five consecutive measurement moments. In this study learning performance is operationalized as the learning gain (score) in the field of conceptual knowledge development. In other words: do students develop new concepts on the subject matter during the TBL phases? The design of this study is based on the design that Yew et al. (2011) used in their study of knowledge development within Problem Based Learning (PBL).

Context

This study was conducted at the Faculty of Medicine of the University of Amsterdam. This medical school has a hybrid curricular structure that includes both traditional lecture and small group instruction, of which TBL is one of the methods used. In each four-week block of education, one subject is offered using TBL. Data was collected during the TBL-education in the third week of their course 'Observing, Thinking, Acting 2.' The subject of this TBL was Post-Traumatic Stress Disorder (PTSD). TBL took place according to the structure as pictured in Figure 1. Within this structure, the iRAT, tRAT are assessed summatively, this does

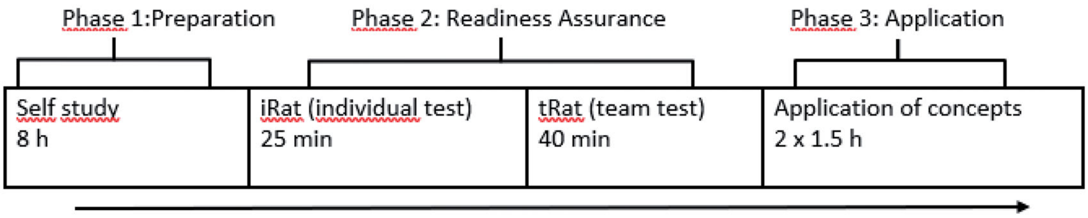

Figure 1. Team-based learning instructional activity sequence within Epicurus, Bachelor's degree program.

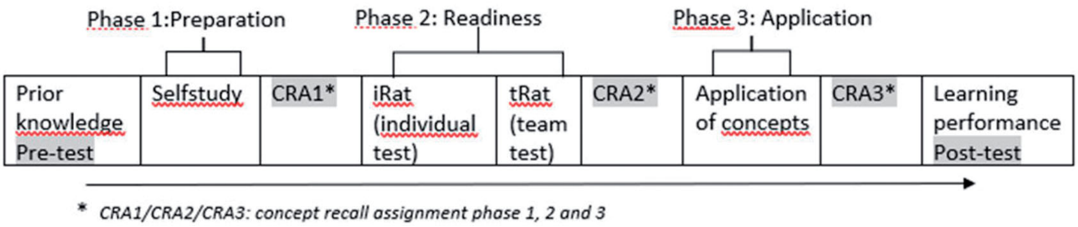

Figure 2. TBL process with measurement moments (marked in grey).

not apply to the application sessions. Due to examination requirements within the programm, appeals are in writing and must be submitted individually. In addition, the peer evaluations, which are part of the TBL structure, have not been included because the focus of this study was on knowledge development within TBL and peer evaluations are not primarily intended for knowledge acquisition.

Participants

In order to estimate the knowledge development during the TBL process as accurately as possible, students were included who are already familiar with the TBL approach. Therefore, we asked all second-year medical students ($N = 339$) during the 2019–2020 academic year to participate in this research. These students already completed the first year of their study in medicine and weren't new to the TBL approach. Students who had to take a re-sit for this course and who have therefore taken this course before were not included in this study.

Ethics

Although the seminars were mandatory, enrolment in the study was on a voluntary basis as students autonomously decided if their answers could be used for research purposes by signing the informed consent form. Students were informed that data analyses would be performed anonymously and that they could withdraw their consent at any given time. Moreover, they were ensured that the results would not affect their course grades. The study protocol was reviewed and approved by the NVMO Ethical Review Board on October 14th, 2019, under reference number 2019.7.6.

Procedure/materials

The conceptual knowledge development of second-year medical students of the Faculty of Medicine of the University of Amsterdam was measured at five times during the TBL-process, before the TBL-process, after each of the three TBL phases and after the TBL-process (Figure 2).

We chose to measure the gain in scientific concepts on the subject that the student could reproduce after each stage and thus used a similar measurement technique as in the study by Yew et al. (2011). It is assumed that, when students participated in the learning activities in these phases, they build networks of concepts related to the different learning topics and that they establish relationships between their prior knowledge and new ideas (Glaser and Bassok 1989; Yew et al. 2011). When students learn more about a topic, more connections and integration will be constructed between new and existing ideas. They can therefore remember more concepts and do this more easily. Measuring at the end of each phase the number of relevant concepts that students can remember in relation to the topic being treated therefore gives a good indication of what the student has learned in that phase.

The procedure and materials used are described below.

Student's prior knowledge about the subject of the course was measured using a pre-test (Yew et al. 2011). This pre-test consisted of a short essay assignment where students were asked to write down what they already know about Post-Traumatic Stress Disorder (PTSD). This pre-test was taken one week before the TBL week.

Students' knowledge development in each of the three phases of TBL was measured with a concept recall assignment (CRA) (Yew et al. 2011). In these assignments, students were asked to write down all key words/concepts related to Post-Traumatic Stress Disorder (PTSD). The assignments were administered immediately after each of the three phases of TBL.

Students' learning performance of TBL, the total conceptual knowledge related to the subject of the course that the student has at the end of the TBL, was measured with a post-test (Yew et al. 2011). This post-test consisted of a short essay assignment, similar to the pre-test, where students were asked to write down what they know about Post-Traumatic Stress Disorder (PTSD). The post-test was taken at the end of the TBL week, after finishing the last application session.

Data

The following steps have been taken to prepare the data for analysis. First all assignments were scored. Students' responses on the pre- and post-test assignments were scored by using the 'idea unit' (Yew et al. 2011). These responses were segmented into idea units; a comment/statement ending with a comma, period, or 'and.' A score of 2, 1, or 0 was assigned to each idea unit. A score of 2 was given for a completely correct idea unit, 1 for a partially correct idea unit, and 0 when the idea unit was completely incorrect. Scoring was conducted by the first author and the teacher of the course, a subject-expert. They first independently scored about 20% of the tests, after which an inter-rater reliability (IRR) analysis was performed. To calculate Cohen's Kappa we used CROSSTABS in IBM SPSS Statistics, version 26.

Students' responses to the concept recall assignments were scored by assigning 1 point to each relevant concept given by the student. The relevant concepts listed were counted for each student for each of the three phases of the TBL-process (i.e., preparation, readiness assurance and application).

In order to gain insight into the knowledge development per phase, in addition to the total number of concepts recalled per student per phase, the number of repeated and the number of new concepts per phase were documented. The total number of concepts refers to the total number of relevant concepts recalled, including the repeated concepts. Newly developed concepts were concepts not previously mentioned by the student in any preceding learning phase. Repeated concepts were concepts already mentioned by the student in an earlier phase. For the preparation phase, the concepts mentioned were compared with the concepts mentioned in the pre-test.

Analysis

After scoring all assignments, data were checked for missing data and outliers.

Data from six students were not included in this study because they only completed one or two assignments out of a total of five assignments. Data were then checked for normal distribution.

The student characteristics were described in terms of age and gender and analyzed using descriptive statistics.

To answer the research question to what extent knowledge development in each phase of TBL is associated with knowledge development in the subsequent phase and with total learning performance of TBL, we performed the following analysis.

The effect of TBL as a whole on learning, measured by the difference between the pretest and posttest, was analyzed using a paired sample *t*-test.

To test our expectation that knowledge development in each phase of TBL is associated with knowledge development in the subsequent phase, we determined the statistical association between the outcomes of the three assignments (CRA1, CRA2, CRA3) conducted after the consecutive phases by using multivariable regression analysis. The assumptions of multiple regression were checked when performing the analysis. We entered the various knowledge development variables as independent variables into the model one by one, starting with prior knowledge and used the knowledge development variable of the subsequent phase as dependent variable. To test our expectation that knowledge development in each phase is associated with TBL's total learning performance, we carried out a similar approach with learning performance as dependent variable. Effect size was expressed as by the multivariable regression model explained variance (R^2). $p < 0.05$ was considered statistically significant. All statistical analyses were performed with IBM SPSS Statistics, version 26.

Results

Participants

A total of 339 second-year medical students were enrolled in the course, of whom 62 completed the pretest and 56 completed all assignments. Of these participants 44 (71%) were women, which resembles the overall gender distribution in the Bachelor's Degree program at the Faculty of Medicine of the University of Amsterdam. The mean age was 20.9 years, with a minimum age of 19 years and a maximum age of 29 years. Both the mean age and the range correspond to the population of second-year medical students at this faculty.

Effect all phases of TBL on learning performance

For calibration purposes, the first author and the teacher of the course scored independently about 20% of the posttests with an interrater correlation of $r = 0.73$. This was considered as satisfactory. The remaining tests were scored by the first author. Results of mean student performance for the pre- and posttests showed improved scores for the posttest. The average difference between the posttest and pre-test scores was 42.04 (SD = 21.19), indicating a significant increase in learning performance at the end of the TBL process, t (55) = 14,71, $p<.01$.

Effect/impact phases on subsequent phases

The first author and the teacher of the course also scored independently about 20% of the concept recall assignments after phase 1 with a interrater correlation of $r = 0.81$. This was considered as satisfactory. The remaining assignments were scored by the first author. The relevant concepts recalled by students at the end of each of the three phases of the TBL process, during the concept recall assignments, were counted in three different ways: the total number of relevant concepts, newly emerged concepts and repeated concepts. The distribution of the average number of these relevant concepts is shown in Table 1.

Table 1 shows that there is a decrease in the number of new concepts per phase as students go through the TBL process. The table also shows that the number of repeated concepts per phase is increasing. No major differences between the phases were observed in the total number of relevant concepts per phase.

The impact/effect of knowledge development in each of the three phases of the TBL process on the knowledge development in the subsequent phase is shown in Figure 3.

Figure 3 shows that prior knowledge has no significant association with knowledge development in the preparation phase, the readiness assurance phase and the

Table 1. Distribution of the mean number and standard deviation of total, new and repeated relevant concepts recalled at the end of the each of the three phases of the TBL process.

	Phase 1 Preparation ($N = 56$)			Phase 2 Readiness Assurance ($N = 56$)			Phase 3 Application ($N = 56$)		
Number of relevant concepts	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Average number of new concepts	25.02	10.44	9–54	8.43	5.21	1–24	7.29	5.43	0–26
Average number of repeated concepts	2.43	2.06	0–11	16.52	7.18	5–38	19.43	7.72	4–38
Average number of total concepts	27.45	10.73	11–55	24.95	10.26	6–56	26.71	10.60	8–59

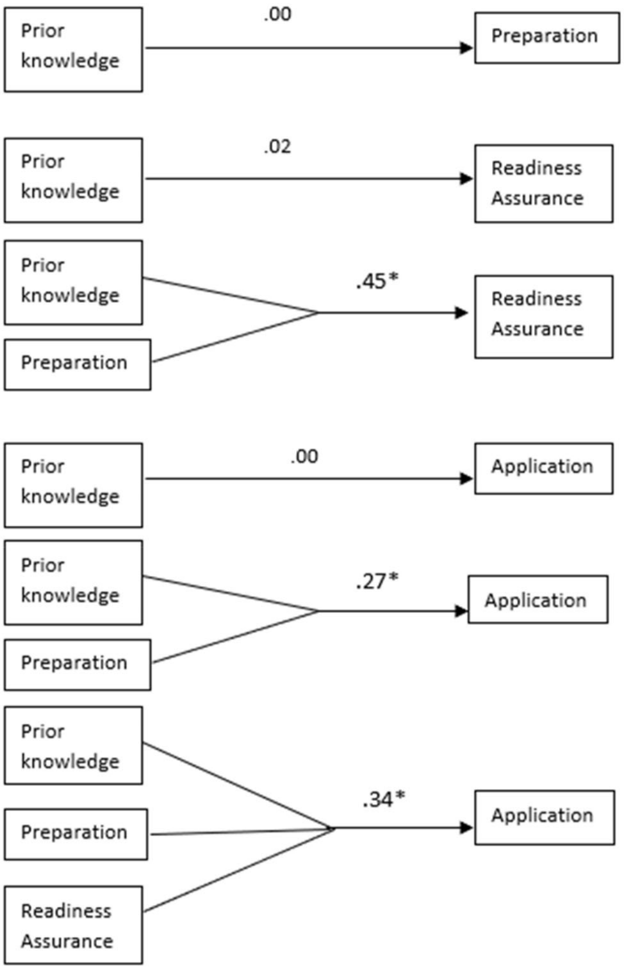

Figure 3. Effect of each phase of the TBL process on the subsequent phase expressed in explained variances, calculated by multivariable regression modelling. *$p<.01$.

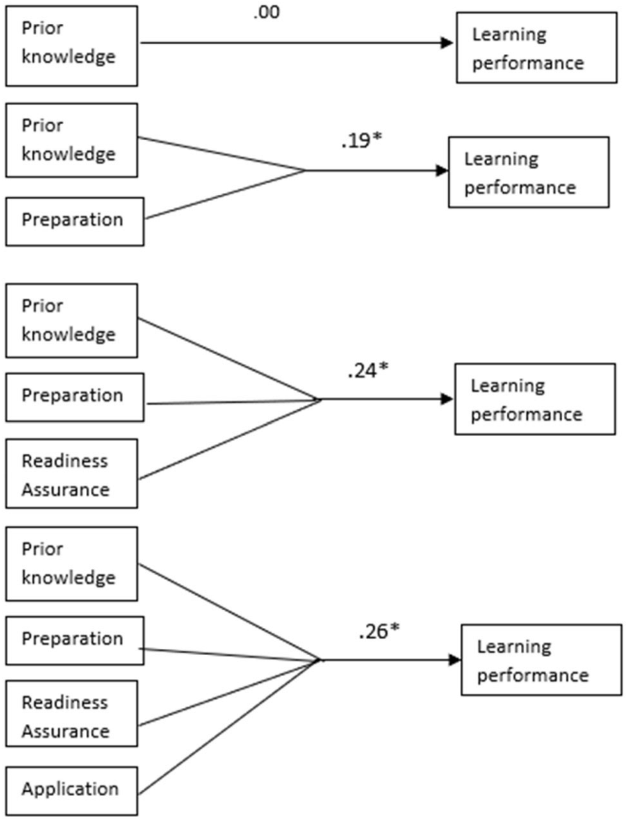

Figure 4. Effect of the phases of the TBL process on learning performance expressed in explained variances, calculated by multivariable regression modelling. *$p<.01$.

application phase. Prior knowledge and knowledge development in the preparation phase explain 0.45, $p < .001$ of the variance of knowledge development in the readiness assurance phase. Prior knowledge and conceptual knowledge acquired in the preparation phase together appear to be a reasonable predictor for the amount of conceptual knowledge acquired in the readiness assurance phase. This suggests that greater prior knowledge and higher conceptual knowledge development in the preparation phase can lead to higher conceptual knowledge development in the readiness assurance phase.

Prior knowledge and the preparation phase determine the variance of application phase for 0.27 ($p < .001$), when the readiness assurance phase is added the explained variance of the application phase increases from 0.27 to 0.34 ($p < .001$). The conceptual knowledge development in the preparation phase and in the readiness assurance phase appear also to be predictors in knowledge development in the application phase.

Effect/impact phases on learning performance

The impact/effect of knowledge development in each of the three phases of the TBL process on learning performance is shown in Figure 4.

Figure 4 shows that prior knowledge was not statistically associated with learning performance. Prior knowledge and the preparation phase explain 0.19 ($p = .003$) of the variance of learning performance. Prior knowledge and conceptual knowledge acquired in the preparation phase together appear to be a reasonable predictor for the learning performance of TBL. This suggests that greater prior knowledge and higher conceptual knowledge development in the preparation phase can lead to higher learning performance.

When the readiness assurance phase is added, the explained variance of learning performance increases from 0.19 to 0.24 ($p = .002$) and when the application phase is also added, the explained variance increases further to 0.26 ($p = .004$).

Discussion

In Team Based Learning (TBL) it is assumed on the basis of the underlying (social) constructivist learning theory, that knowledge development in each phase contributes effectively to the subsequent phase and to total learning performance. However, to date there was no empirical evidence for this in the context of TBL. The aim of this research was to strengthen the theoretical underpinning of TBL by determining to what extent knowledge development in each phase of TBL is associated with the knowledge development in the subsequent phase and with the total learning performance of TBL.

The assumption investigated was that the knowledge development in each phase of TBL is associated with the knowledge development in the subsequent phase. Results of this study showed that number of concepts recalled at the end of each of the three phases are indeed associated with the number of concepts recalled at the end of the subsequent phases. The knowledge development in each phase of TBL explained a statistical significant part of the variance of knowledge development in the following phases. This finding is in line with the study of knowledge development within Problem Based Learning (PBL)(Yew et al. 2011) which showed that knowledge development in each phase of the PBL process has a positive effect on the subsequent phase. This may suggest that in both PBL and TBL a higher knowledge development in one of the phases of processes could lead to a higher knowledge development in the next phase and that the mechanism behind both learning approaches could be similar.

We also assumed that the knowledge development in each phase of TBL is associated with the total learning performance of TBL. This study finds that the number of concepts recalled at the end of each of the three phases are a reasonable predictor for learning performance. For each added phase, the explained variance of learning performance increased, which is a cautious indication that the phases together reinforce the effect on learning performance. Since each phase adds to the effect on learning performance, we therefore consider that the phases are all important for the learning performance of TBL and findings may suggest that the higher the knowledge development in one of the phases, the higher the learning performance could be at the end of the TBL process. This finding is also consistent with the study by Yew et al. (2011) on Problem Based Learning (PBL), another educational strategy that relies on the social constructivist learning theory, that showed that learning within PBL is cumulative. Our findings support that learning in the TBL process is a constructive process in which students build on and link the new knowledge to previously learned, the various phases contribute to knowledge development as well as total learning performance. These findings underpin the underlying (social) constructivist learning theory of TBL (Hrynchak and Batty 2012).

Having said that, contrary to previous studies (Gijselaers and Schmidt 1990; Yew et al. 2011; Zambrano et al. 2019) and our expectations, in this study prior knowledge is neither significantly associated with the knowledge development in the first phase of the TBL process nor significantly associated with learning performance. A possible explanation for this seems to be the subject of the Post Traumatic Stress Disorder (PTSD) course. This topic was new to all students and therefore they had limited prior knowledge in this area. In addition, it is possible that the tool used was not accurate or sensitive enough to activate prior knowledge.

Based on the underlying theory of TBL, we expected that the conceptual foundation for knowledge development in the subsequent phases would be laid in the preparation phase. This study shows, that based on the number of relevant concepts recalled by students after each phase of TBL, that the acquisition of new concepts mainly takes place in the first phase, the preparation phase, but that new concepts are also acquired in the subsequent phases, the readiness assurance phase and the application phase. We found that the number of new relevant concepts decreases over time and the number of repeated concepts increases as students go through the TBL process. This shows that conceptual knowledge development takes place during the entire TBL process, but that, in line with our expectations, the foundation is laid in the preparation phase. Our expectations are also confirmed by showing that knowledge development in the preparation phase is more strongly associated with learning performance than knowledge development in the readiness assurance phase and in the application phase. These findings support the ideas behind the design of the TBL process as described by Michaelsen (2004) and Michaelsen et al. (2008a) and underlying theory.

The third phase, the application phase, does not seem to add much more to the explained variance of learning performance. This finding suggests that knowledge development in the application phase, the part where students learn as a team, contributes less to learning performance than the preparation phase, the part where students learn individually. This seems to be at odds with the principles of social constructivist learning theory, but this may be because we focused on conceptual knowledge development in this study. We therefore measured the recall of scientific concepts while the third phase is more about applying these concepts, thus a lower contribution of this phase to conceptual knowledge development can be expected (Michaelsen et al. 2008b). Future research into knowledge development within TBL, taking into account the higher levels of knowledge such as applying knowledge, is needed to gain more insight into the contribution of the application phase to TBL's total learning performance.

A remarkable outcome of this study was the lower total number of relevant concepts after the application phase compared to the total number of relevant concepts in the preparation phase. It is expected that students will be able to remember more concepts at the end of the TBL process than after the preparation phase. At the end of the TBL process, students have been able to practice the concepts more often and have learned more about the topic, which allows more connections to be made between new and existing ideas (Glaser and Bassok 1989; Yew et al. 2011). As a result, they should have built a larger network of concepts and would therefore remember more concepts and do this more easily. We considered four explanations for the unexpected finding. Either this could be due to the fact students had difficulties maintaining acquired knowledge or that the outcomes are due to the mental fatigue of students after an intensive application session (Gaillard 2001; Sweller 2011). According to Sweller's cognitive load theory, short-term memory can block when too much information is received in a short time (Sweller 2011). As a result, the information is no longer processed. In addition, it is possible that the students did not apply all the concepts learned in the application assignments. Finally, the tool used may not have been accurate or sensitive enough to measure concept acquisition in this setting.

Limitations

The limitations of this study should be acknowledged. In this study we measured the total learning performance and the knowledge development per phase on the basis of the number of relevant concepts and ideas that students can remember and produce in relation to the content of the course. This means that we have only focused on acquisition of and familiarity with scientific concepts and not on application of these concepts. As a result, the higher order cognitive tasks are not included in this study. We measured total learning performance with a pre-post design. This means there is always a risk of students 'learning the test.' Choosing the essay assignment helped to reduce this risk.

In addition, the number of respondents limited the ability of using more advanced statistical analyses, such as structural equation modelling. As a result, we have not been able to determine the pure effect of each phase (the real learning gain per phase) and we are therefore unable to make any statements about the extent to which each phase individually contributes to the knowledge development in the subsequent phase and to the learning performance. Despite these shortcomings, given the intensity of what we asked of the students, we are satisfied with the sample obtained. We consider the sample a representative reflection of the entire cohort. Given the size of 56 the effect sizes should be treated with caution. As this study was only conducted among second-year medical students of the Faculty of Medicine of the University of Amsterdam, this may limit the generalizability of the results to other years and domains other than health science education.

Finally, we cannot completely rule out that the study itself was also an intervention and that this may have had a positive influence on the results found.

Implications and future directions

Based on these results, we suggest that knowledge development in each phase of TBL contributes to of knowledge development in the subsequent phase and to learning performance. This means that interventions that benefit knowledge development in one of the three phases of TBL can lead to an improvement in the total learning performance of TBL. It also means that interventions in each of the three phases of TBL are useful to improve the learning performance of TBL. Possible interventions that benefit the development of knowledge in TBL can be the use of discussion in TBL teams to activate the prior knowledge, more stimulation of self-regulation in the preparation phase and grading of the application assignments (Michaelsen, Parmelee, et al. 2008; Dolmans et al. 2015). To gain further insight into the effect of knowledge development in each of the three phases of TBL on knowledge development in the following and on learning performance, further research is needed with a larger sample, so that modelling becomes possible. Because this study examined the associations of knowledge development in each phase of TBL with short-term learning performance and only within one course subject, follow-up research could also examine whether the associations found in this study also hold up in the longer term and across multiple course subjects.

Conclusion

With this research we have shown that each phase of TBL is important for the knowledge development in the subsequent phase and for the learning performance of TBL. The results support the idea that TBL is underpinned by the underlying social constructivist learning theory. With this, this study contributes to the scientific evidence of TBL and supports its basis in constructivism. This study offers leads to more elaborate research into the importance of each phase for the learning performance of TBL. Finally, it may lead to interventions to improve the contribution of each phase in the TBL process.

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Notes on contributors

Linda Roossien, MSc, is PhD-student Team-Based Learning at the Centre of Evidence Education at Amsterdam University Medical Centra, Faculty of Medicine, University of Amsterdam, the Netherlands.

Tobias Boerboom, DVM, PhD, is head of the Centre of Evidence Based Education at Amsterdam University Medical Centra, Faculty of Medicine, University of Amsterdam, the Netherlands.

Gerard Spaai, PhD, is educational psychologist, educational advisor and researcher at the Centre of Evidence Education at Amsterdam University Medical Centra, Faculty of Medicine, University of Amsterdam, the Netherlands.

Rien de Vos, PhD, is Professor in Medical Education and Training, interprofessional care at the Institute for Education and Training, Amsterdam University Medical Centra, Faculty of Medicine, University of Amsterdam, the Netherlands.

ORCID

Linda Roossien http://orcid.org/0000-0002-3891-2502
Rien de Vos http://orcid.org/0000-0003-0901-3310

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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