Assessing the effectiveness of a problem-based learning compared to a traditional learning methodology

Sebastian Jentschke & Wang Wei
University of Bergen, Norway

Introduction

Traditional learning (TL) approaches often do not prepare students well for real-world settings. This under-desired performance was often attributed to the emphasis on memorization of fragmented knowledge. The problem is particularly evident in traditional health science education where students' often show unsatisfactory clinical performances. To overcome this problem, problem-based learning (PBL) was conceived and implemented as an instructional method. It requires students to solve problems, aiming to enhance these learning outcomes by promoting their abilities and skills in applying knowledge, solving problems, practicing higher order thinking, and self-directing their own learning. From medical and health science education, for which PBL was initially developed as an instructional method, it has been widely adopted by various other disciplines (such as management education, biology or biochemistry, physics; cf. Bonney, 2015; Culpin & Scott, 2011; Nair, Shah, Seth, Pandit & Shah, 2013; Rayner, 2005). Case-based learning (CBL) is often used synonymously and bases learning activities in health professional education around patient cases. To our knowledge, the current study is the first publicly available report of an application of the method in pharmacy.

PBL was demonstrated to be effective in alleviating students' problems of inert knowledge as well as enhancing students' problem solving, higher-order thinking, self-directed learning skills, and motivation to learn (cf. Bonney, 2015; Jonassen & Hung, 2012). In addition, students taught with PBL showed superior long-term retention compared to students taught with TL. Finally, PBL was shown to enhance critical thinking skills and meta-cognitive awareness; skills that were not enhanced after TL (Gholami et al., 2016).

Several studies as well as a narrative synthesis of 104 studies examining the effectiveness of PBL (among them 23 studies that were regarded as being og high quality and significance), documented that students enjoy PBL and believe that it enhances their learning (Bonney, 2015; Jonassen & Hung, 2012; Thistlethwaite et al., 2012). However, not all studies report an increased performance: Newman (2003; p. 5) conducted a systematic review on the effectiveness of PBL in higher education programs for health professionals, and concluded that "existing overviews of the field do not provide high quality evidence with which to provide robust answers to questions about the effectiveness of PBL". Likewise, Sanson-Fisher and Lynagh (2005, p. 260) claim that "available evidence [...] offers little support for the superiority of PBL over traditional curricula". Onyon (2012) summarizes "students tend to perform either a little better or a little worse in examinations". As a consequence, Sanson-Fisher and Lynagh (2005) call for further research, particularly regarding the short-term vs. long-term effectiveness of PBL and the influence of learner populations. Onyon (2012) demands to "concentrate on the reasons behind this uncoupling of theory [*hypothesized improvements in performance*] and outcomes".

PBL is a form of inquiry-based learning and characterized by (cf. Jonassen & Hung, 2012):

(a) learning by solving an authentic, ill-structured problem;
(b) a reciprocal relationship between knowledge and problem (i.e., knowledge building is stimulated by the problem and applied back to the problem);
(c) student-centered, self-directed learning;
(d) self-reflective learning (i.e., students monitor their understanding and learn to adjust their learning strategies); *and*

(e) instructors act as facilitators, instead of being knowledge disseminators (i.e., they support and model reasoning processes, facilitate group processes and interpersonal dynamics, probe students' knowledge deeply).

Several mechanisms have been suggested to contribute to the performance increases observed after PBL (Onyon, 2012). The increased performance appears to result from:

(a) assistance in the formation of memories by activating and building upon prior knowledge;
(b) knowledge that is elaborated through discussion with other students and context matching (with cases used in PBL reflecting real-world-problems which may be encountered in work life);
(c) assistance to learn cooperatively and discussions which might challenge and conceptually change conflicting prior knowledge (and, in addition, develop team-working skills which are also an essential part of later working life);
(d) enhancement of reasoning abilities and effective pattern recognition (the various examples and different cases PBL provides improves diagnostic accuracy); *and*
(e) encouragement of autonomous motivation, and self-directed learning.

PBL is usually conceptualized to take place in several steps (cf. Hung et al., 2008). Students or student groups:

(a) encounter and reason through the problem;
(b) define the problem, identify what they need to learn in order to solve the problem, and generate hypotheses to the cause of the problem;
(c) study self-directed;
(d) share their research results with the group, revisit the problem, and generate additional hypotheses and reject others based on their learning;
(e) generate or select a most viable solution to the problem; *and*
(f) summarize and integrate their learning.

Methods

Participants

The study group consisted of 24 fourth-year-students (20 females, 4 males) with an age range between 21 and 37 years (mean age = 24.6 yrs). One student left early in the second session, data from that student for the second session are therefore missing.

Materials

Two custom-made questionnaires were developed to assess the learning outcome. Both were designed to be similarly difficult. Either consisted of ten multiple-choice-questions, each with 4 possible and 1 correct answer option. The questionnaires can be found the appendix.

Procedure

Two lectures were chosen to evaluate the influence of two different learning approaches: A traditional learning approach was chosen for the "Solids and dissolution" lecture, a problem-based learning approach for the "Pharmaceutical solutions" lecture. Both lectures were similar in terms of taught contents, the difficulty of the introduced terms and concepts, and the expected learning outcome. The outcome included (for either lecture) understanding the relevant terms, concepts, and their application (using formulas for numerical calculation). These formulas were also used in the questionnaires used to assess student performance.

The lecture "Solids and dissolution" employed a traditional knowledge-delivery method. All the terms and concepts were introduced sequentially, and examples were used to illustrate these concepts. The lecture introduced the physical properties of solids, crystal structures, the process of dissolution, dissolution rate, and the Noyes-Whitney relationship.

In the lecture "Pharmaceutical solutions", the lecture started with a case / a problem requiring the students to formulate an ophthalmic solution (i.e., to define the components of the solution and to determine their mixing proportion). The lecture was organized around analyzing this case / problem. Along the analysis, the terms and concepts were introduced. Furthermore, the chemical principles to characterize a pharmaceutical solution were introduced (including, e.g., Raoult's law, ionization of solutes, colligative properties, and diffusion in solution). Students were involved particularly group discussion, and the presentation of the results from these.

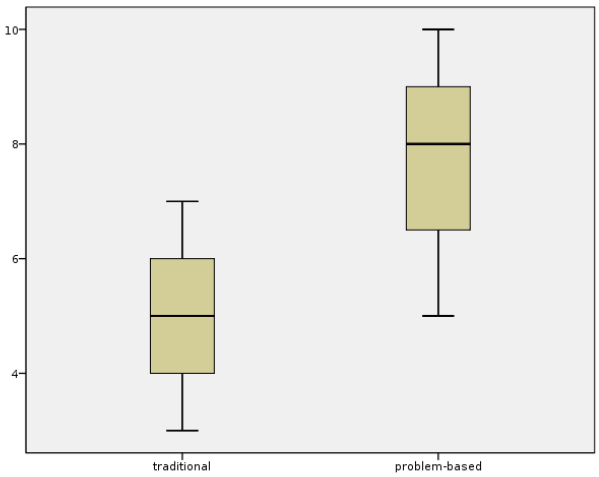
Lecture slides for both lectures can be found in the appendix / on MittUIB.

Statistical analyses

The students' performance in the multiple-choice-questions and some personal characteristics were analyzed using t-tests within SPSS 24. For data protection and the sake of simplicity, the performance was not collected in a way that would have allowed within-subject analyses (i.e., the questionnaires were not to be marked with a subject code).

Results

Using the traditional-learning-approach (TL), students answered between 3 and 7 questions (out of 10) correctly (Md = 5); after the problem-based-learning-approach (PBL) the number of correct responses was between 5 and 10 (out of 10; Md = 8). Already from visual inspection of the Box-plot it becomes obvious that the student performance after the PBL session was recognizably above the performance after the TL session. Descriptive statistics revealed that the students answered (on average) about 2.6 more questions correctly after PBL (M = 7.79; SD = 1.62) as compared to TL (M = 5.17; SD = 1.30). The Box-plot also shows (a) that there are no outliers in either group, and (b) minor ceiling effects due to the good performance of the students after the problem-based-learning session.



The two teaching methods were compared using a t-test. It confirmed a significantly better student performance after PBL as compared to TL ($t_{(45)} = 6.10$, $p < 0.001$).

To ensure that the performance of the students was not barely due to chance, one-sample t-tests were carried out for either group with 2.5 as expected value (from 10 questions with 4 response options, 2.5 should be answered correctly by chance). It revealed that for either group, performance exceeded chance (TL: $t_{(22)} = 9.85$, $p < 0.001$; PBL: $t_{(23)} = 16.06$, $p < 0.001$).

Although there was no quantitative assessment, individual verbal feedback from individual students indicated that they preferred the session that used PBL methodology.

Discussion

The results reveal that the student performance significantly improved as a consequence of adopting a problem-based learning (PBL) as compared to a traditional learning (TL) approach. This result concurs with the wealth of studies that document the effectiveness of PBL (Bonney, 2015; Jonassen & Hung, 2012; Thistlethwaite et al., 2012), even though – mainly due to limitations of time and ressources that are discussed in more detail below – the current study also can not be regarded as "high quality evidence" in the sense of Newman (2003).

The current study provides evidence particularly regarding the short-term effectiveness of PBL. It is planned to further assess the long-term effectiveness comparing the final-exam-performance on the topics taught in the two teaching sessions that were part of the current study.

Performance measurement should be complemented by questionnaires assessing the preference of the students for either teaching method as well as their impression regarding which method was better suited to transfer the knowledge and make it stick. Unfortunately, it would have been difficult to fit a more comprehensive assessment in a 90-min teaching session. Thus, we decided that the performance on the multiple-choice-questions where the students had to reproduce and apply content taught in the session would be a more valid measure than their preferences and feelings regarding the teaching style.

There are also some limitations to the current study, most importantly that it did not follow a fully "experimental" design. However, this would have taken more time and resources as were available for the current project. It would be desirable to repeat the intervention with a reversed assignment between learning methodology and lecture topic (i.e., using the traditional learning approach for the "Pharmaceutical solutions" lecture, and the problem-based learning approach for the "Solids and dissolution" lecture). An experimental design would also better allow controlling for other factors in the environment (e.g., position of the lecture within the semester [and hence different workload of the students over the course of the semester]; day-to-day-performance-fluctuations within the students, etc.).

References

Bonney, K. M. (2015). Case Study Teaching Method Improves Student Performance and Perceptions of Learning Gains. *Journal of Microbiology & Biology Education*, *16*(1), 21–28. DOI: 10.1128/jmbe.v16i1.846

Culpin, V., Scott, H. (2011). The effectiveness of a live case study approach: Increasing knowledge and understanding of 'hard' versus 'soft' skills in executive education. *Management Learning, 43*(5), 565-577. DOI: 10.1177/1350507611431530.

Hung, W., Jonassen, D. H., Liu, R. (2008). Problem-based learning. In M. Spector, D. Merrill, J. van Merrienboer, & M. Driscoll (Eds.), *Handbook of research on educational communications and technology* (3rd ed., pp. 485–506). New York: Erlbaum.

Gholami, M., Moghadam, P. K., Mohammadipoor, F., Tarahi, M. J., Sak, M., Toulabi, T., Pour, A. H. H. Comparing the effects of problem-based learning and the traditional lecture method on critical thinking skills and metacognitive awareness in nursing students in a critical care nursing course. *Nurse Education Today, 45*, 16-21. DOI: 10.1016/j.nedt.2016.06.007.

Jonassen, D. H., Hung, W. (2012). Problem-Based Learning. In Norbert M. Seel (Ed.), Encyclopedia of the Sciences of Learning (pp. 2687-2690). Boston: Springer. DOI: 10.1007/978-1-4419-1428-6_210.

Nair, S. P., Shah, T., Seth, S., Pandit, N., & Shah, G. V. (2013). Case Based Learning: A Method for Better Understanding of Biochemistry in Medical Students. *Journal of Clinical and Diagnostic Research* , *7*(8), 1576–1578. DOI: 10.7860/JCDR/2013/5795.3212

Newman, M. (2003). A pilot systematic review and meta-analysis on the effectiveness of problem-based learning. http://files.eric.ed.gov/fulltext/ED476146.pdf

Onyon, C. (2012). Problem-based learning: a review of the educational and psychological theory. The Clinical Teacher, 9, 22–26. DOI: 10.1111/j.1743-498X.2011.00501.x

Rayner, A. (2005). Reflections on context-based science teaching: a case study of physics for students of physiotherapy. *Proceedings of The Australian Conference on Science and Mathematics Education*. https://openjournals.library.sydney.edu.au/index.php/IISME/article/view/6476

Sanson-Fisher R. W., & Lynagh, M., C. (2005). Problem-based learning: A dissemination success story? Medical Journal of Australia, 183(5), 258-260.

Thistlethwaite, J. E., Davies, D., Ekeocha, S., Kidd, J. M., MacDougall, C., Matthews, P., Purkis, J., Clay, D., (2012). The effectiveness of case-based learning in health professional education. A BEME systematic review: BEME Guide No. 23. Medical Teacher, 34, e421-e444. DOI: 10.3109/0142159X.2012.680939.

Appendix

Lecture slides on MittUIB

"Solids and dissolution": https://mitt.uib.no/courses/7013/files/folder/Lectures?preview=432921

"Pharmaceutical solution": https://mitt.uib.no/courses/7013/files/folder/Lectures?preview=558391

Questionnaires

Learning outcome assessment "Solids and dissolution"

1. Which of these drugs ionize?
[A] neither acids nor bases [B] only acids [C] only bases [D] both acids and bases

2. What is pH?
[A] $+\lg [H^+]$ [B] $+\lg [OH^-]$ [C] $-\lg [H^+]$ [D] $-\lg [OH^-]$

3. If we have a K_a of 4 x 10-4, a pH of 5 and an S0 of 0.02, what would be the solubility?
[A] 0.82 [B] 0.5 [C] 8.2 [D] 0.05

4. What is a buffer solution?
[A] a mixture of a weak acid and its conjugate base
[B] a mixture of a weak acid with water
[C] a mixture of a base with water
[D] a mixture of a salt with water

5. What is a typical range of buffer capacity in pharmaceutical solutions?
[A] between 0.001 and 0.01
[B] between 0.05 and 0.5
[C] between 0.1 and 1
[D] between 0.01 and 0.1

6. What is the correct interpretation of the van Slyke equation?
[A] the buffer capacity increases with the buffer concentration
[B] the buffer capacity increases with the dissociation constant K_a
[C] the buffer capacity increases with the H^+ concentration
[D] the buffer capacity is irrelevant for the buffer concentration

7. If you have a pH of 9, which buffer solution would you use?
[A] HCl and Kcl
[B] H_3BO_3, NaOH and KCl
[C] HCl and $C_8H_5KO_4$
[D] NaOH and C_2H_5OH

8. What is the relation between particle size and solubility?
[A] larger particles lead to lower solubility
[B] smaller particles lead to lower solubility
[C] larger particles lead to higher solubility
[D] the particle size doesn't influence the solubility

9. What does the term isotonic describe?
[A] isotonic has the same meaning as iso-osmotic
[B] the solution has a higher osmotic pressure inside the cell membrane
[C] the solution has a higher osmotic pressure outside the cell membrane
[D] the solution has the same osmotic pressure across the cell membrane

10. You want 10 ml of tobramycin 1% ophthalmological solution. You have tobramycin 40 mg / ml solution, as well as some NaCl in crystalline form. Tobramycin's MW is 468, so you calculate the E to be 0.07. How much tobramycin solution and how much NaCl do you need?
[A] 5 ml tobramycin and 41 mg of NaCl
[B] 8 ml tobramycin and 8.2 mg of NaCl
[C] 2.5 ml tobramycin and 82 mg of NaCl
[D] 2 ml tobramycin and 410 mg of NaCl

Learning outcome assessment "Pharmaceutical solution"

1. If particles are not arranged in a repeating, long-range order, how is this state called?
[A] Crystalline [B] Amorphous [C] Polymorphous [D] Hydrates

2. What is NOT a common type of crystal lattice for drugs?
[A] Orthorhombic [B] Monoclinic [C] Triclinic [D] Trigonal

3. What are crystalline materials?
[A] Crystalline materials are solids and have only one possible arrangement of their molecules.
[B] Crystalline materials may be liquids and have a disordered arrangement of their molecules.
[C] Crystalline materials may be liquids and have an ordered arrangement of their molecules.
[D] Crystalline materials are solids and have an ordered arrangement of their molecules.

4. Which one of the following statements is FALSE?
[A] The hydrate form of a drug has an ordered arrangement of its molecules.
[B] Nedocromil magnesium heptahydrate has seven molecules of water present for every one molecule of Nedocromil magnesium.
[C] Within the crystal lattice of the hydrate form of a drug, water interacts via non-covalent bonding with the molecules of the drug.
[D] The hydrate forms of a drug tend to have a higher aqueous solubility than the corresponding crystalline non-hydrate form.

5. What is the correct diffusion coefficient of β-casein in water and at 25°C.
Constants: Radius of β-casein: 75 Å; Gas constant: 8.314 kg K^{-1} m^2 s^{-2} $mol^{-1;}$ Viscosity of water: 10^{-3} kg m^{-1} s^{-1}; Avogadro constant: 6.02214 x 10^{23} mol^{-1}
[A] 2.9 x 10^{-7} m^2 s^{-1} [B] 2.9 x 10^{-11} mm^2 s^{-1} [C] 2.9 x 10^{-11} m^2 s^{-1} [D] 2.9 x 10^{-11} km^2 s^{-1}

6. Calculate the dissolution rate of campothecin!
Physical characteristics: Surface area: 2.5 x 103 cm^2; saturated solubility: 0.35 mg / mL (at room temperature); diffusion coefficient: 1.75 x 10^{-7} cm^2 / s; thickness of diffusion layer: 1.25 µm concentration of drug in the bulk: 2.1 x 10^{-4} mg / ml.
[A] 1.22 mg / s [B] 1.22 µg / s [C] 1.53 mg / s [D] 1.53 µg / s

7. What would the rate of dissolution be if the surface area was increased to 4.3 x 104 cm^2?
For physical characteristics see previous question.
[A] 21 µg / sec [B] 21 mg / sec [C] 26 µg / sec [D] 26 mg / sec

8. How would temperature affect drug dissolution?
[A] if the temperature rises, this doesn't affect the dissolution rate
[B] if the temperature rises, the dissolution rate increases
[C] if the temperature falls, the dissolution rate increases
[D] all answers above are wrong

9. Based on the Higuchi model, which comment is correct?
[A] drug release is proportional to time
[B] drug release is proportional to the square of time
[C] drug release is proportional to the square root of time
[D] drug release is exponential to time

10. For drugs in which class of the biopharmaceutics classification system (BCS) can we use dissolution tests to evaluate absorption?
[A] Class I [B] Class II [C] Class III [D] Class IV