Research Article

Pharmacology through Play: using Lego® to revise core concepts for undergraduates [version 1]

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Abstract
This article was migrated. The article was marked as recommended. Background: Pharmacology, while critical knowledge for healthcare professionals, is often viewed by students as dry and difficult to understand. We sought to examine the student acceptability of a Lego®-based learning session, in an attempt to improve pharmacology learning.

Methods: In line with constructivist theories, students were facilitated to build, in small groups, their own Lego® shape to represent an area of core pharmacology and to use this to explain the concept to other students (e.g. agonist-receptor interactions). The validated Course Experience Questionnaire (CEQ) was used to gauge students’ ideas on the session. Multiple choice questions were used before and after the session to evaluate knowledge.

Results: Most students were positive regarding the session, finding it enjoyable, relevant for their learning and even recommending it be used to explore more complex areas of pharmacology. In addition, there was a significant increase in the MCQ scores following the session.

Conclusions: This study used constructivist theory to develop a novel teaching intervention to create a more student-centred, active learning environment. This effective low-cost method could be applied to other teaching programmes to enhance student learning.

Keywords
Pharmacology, Lego®, Constructivist theory, Play, Medical Education

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Introduction

Pharmacology is a core component of any health sciences curriculum, in particular, pharmacy and medicine degrees. There is an ever-expanding body of pharmacological agents falling within the remit of healthcare professionals, particularly pharmacists as recognised medication experts. Without a good grasp of the underlying basic principles of pharmacology, students, and ultimately practicing healthcare professionals, will find it more difficult to integrate this new information and use it to make informed decisions about drug use and therapeutic regimes. It is important therefore to ensure these generic, transferable skills are well taught and understood by students.

Because of the increasing volume of information in the field of pharmacology, there has often been considerable focus on content rather than attending to the learning process, resulting in information overload (Achike and Ogle, 2000). In response, attempts have been made to develop more interactive methods to teach pharmacology in order to promote more active learning and a deeper understanding (Sharma et al., 2004; Zgheib, Simaan and Sabra, 2010). Hence, the teaching of pharmacology has become more learner-centred, with the traditional lecture-based teaching delivered in conjunction with more novel and interactive methods. These mixed approaches are important to ensure students remain engaged with their learning.

One of the mainstays of pharmacology education has always been so-called ‘wet practicals’ involving isolated tissue preparations, whereby students apply their knowledge in a hands-on approach to practical pharmacology. These are particularly useful in demonstrating the basic principles of drug & receptor interaction. However, given the increased expense and ethical issues surrounding such practical laboratory classes, alternatives have to be found. Computer simulations have been used to replace the isolated tissue preparation practical classes (Aaron et al., 1988; Coleman et al., 1995; Dewhurst, Hughes and Williams, 1996; Kuruvilla et al., 2001). However, while a useful alternative, which promotes independent student learning due to the students’ need to organise their own study time effectively (Dewhurst, Macleod and Norris, 2000), the learning could be viewed as being less active as there is no ‘hands-on’ component. It is important, therefore, to develop new approaches of teaching pharmacology that incorporate active learning tasks and thereby allow students to form and implement their learning more easily.

Numerous studies have shown that allowing students to explore and construct objects to demonstrate their understanding leads to deeper learning of the concepts. Hobby kits and toys, such as Meccano®, have been used in the teaching of engineering and more broadly in the teaching of STEM subjects (Parkin, 2002; Das, Yost and Krishnan, 2010). In pharmacology, to illustrate different concepts, novel methods have been used such as simulated role play (Richardson and Maddock, 2013), the use of crosswords (Gaikwad and Tankhiwale, 2012) and even pharmacology songs (MacDonald and Saarti, 2006). Linked with the use of objects, and stemming from a consideration of how young children learn, play has been shown to enhance learning and, consequently, life-long learning through life-long play has been advocated (Farne, 2005). This so-called “Pedagogy of Play” has its basis in constructivist theories and could be a useful active learning technique to apply in the pharmacology class. Furthermore, combining this with group work and peer-demonstration/teaching, which have been widely demonstrated to be effective teaching methods (Krych et al., 2005; Letassy et al., 2008; Beatty et al., 2009), should lead to an active and supportive learning environment which will further the students’ understanding and application of the basic principles of pharmacology.

The theory of constructivism, as articulated by Piaget (Piaget, 1971), is concerned with active learning whereby students create and further their own understanding through their own perceptions and experiences. The overall aim of this study was to introduce and evaluate a novel teaching method based on constructivism and using Lego® for play, to complement the existing teaching of the basic principles of pharmacology and to aid pharmacy student learning. The intervention used elements of play, teamwork and peer-teaching to revise core concepts in pharmacology.

Methods

We hypothesised that students would benefit from a constructivist educational intervention through increased understanding and ability to apply their knowledge of the basic principles of pharmacology.

The objectives of this study were framed according to the principles of educational evaluation developed by Kirkpatrick (Kirkpatrick and Kirkpatrick, 2007; Kirkpatrick and Kirkpatrick, 2016).

1. Reaction/Perception: To examine the feasibility of using Lego® to revise core pharmacology topics.

2. Learning/Outcome: To determine the acceptability of the use of Lego® as a teaching tool for students and the impact on learning.
Sample
Students were recruited from second and third year Pharmacy classes. For normal teaching and academic purposes, these students are routinely allocated to two groups (A&B).

While participation in this novel optional activity was voluntary, it was scheduled as part of the students’ normal timetable. Volunteers in each group, from both the second and third years, on attending the teaching session, were randomised and anonymised through allocation of a study number (drawn ‘out of a hat’) (Figure 1). The intervention was conducted in two sittings, with the second immediately following the first.

The intervention
The focus of the session was to help student learning by providing the opportunity to recall and re-imagine their understanding of the basic concepts of pharmacology (see below). Through group work, and subsequent peer-led teaching, the students refined and shared their knowledge of core pharmacology concepts.

Students answered a 30-question multiple choice (MCQ) assessment on the core principles of pharmacology, selected from an existing MCQ bank. This allowed the establishment of baseline knowledge prior to the learning session which then had the following format:

- Overview of structure, learning outcomes and approaches to the session
- Directed play time focused on one assigned area of pharmacology (agonist-receptor interactions (ionotropic receptors); agonist-receptor interactions (metabotropic receptors); competitive antagonists; non-competitive antagonists; partial agonists; inverse agonists). Plastic building blocks (Lego®), were used during the session to allow the students to work together to create a Lego® construction that helped them to understand and describe their assigned area of pharmacology.
- Presentation to peers of each student groups’ understanding of their assigned area of pharmacology with questions asked by other students and the facilitator.
- Students then sat the same MCQ at the conclusion of the session. The purpose of the MCQ was to gauge, through analysis of individual’s results, whether or not there was an improvement in MCQ scores as a result of the
session. After the session, students were invited to complete an online questionnaire, (5-point Likert scale and free-text answers), to gauge their perception and the acceptability of the teaching intervention.

Ethical considerations
All participants were provided information regarding the session, via an independent gatekeeper, and subsequently, gave informed consent before participating as required by the institution’s Research Ethics Committee and the Declaration of Helsinki (1964).

Data analysis
A paired t-test was used to compare individual students’ scores in the MCQ assessment before and after the intervention (Barry, O’Sullivan and McCarthy, 2015). This pragmatic approach, with a short timespan around the timing of the MCQs and the use of the same instrument, was adopted to identify change as a result of the intervention.

The validated Course Experience Questionnaire (CEQ) was used to examine students’ acceptance of the novel method and a self-assessment of their own learning as a result of the session, it included negatively scored questions (Ramsden, 1991; Wilson, Lizzio and Ramsden, 1997). Most questions were scored on a 5-point Likert scale (1=strongly agree to 5=strongly disagree). Students were asked for free-text responses to three questions concerning; what worked well in this session, suggested improvements, and perceived value.

Results/Analysis
Participation was high (73% and 77% of the total 2nd and 3rd year students respectively) and all students engaged in the Lego® play with considerable interaction within the groups. The two cohorts of students were broadly similar in terms of demographics. The entire second year class had a mean age (± standard deviation) of 21.1 ± 2.7 with 39% male students and EU:non:EU ratio of 5:1 compared to third year 21.5 ± 2.3, 30% male and 2.64:1 (EU:non-EU). These proportions were not statistically different between the two groups (p=0.33 and p=0.19; gender and nationality respectively).

Lego® Constructions
Each group of students made a Lego® creation to represent their assigned area of pharmacology. While some created models similar to illustrations found in pharmacology texts, most groups created very different objects that explained the concept in an unusual but understandable and memorable manner. Figure 2a & b shows the creations of two groups, which were used to explain the action of agonists on ionotropic receptors and inverse agonists respectively. These models were novel and based on the students’ own re-imagining of the function of receptors.

Course Experience Questionnaire (CEQ)
Student response rate was 43% (32 of 74 who attended the session). This was in line with other surveys conducted within the institution and also in line with other published online surveys of teaching (average 33%) (Nulty, 2008). Responses to the set questions (Table 1) show the Lego® session was very positively received with the majority of students agreeing or strongly agreeing with most statements. Students appreciated the style of the session, particularly the interactive student/lecturer style (84% agreed or strongly agreed), and reported that the session aided their understanding of the basic concepts of pharmacology (76% agreed or strongly agreed; Table 1).

In their free-text responses when asked what worked well, students were extremely positive, commenting that ‘the unusual methods used in this session made it very engaging and for the majority of the time it didn’t even feel as though we were trying to understand difficult concepts’ (student #7) and ‘the Legos were fun to work with and the fact that we had
to think of how we were going to represent our knowledge through them is what I think helped us remember the concepts better (student #29).

Regarding improvements, there were useful suggestions around sequencing, ensuring that this intervention is timetabled closer to the teaching of the core concepts of pharmacology (these comments were mainly from the Year 3 Pharmacy students). Students found the session useful and applicable to other areas commenting that they would like ‘more time with the Legos’ and it could cover ‘further topics not just agonists and antagonists’ (students #10 and #12, respectively).

Finally, the answer to the third question (Do you think this session would fit well with other parts of the Pharmacy course and be of value to Pharmacy students?) was a resounding ‘yes’. Students thought it could be ‘an easier way to learn the topics and solidify the key concepts’ (student #27) and that ‘it could provide a practical, hands-on method of learning to compliment the abstract theoretical aspects of our course’ (student #18). One student voiced a contradictory opinion the he/she would ‘just get frustrated with the small fiddly Lego pieces but perhaps for others it might be beneficial but not for me’ (student #25) but this contrasted with another student who stated that he/she is ‘a kinaesthetic learner, [and] this session helped [him/her] remember basic concepts from recalling the shape of the Legos’ (student #2).

Figure 2. Photographs of sample Lego® models constructed by students to explain basic pharmacology concepts during the play session. A) Ionotropic receptors B) Inverse agonists.

Figure 3. Graph illustrating the improvement in MCQ scores following the Lego® play session for both 2nd and 3rd year pharmacy students. Mean ± SEM. ** p<0.01; *** p<0.001 (paired t-test).
The other beneficial element of the session that was apparent from the student feedback was around peer-learning. Students appreciated both peer learning and interactive learning and that the simple explanations used helped learning as ‘other peoples’ understanding often helps as lecturers can sometimes complicate an example whereas peers tend to simplify it right down so it’s easier to remember’ (student #19).

**Pre-, post-MCQ assessment**
There was a significant improvement in MCQ scores following the Lego® play intervention (p<0.001, Figure 3) and Year 2 students showed a greater improvement compared to the Year 3 students (7.6% (p<0.001); 4.4% (p<0.01)). This was consistent with the questionnaire responses and free text in which the students reported benefit to their learning (Table 1 and above).

**Costs**
Two “classic large creative brick” Lego® boxes were used for the session, costing €40 each. This initial, once-off outlay could continue to be used for future sessions. In addition, employed staff costs can be estimated and would represent a recurring cost. To estimate this, the pay rate for individual external lecturers was used, meaning that to run this session, the estimated cost was €5.19 per student. Going forward, the only recurring costs would be those of staff and occasionally replacing the Lego®.

**Discussion**
This study has demonstrated a novel approach to the revision of core concepts in pharmacology that could be utilised in any programme where pharmacology is taught. Focussing on constructivist theory and using group work and peer-teaching, we used Lego® building blocks as a teaching tool which the students clearly enjoyed and felt was applicable and beneficial to their studies. Engagement with the session was high. In addition to their perceptions, we demonstrated that the intervention had a beneficial impact improving their MCQ scores. Furthermore, this offers a cost-effective method for increasing active learning, useful for large numbers of students.

In the healthcare setting, as care models of practice evolve, healthcare professionals, and in particular pharmacists, are expected to be able to provide expert knowledge on drug action and interaction. Therefore, it is vital that the core concepts of pharmacology are effectively taught to ensure that students and qualified professionals are able to integrate and utilise all of the information that depends on them. We have demonstrated that using Lego® building blocks, to allow the students to explore and share their understanding of basic pharmacology, improved performance in an MCQ knowledge test. Furthermore, the students reported that the play session was interesting, enjoyable and supported their learning.

The need to engage students in their own learning has been recognised for some time but the move from purely lecture based teaching has been slow in pharmacology. Poor retention of knowledge from lectures is high: McKeachie showed students can, on average, only recall 70% of the material from the first 10 minutes of a lecture, dropping to 20% of the content from the final 10 minutes (McKeachie, 1986). While there are caveats e.g. individual differences in attention or whether retention would be reflected in student notes (Wilson and Korn, 2007), it nonetheless highlights the need to engage students in different ways to improve their attention, engagement and learning. More recent evidence has shown even lower retention, with Bligh finding students recalled less than 10% after three days (Bligh, 2000).

A review from 2009 by Jungnickel and co-workers examined pharmacy practice and the development of future competencies with recommendations for the education of pharmacists. One highlight was the need for student- or learner-centred teaching, with the suggestion that problem-based learning (PBL) may be one method to achieve this (Jungnickel et al., 2009). Certainly there is evidence that PBL helps student engagement (Galvao et al., 2014) as do other learning strategies that have been widely investigated in pharmacy and other healthcare education programme. These include process-oriented guided inquiry learning (POGIL), clicker or audience response systems and team-based learning (Beatty et al., 2009; Soltis et al., 2015; Stevens et al., 2017). The key feature with all of these is that they are active, rather than passive, forms of learning and all attempt to reduce the extraneous cognitive load.

Our intervention uses a combination approach to the active learning session. The first part was a hands-on, active play session allowing the students to construct a representation of their understanding. This aligns with the constructivism as the students demonstrated their own understanding with their Lego® construction but also in the way they create new understanding through their interaction with other students (Piaget, 1951; Piaget, 1971). Similarly, our intervention aligns with the constructionist view on the development of knowledge (inspired by constructivism and developed by Papert) in that it is student centred, involves discovery learning with tangible objects that allows the students to build something to represent and further their knowledge and understanding (Papert and Harel, 1991). It is also evident in the creation of the Lego® models as their understanding and meaning is personal to them (Bruner and Anglin, 1973).
addition, we used elements of peer-led team learning, which has also been extensively evaluated in undergraduate science and health science programmes (Preszler, 2009; Walpola et al., 2015). Peer-led teaching and team work allows students to engage with each other and to enhance their learning in a supportive environment (Eberlein et al., 2008), which has been demonstrated to benefit some students, and in particular students’ critical thinking skills (Lewis, 2011; Wilson and Varma-Nelson, 2016). The freetext comments provided by the students clearly illustrate the value they placed on the peer-led aspect of this intervention, further underlining its importance.

The decision to use Lego® was based on growing literature around the importance of play as a learning tool and also the recent use of Lego® as a management tool to explain and understand processes - Lego® Serious Play® (Frick, Tardini and Cantoni, 2013). Play is important for learning, not just in children, but through life, as long as it is appropriate play, building on constructivist and constructionist theories (Piaget, 1951; Papert and Harel, 1991). Lego® Serious Play® was built on these principles and has been used in business settings to allow people to, for example, understand the management structure and functioning of an office or department. Linked with this use are the theories around the mind-hand connection and haptic feedback that is received during play or construction (Roos and Victor, 1999; PLAY, 2002; Chang and Yeh, 2015). These all contribute to the understanding and learning of the concepts. Furthermore Lego® has been used to stimulate reflective practice on teamwork skills in the third level setting (Seidl, 2017). Other authors used Lego® Serious Play® to allow pharmacy students to explore definitions of professionalism (Wilson and Becket, 2012). Our session used many of the same principles but applied them to a different area of learning and has further highlighted the value of a hands-on experience in science education (Felder, 1993).

The final advantage of this technique was its cost effectiveness. All teaching establishments have embraced technology-enhanced learning (TEL), but striving to use the latest technologies has significant cost associated with them, particularly set-up costs. Indeed, to study drug receptor interactions, 3D virtual environments and 3D printing have both been used (Richardson et al., 2013; Hall et al., 2017). Given the additional cost of human time it was surprising that more authors do not comment on cost effectiveness of novel teaching interventions. Costs and resources have hardly been explored to date although potential frameworks have been long proposed: Carpenter (Carpenter, 1995) (personnel, standardised patients and administrative), Reznik (Reznik et al., 1993) (development, production, administration and analysis), and Poenaru (Poenaru et al., 1997) (costs of materials, indirect costs e.g. salaries). When it comes to technologies, the argument for cost effectiveness is usually based on the long-term use of the technology and applicability to other areas, thus mitigating costs (Lewis, 2014). Certainly in the case of Lego® it is both cheap and applicable to different areas.

Limitations
We used Kirkpatrick to frame our research question (Kirkpatrick and Kirkpatrick, 2007). While there has been debate over its suitability to examine interventions in medical education (Yardley and Dornan, 2012), we felt that it was applicable for our intervention, particularly after Kirkpatrick’s recent revision (Kirkpatrick and Kirkpatrick, 2016).

While a crossover design with a control group may be ideal, it was not possible in this situation with an already finalised annual timetable. Furthermore, it was not feasible in the timeframe of this study to track results over a longer time span, as it is anticipated that active learning techniques have a long-term positive impact on student examination scores (Ernst and Colthorpe, 2008). However, evidence has shown that the use of Lego®, albeit in a different context, has provided long lasting and significant learning (Harding and D’Eon, 2001). Both of these (crossover and longitudinal tracking) should be investigated in future work and also extrapolated to examine other healthcare professions. While the students’ results showed an improvement in MCQ score, as the same set of questions was used, one cannot rule out a test-retest phenomenon, however, what is most encouraging is the student-reported responses to the use of Lego®, which was overwhelmingly positive. Finally the interpretation of the results is influenced by the fact that the students were self-selected. The session formed part of their normal teaching schedule and while the attendance reflected normal tutorial attendance levels amongst our students, it must be remembered that the students decided themselves to attend the teaching session.

Conclusion
Students had a positive response to the introduction of the Lego® session and felt they benefitted from it through improved understanding. This was evident in the improvement in MCQ scores following the Lego® intervention. Furthermore, significant effort is going in to developing novel teaching techniques, often taking advantage of cutting-edge technology, such as simulation and other Technology Enhanced Learning approaches. This study illustrates the possibility of using Lego® as a cost-effective tool in the teaching of pharmacology, but this should not be restrictive and other areas of healthcare education could well benefit from its use as an additional student-centred learning activity, particularly due to its engagement, cost and accessibility.
Take Home Messages

- Lego and other construction based tools are effective for teaching complex subjects to health professions students
- Pharmacy students enjoy the Lego based intervention, which improves their engagement with pharmacology as a subject
- The Lego based intervention improves pharmacology knowledge
- The Lego based intervention offers a low-cost option for learner-centred teaching in health professions education institutions

Notes On Contributors

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Declarations

The author has declared that there are no conflicts of interest.

Ethics Statement

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This is an interesting and well written paper. The authors have used Lego bricks in a group activity to help students learn complex abstract concepts in pharmacology. They have used Lego bricks to explore the topic of agonist receptor interactions. They have also shown two examples of the student creations. If possible, the student groups can explain their models and how it illustrates the particular concept, which will be very interesting. The methodology of the study is well described. The administration of the second set of MCQs immediately after the activity can influence the results. As the authors rightly point out the activity can be expanded to other areas and other groups of students. Peer learning in groups is a powerful learning modality. Here the groups also manipulate Lego bricks to create their own understanding of the concept. The other major advantage is that the activity is relatively cheap compared to more high technology learning options.

**Competing Interests:** No conflicts of interest were disclosed.
This review has been migrated. The reviewer awarded 2 stars out of 5

Many thanks to the authors for this interesting, if rather brief, article describing an innovative approach to active learning. The authors have provided a considered introduction outlining some of the supporting evidence and theory behind the approach and an effective discussion setting the findings in the context of current research in this area. The study design requires some improvements, and a further limitation to consider would be with respect to pre-post testing. The MCQ post-test was identical to the pre-test, so students may have been targeting their learning to those specific questions in the session and this approach may therefore only be testing their short-term memory of those questions. As the authors state, a long-term follow up would also be important. Furthermore, cross-over design is not essential for a valid experimental educational research study. An alternative activity could be used for the control session (i.e. how the authors would otherwise deliver this session or an alternative active 3D approach, as suggested by another reviewer) for a different but related topic, which is delivered to the entire cohort. This would ensure equitable access for all students. The authors would then compare the difference between both pre and post test scores (i.e. learning performance) for the intervention and control. Additionally, any novel intervention is perhaps likely to provide positive feedback from students. I would like to have seen deeper and richer exploration of the cognitive and constructivist elements and learning value of the approach from the student perspective, perhaps through focus groups and/or semi-structured interviews.

**Competing Interests:** No conflicts of interest were disclosed.

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Peter Dieter
AMSE

This review has been migrated. The reviewer awarded 2 stars out of 5

The authors examined the student acceptability of a Lego®-based learning session in an attempt to improve pharmacology learning. Most students were positive regarding the session, finding it enjoyable, relevant for their learning and even recommending it be used to explore more complex areas of pharmacology. In addition, there was a significant increase in the MCQ scores following the session. The study used constructivist theory to develop a novel teaching intervention to create a more student-centered, active learning environment. This effective low-cost method could be applied to other teaching programs to enhance student learning. A major concern is that the authors did not compare their method
with other methods with respect to effectiveness and costs.

**Competing Interests:** No conflicts of interest were disclosed.

**Reviewer Report 15 November 2019**

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**Simonetta Ausoni**  
Department of Biomedical Sciences- University of Padova- School of Medicine

This review has been migrated. The reviewer awarded 3 stars out of 5

This is an interesting paper showing how knowledge in pharmacology can be improved with the application of the Pedagogy of Play. In particular, the authors used Lego as a easy-to-use and cheap method of representation to develop the ability to conceptualize complex issues of pharmacology. Students’ feedback is extremely positive and the assessment shows significant improvement. I think that the paper is an example of good practice and I strongly agree that the teaching of scientific disciplines is very much learner-centered and minimally opened to practice. My major concern is that I do not see the advantages of this approach as compared to other models of representation, such as 3D construction. Although costs of Lego is very low, I am sure that there are many cheap programs that can be used to assist this learning activity. 3D construction could improve molecular shapes, place names to molecular subunits, ions etc., in addition to being computer savable.

**Competing Interests:** No conflicts of interest were disclosed.

**Reviewer Report 14 November 2019**

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**Felix Silwimba**  
University of Lusaka

This review has been migrated. The reviewer awarded 5 stars out of 5
this is a clearly written illustrative research report on medical education involving a difficult topic to explain in pharmacology. It has clearly demonstrated use of low cost affordable teaching aid. Its methods are applicable everywhere. I recommend the study to medical educators in low-middle income countries.

**Competing Interests:** No conflicts of interest were disclosed.