6

Building Knowledge and Learning Communities Using LEGO® in Nursing

Rachel Stead, Ralitsa Dimitrova, Avgi Pourgoura, Sarah Roberts and Sarah West

Introduction

This chapter explores the potential of LEGO® and adapted LEGO® SERIOUS PLAY® (LSP) activities to deepen critical engagement and encourage inclusive classroom-based activities. Two case studies are presented here involving final-year undergraduate nursing students. Both are examples of collaborative action research projects. The first, within Child Nursing, utilises a care scenario for holistic care planning in preparation for a written exam. The second, within Adult Nursing, uses the Personal Tutor Group (PTG) setting to explore feelings around preparing to embark upon the final year of study and, in particular, the undergraduate dissertation. Both case studies address anxieties around transitioning to higher level academic and professional work beyond university.

R. Stead (✉) · R. Dimitrova · A. Pourgoura
University of Surrey, Guildford, UK
e-mail: r.stead@surrey.ac.uk

S. Roberts · S. West
School of Health Sciences, University of Surrey, Guildford, UK

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The two co-enquiry teams for these case studies were composed of Nursing Teaching Fellows, a faculty Learning Developer, and a student research partner. We also view the student participants in the workshops as partners in the co-construction of knowledge and of communities of learning through their participation and valuable insights. The chapter is co-authored by the staff and student research partners from the co-enquiry teams, who worked closely in their analysis of the findings and their reflections on both the learning approaches and the partnership. We adopt the Healey, Flint, and Harrington (2014) principles as a model on which to base our student–staff partnership.

LEGO® SERIOUS PLAY®

LSP has its roots in the corporate sector as a strategic and creative thinking tool (Frick, Tardini, & Cantoni, 2013). It is gaining increasing attention within higher education (HE) as an innovative approach to unlocking and building knowledge. It is through the construction of LEGO® models, and the subsequent discussion and deep critical reflection, that new knowledge is created (Gauntlett, 2013). LSP is underpinned by psychological theories of learning, and draws on constructionism, play theory, imagination and the hand–mind connection (Frick et al., 2013). A constructionist philosophy of learning (Papert & Harel, 1991) expounds that we learn best by making physical representations or stories of our abstract ideas, and then examining, discussing and reflecting upon them. This creative process, sometimes referred to as "concrete thinking", reveals the interplay between the hands and brain in guiding a wide range of cognitive and emotional, as well as physical processes (Wilson, 1999). LSP draws on our tacit knowledge, or as in Jung's (in Gauntlett, 2007) terms, our "creative unconscious" and the "significant truths" that lie within it. Jung argued that it is engagement in creative activities, which provides opportunities to draw out these "significant truths" from the depths of the unconscious mind, and through this to gain fresh insights leading to the construction of new knowledge.

Whilst traditional epistemology tends to treat abstract knowledge as somehow superior in form (Papert & Harel, 1991), a fundamental principle of constructionism by contrast is the complementary nature of concrete and abstract thinking, or what Sotto (2007) terms holistic thinking, in the building of knowledge. This has a deep resonance with Maton's (2013) notion of knowledge building in semantic waves and, in particular, what he terms "semantic gravity": the extent to which information is dependent on a specific context. Good teaching allows students to move up and down between concrete and highly contextualised examples to more abstract, conceptual, ideas, which are independent of context in order to build cumulative knowledge, enabling students to build on their previous knowledge and understanding and transfer this to future contexts. Maton (2014) sees the mastery of semantic gravity, the ability to move between these types of knowledge, as key to success in meaningful learning.

LSP has been shown to encourage lateral thinking amongst students through a systematic process of building, sharing and deep critical reflection (James & Brookfield, 2014; Peabody & Noyes, 2017). According to Barton and James (2017), due to the fluid, incremental and generative nature of the approach, whereby participants both build upon existing and construct new ideas, LSP and other LEGO® building activities can enable learning to occur in more agile and spontaneous ways. The LSP methodology is suited to exploring a wide variety of complex issues, or "wicked problems", in multiple educational contexts (James, 2018). A number of examples of LSP being used to explore personal identities and aspects of personal and professional development in HE can be found in the literature (Gauntlett, 2007; James, 2013), as well as engaging with key learning skills such as critical reflection (Cavaliero, 2017; Peabody & Noyes, 2017). More recently, studies have begun to explore the benefits of LSP for subject learning gain (McNamara, 2018) and conceptual understanding of disciplinary threshold concepts (Barton & James, 2017).

A growing body of evidence strongly advocates playful learning approaches across the learning lifecycle, because of the wide range of cognitive, emotional and social benefits (Holliday, Statler, & Flanders, 2005; Kane, 2004). LEGO® is particularly useful as a learning tool, according to McCusker (2014, p. 34), because it is an "easily manipulated mediating artefact", which actively invites people to engage in play. The higher order cognitive processes of analysing, evaluating and creating new knowledge (see Bloom's revised taxonomy in Krathwohl, 2002) are activated during play through having the freedom to take risks, to test out new scenarios and to explore different ways of working (Holliday et al., 2005; James, 2015). LSP appeals not only to the cognitive but also to the affective domains of learning, enabling reflection upon values, beliefs, relationships and self-awareness (Valiga, 2014). This is enabled via the social and emotional activities of closely working in teams for the purposes of co-construction, which requires active listening, dialogue and receptiveness to the perspectives of others. This, according to both Hayes (2016) and Nerantzi, Moravej, and Johnson (2015), helps to build strong learning communities. Hayes (2016) sums up the key benefits of using LSP in her teaching with Health Care Assistants as enabling students to move from superficial engagement to deeper levels of engagement with their learning. She argues that LSP encourages the development of active meaning-making, at the same time as discouraging passive learning approaches (Hayes, 2016).

Ensuring Pedagogic Value

Some academics may be wary of engaging with LSP because the activities cannot be designed with a prescribed set of outcomes (Barton & James, 2017; James, 2018) as has become apparent from our observations. However, there was careful consideration of programme outcomes during the collaborative design stages to ensure pedagogic value, and appropriate levels of "complexity and robustness" (James & Nerantzi, 2019) to ensure meaningful learning. Gauntlett (2013) sets out the key guiding principles of LSP:

- Challenges should have no obvious or expected answer
- Individuals should respond to challenges before groups
- Everyone should build and share
- There are no right and wrong ways to build

- Models are what the builder says they are
- The focus of the discussion should always be the model and not the builder
- What counts is the meaning assigned to the model by the builder, so allow plenty of time for sharing and reflection.

Contexts and Rationale for Using an Adapted LSP Approach

The setting for the first case study is a Child Nursing module focusing on the challenges of working with children and young people with complex illness, in partnership with their families. The students are assessed formatively and summatively via an exam consisting of unseen questions relating to a seen scenario. One sought after consequence of effective nurse education is the ability to link theory to practice, often referred to as "application to practice" (Allan, Smith, & O'Driscoll, 2011). Rolfe (1993) identifies that a theory/practice gap is felt most keenly by student nurses who are faced with clinical scenarios but may lack experience to apply theory accurately. This may result in knowledge remaining abstract. It was felt that the use of LEGO® activities would allow students to engage with and make sense of the scenario as a more holistic and three-dimensional proposition (James, 2015).

To meet the learning outcomes, the scenario needed to be multifaceted, including issues around both physical health and the psychosocial aspects of care. Research has shown that LSP can add real value in inquiry-based learning, particularly for encouraging deeper critical engagement with case-based scenarios (Hayes, 2016). Anecdotal evidence from similar workshops suggests improvements in criticality and a reduction in support required by the cohort for their exam, a possible indicator of increased confidence in their learning. Other important benefits of embedding such playful practice in HE learning environments include allowing students to explore their own and others' perspectives on key elements of practice, to both reflect on the value of what they and others do, and experience transformations in their thinking (James, 2018).

These benefits are also key to rationale behind the second case study with two PTGs of final-year Adult Nursing students. Making the transition to the final year of a nursing degree can present numerous challenges. These may include feelings of anxiety and stress (Chernomas & Shapiro, 2013), as well as uncertainties about life after graduation, or what Gale and Parker (2014) have termed "transition as becoming". These feelings, coupled with a lack of confidence in undertaking a dissertation, mean that the PTGs are intended to be a source of support for and discussion around the diversity of issues students experience. However, the staff report a lack of engagement and the unwillingness of some students to bring ideas for discussion to the groups, leaving a gap in which students often expect more teaching.

Building LEGO® models about students' perceptions of their identities or anxieties can be useful for discussion and reflection (Gauntlett, 2007). A trial of this approach in 2017, using LEGO® modelling to stimulate dialogue within the Adult Nursing PTGs, generated positive feedback from students and tutors, and suggested enrichment of discussions around shared anxieties about the final year and tackling a dissertation. Both these case studies share a focus on engaging students in their learning and addressing anxieties, and in both we explore the role of adapted LSP activities in engaging students in playful activities to deal with serious issues. Using LSP has been described as a "paradox of intentionality" by Statler, Heracleous, and Jacobs (2011, p. 237), which means deliberate engagement in an activity which is not only fun and intrinsically motivating but has serious work objectives that are of extrinsic value to those participating. Serious Play techniques work particularly well, according to James (2015), in contexts where players are mutually invested in their learning with a strong, shared sense of purpose, resonating with Csikszentmihalyi's (2000) notion that only artificial boundaries exist between work and play. The Child Nursing cohort used this approach as an aid to critical engagement with health care scenarios in preparation for their exam, and the Adult Nurses explored the way in which LSP can facilitate engagement with the PTG system.

An additional shared focus is the value of building learning communities. The students in both groups did not know each other well, so building group cohesion and facilitating lines of communication was also key to the sessions. Evidence from Peabody and Noyes (2017) suggests that positioning this type of session early in the semester, as with ours, can aid the building of communities of learning for the year ahead. Anecdotal evidence from workshops at Surrey, and published studies have shown that activities of this nature can help to foster a sense of community; for example, Nerantzi et al. (2015) showed a strengthening of learning relationships, both with peers and tutors, as well as fostering a sense of belonging amongst students. These factors, according to Lear, Ansorge, and Steckelberg (2010) and Zhao and Kuh (2004), can have a positive effect on student engagement in learning.

The Workshops

Child Nursing

After a short individual skills-building task (Gauntlett, 2013), a multi-faceted scenario centred around an adolescent male with epilepsy and his parents was introduced to the students as the basis for the main activity. In small groups, the students were tasked with building a model representing the complexities of the care needs of the child and his family (see Fig. 6.1). During a 15-minute building stage, the student–staff partnership team facilitated and observed the building process of unpacking the scenario to bring it to life. The process is not dissimilar to the process of using semantic waves (Maton, 2013), in which a teacher will move from a specific scenario to less context-dependent but highly relevant concepts and theories, and then return to the scenario to give these more meaning.

Groups shared with the room the factors they had included in their models and were encouraged to reflect on both the concepts and underpinning theory. Discussions also centred around which particular ideas had been afforded significance in consideration of colour, positioning and metaphor. In the final stage of the workshop, each student was given an action planning template, based on Driscol's reflective model. It was intended that the final reflection and revision planning stage would allow the students to make sense of their models, link clearly to the scenario, and help them formulate a meaningful revision plan.

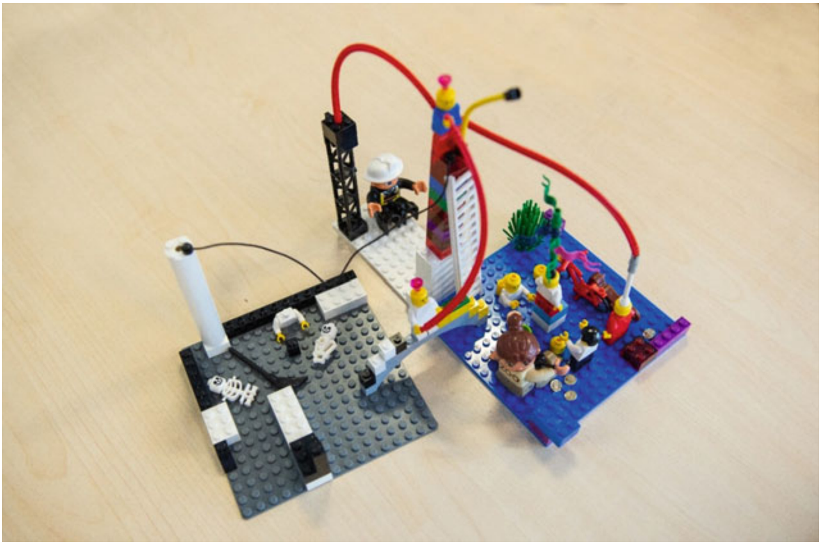

Fig. 6.1 An example of a Child Nursing group model showing clear distinctions between child (colourful, fun, better resourced, nurturing—on the right) and adult (black and white, scary—on the left) care services—an outcome that emerged through the building process showing emotions related to making the transition

During the session, the students engaged readily with the LEGO® and in lively, collaborative discussion. A minority of the students lacked confidence in building but engaged regardless. Students used LEGO® bricks to represent the child, family, healthcare professionals and the environment in which they felt they existed. There were some consistent themes between groups such as transition to adult services and the complexity of epilepsy as a condition, but the groups addressed the scenario differently, meaning that each group had something to add at the feedback stage, effectively layering their ideas in increments using the interpretation of their peers, in a way that is consistent with the generative nature of LSP (Barton & James, 2017) and is reflected in individual feedback comments.

The whole cohort of 41 students attended the session, all reporting feeling fully engaged in their learning and valuing the collaborative nature of the activity. Assessments are often the most pressing consideration for a student embarking on a new module, so it was reassuring that we received multiple responses relating directly to the way in which our session scaffolded their learning and revision for their exam. Responses included, "I have a better understanding of what is required for the scenario exam", "it was a creative approach to getting us to discuss issues for our exam" and "it was both group work and assignment help – very engaging". 32 out of 41 students reported that there was nothing about the session they did not enjoy. Of the nine who mentioned dislikes, these related to anxiety around speaking in class despite knowing it was good for their development, wanting more information about the exam, or not fully understanding the relevance of the activities.

Adult Nursing

Two groups of Adult Nursing students were invited by their personal tutors to their first PTGs of the year. The workshop was designed around students engaging in two individual building activities: the first to build their ideal dissertation supervisor (see Fig. 6.2) and the second, a model

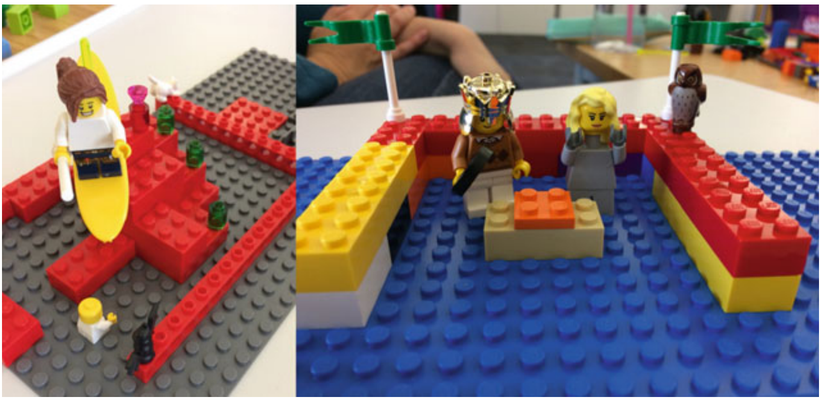

Fig. 6.2 Examples of models from two Adult Nursing students depicting disparate perceptions of the role of the dissertation supervisor. On the left, supervisor as "super surfer" and student as LEGO® baby looking up at her. On the right, supervisor wearing a crown but in partnership with the student

representing their feelings about embarking upon their final year. Again, our role was to circulate throughout the activities and talk to the students about their models. As the groups were small, everyone agreed to feedback individually to the whole group.

Minor apprehension was noted amongst a few students at the beginning of the session. However, in the main, students were enthusiastic and willing to discuss ideas and feelings openly. Some creative metaphors for the supervisor relationship were revealed. Examples include supervisor as "font of all knowledge", as a "superhero", with "buckets of knowledge", having a "clear head". These were often presented as either physically larger or positioned higher than the student. A few students depicted the notion of being guided, or "steered". Less common in the models was the notion of true partnership. A total of 22 students attended in two PTGs, all of whom stated in feedback that they felt the LEGO® had a positive impact on their learning. The vast majority of challenges identified for the year ahead related to undertaking a dissertation. However, the models also proved a useful conduit to discussions around accessing support. The tutors from the faculty reported finding it significantly more engaging than their usual PTG format.

Written evaluations were collected from all participants immediately following the workshops in both case studies, and individual semi-structured interviews with volunteers were conducted a week later.

Findings

Besides the high self-reported levels of engagement in both these studies, clear shared ideas emerged from our analysis of student responses around the construction of knowledge and collaborative learning. It is clear from the themes below that our activities enabled the more tacit elements of knowledge to come to the fore, emphasising the seriousness of the learning which can be enabled through play. Connecting and sharing was another core theme running through the findings. Interestingly, whether the students were building individually or collaboratively, the sharing of knowledge and perspectives and anxieties with others was central to the sense of enjoyment and engagement with their learning.

"Without the LEGO®, I think we would have just presented our grown-up, adult self"

One student observed that the use of LEGO® removed the assumptions about the purpose of the group, that utilising a non-verbal technique bypassed the cognitive part of her that would give the automatic responses that may be expected. Some of the comments from interviews and evaluations from both case studies suggest that the LEGO® activities were able to access the more tacit aspects of the students' knowledge and experience, their "significant truths", as supported by the work of Schwind (2003, p. 25) who found that encouraging creative self-expression amongst nursing students can "elicit the depths of our being unreachable by words". Responses included, for example "It brought out things that I didn't know I knew". The students often commented on not initially considering the significance behind their models: the creative process occurring first, then the meaning emerging during the building process, as previous similar studies have found (e.g. Stead, 2019).

This was supported by other comments stating that the models enabled the students to think about issues they had not previously considered, allowing "honest and authentic feelings to come out". Another student remarked that when she was building individually, she was thinking about what she wanted rather than being influenced by the thoughts of others, which can happen in open discussions, enabling "a thought-through rather than automatic response". This took her in more directions when discussing other students' models and highlights the importance of individual building and reflection time (Gauntlett, 2013).

Two student models of their ideal supervisor (see Fig. 6.2) reflected polarised expectations, but significantly they were also the opposite of that which they would have expected themselves to construct. One student's model reflected that she would like the relationship to be a supportive partnership and a sharing of ideas. However, when questioned about this afterwards, she stated that she had been surprised by her model, because if asked verbally, she would have expressed the desire for someone to "mother" her and look after her. Conversely, the other student expressed that her "adult-self" would have responded to a direct question about her ideal supervisor by saying that she wanted it to be an equal partnership, when her model reflected the opposite. The model suggested that the supervisor was a font of all knowledge, a "superhero", and was of a higher status than her, who she had portrayed as a baby. The use of LEGO® enabled feelings to be expressed that the students were not aware of (Schwind, 2003).

"*Using something as simple as LEGO® to represent more complex ideas*"
Reflecting the inherently paradoxical nature of LSP, as discussed in Statler et al. (2011) and Peabody and Noyes (2017), insightful comments such as the above suggest the depth of meaning that can be built from simple tools. Indeed, one student in her interview commented that her group were "still relating to certain bricks" after the session, which not only highlights the memorable nature of modelling approaches such as LSP (James, 2013) but the deep meanings which can be assigned to individual LEGO® bricks. Related to this is the idea of generative knowledge building and meaning-making (Barton & James, 2017), reflected in comments such as, "being able to … watch each issue spring off of the previous".

Many responses revolved around notions of depth of thought, with students commenting on the complex nature of the scenario. This suggests that a deeper level of critical engagement, necessary for final-year academic and professional practice, was involved in addressing the building challenge, or as one student termed it, "unpicking what you're thinking". Other comments included, for example: "it stimulated thinking and encouraged breaking down of the scenario" and "it has allowed me to…view it as a complex piece". The high volume of responses we received linked to the ideas in this theme are reflective of the literature.

"*Everybody had a chance to express their opinion*"
Inclusion was a strong theme within the students' feedback. It was clear that they felt the LEGO® activities played a key role in encouraging the full participation of everyone in the session, with multiple responses to support this such as: "everyone added a building block to the final model", "each given a chance to speak and communicate ideas" and "all added our thoughts to the scenario". Inclusion is explored by Peabody and Noyes (2017), and McCusker (2019), and is key to the underpinning philosophy of LSP in its ability to address what Kristiansen and Rasmussen (2014) refer to as 20-80 syndrome where 80% of ideas tend

to come from only the more assertive and confident 20% of the room. It is clear that LEGO® works well at levelling the playing field and enabling quieter students to participate in discussions.

One student shared in her interview that:

> we usually tend to be quiet as a group. The LEGO® was a fun way to interact with each other and get to know each other in a less mainstream way. LEGO® made the lecture less formal, so I had the confidence to discuss in my group.

Interestingly, all students in these activities appreciated being asked to explain the meanings behind their models, despite some initial anxieties around speaking, which support previous studies in terms of inclusion and the enabling of quieter students' participation (McCusker, 2019).

"*Everyone got that opportunity to open up and show their concerns, but it wasn't daunting*"
Many of the students suggested that the use of a fun LEGO® activity allowed them to explore their fears and anxieties, mirroring the literature that discusses LSP's paradoxical quality (Peabody & Noyes, 2017; Statler et al., 2011). The students commented on the ease of being able to open up and discuss each other's models in a relaxed way, "tak[ing] the discussion in directions that [they] may not have felt able to in a more formal group discussion", which also supports findings from earlier studies (Stead, 2019).

The few concerns expressed by students, and which echo previous studies (see Peabody & Noyes, 2017; Stead, 2019), relate to feelings of discomfort and challenge felt by some students. This chimes with Mezirow's (1991) notion of a disorienting dilemma, which is so fundamental to transformation in learning. As seen from the evidence above, however, even those students with initial concerns felt more comfortable once they began building. One student remarked that she was not normally proficient at expressing her feelings but found it easier to explain them visually. Another student observed that using an object as a discussion point helped them to express themselves: "you can distance yourself from it like in creative therapy", supporting one of LSP's key principles of focussing on the model not the person (Gauntlett, 2013).

What was also evident from the findings is the students' discovery that many of their fears were shared. Comments included: "nice to hear that I'm not the only one feeling overwhelmed", "we could share common feelings such as fears and expectations" and "everyone got that opportunity to open up and show their concerns, but it wasn't daunting". One student reported that the process actually helped her to "come to terms with [her] thoughts and feelings". They also appreciated the chance to interact with both peers and tutors, strengthening learning relationships and fostering a sense of community as previously reported by Nerantzi et al. (2015).

"*We built a model that everyone agreed on*"

Notably, when revealing what they had enjoyed most, 75% of students in the Child Nursing workshop highlighted their enjoyment of the interaction within their group, despite this not being directly asked in the evaluations. Listening to everyone's ideas and building models that everyone agreed on were also cited, as well as gaining insights into the thought processes of others. Previous research by both Peabody and Noyes (2017) and Nerantzi et al. (2015) found that LSP had a positive effect on group cohesion, helping to build strong learning communities. Students also reported enjoying working with peers that they would not normally work with, explaining that, "after the session, we carried on talking about our model", indicating both deep cognitive engagement with the activities themselves and group cohesion beyond the session.

"*When you built it, it became a real person…makes you realise how complicated a life is*"

Another significant finding which emerged from the Child Nurses' feedback on their modelling of scenarios is that of linking theory to practice. In the individual interviews, students identified that using LEGO® to build the scenario allowed clear linking of the theory underpinning the care of a young person with epilepsy with all the practical aspects of care which this might involve, a clear indication of connections being formed in their thinking processes and of addressing the theory practice gap in nurse education (Allan et al., 2011). This backs up Cavaliero's (2017) study in which students made a working model of their practice using LEGO® as a tool for thinking. Another student particularly valued using the LEGO® as an opportunity to provoke critical and creative thinking about holistic care. Schwind et al. (2014) argue strongly for creating such opportunities that foster reflection, critical thinking and personal knowing as these are key to the development of person-centred and holistic care.

One legitimate concern raised was that building models which involve exploring unconscious issues may become very personal very quickly. One student expressed that when using creative activities, individuals may be fast-forwarded into intensely unexpected personal feelings, which may not be appropriate to share in a PTG setting. We have noted the importance of applying boundaries to the tutor group session, such as limiting the discussion to the course, and to signpost students to support following the group if any personal issues need further discussion individually.

Conclusions

LEGO® SERIOUS PLAY® encourages effective, collaborative, knowledge building and enables the visualisation of ideas which may otherwise have remained unexplored and their potential untapped. It is also an excellent medium through which student nurses can connect theory with its practical application. LEGO® can empower students to connect and share their ideas, feelings and perspectives in a non-threatening, inclusive environment. Using models to represent personal or professional practice allows individuals to explore and critically reflect upon their meanings objectively, and thus upon their own and others' practice. Such playful pedagogies not only promote deeper engagement with classroom-based learning, but also allow students to gain a better understanding of the shared experiences of their peers in order to feel more supported through the potential challenges of their final year.

Reflective Vignette

The Student Perspective

We believe that student–staff partnerships are successful when all members communicate effectively and are honest about how much they can contribute to the partnership. One of the biggest challenges of being in a student role in this type of partnership is the perceived conventional hierarchy of power, especially at the early stages. So effective communication is key to be able to break down the wall created by these conventional relationships and ensure that the power is distributed appropriately.

At the beginning of this process we were not aware of what to expect. It took some time to feel secure and express our opinions, which is not surprising. However, staff having confidence in us was empowering and encouraged us to be more active partners. It is very important that everyone feels included and fairly treated. We felt that these concepts were present within our research team and overall that it was a safe environment to share thoughts and feelings, which motivated us to work harder and succeed. The most important thing is that everyone benefits in some way and learns something new. For example, it has helped in our understanding of the process of conducting a piece of research, particularly applying taught knowledge of qualitative methods. This experience and the transferable skills we learned will help us both, for one of us in our dissertation next year and for both of us in our futures beyond university.

Staff Perspective

It is evident, looking back on the projects, that we did not set clear enough expectations of the partnership at the start. This has been a new experience for all involved, and, therefore, some valuable lessons have been learned for future partnerships. These mainly revolve around establishing clear roles and trying to break down cultural and disciplinary barriers and power relations. Some parts of the project more than others have clearly reflected the partnership principles identified by Healey et al. (2014), particularly in facilitating the workshops and analysing and discussing the data we collected, and in *planning and co-delivering two conference presentations of our project. These aspects felt truly collaborative.*

It was clear at times, but unsurprising, that the students did not see themselves as equal partners. However, we can see now that equal partnerships are not realistic, and we should be seeking equitable ones instead, where roles are distributed fairly, but not necessarily equally. This would be a more inclusive approach to partnership. Whilst we did not foresee the level of support the students might need in some situations, we have also been extremely impressed in others with their willingness to make suggestions inspired by their own disciplines. It was interesting to be at the receiving end of student-led challenges, in a significant shift in the balance of power, moving us temporarily out of our comfort zones: a sensation often experienced by our own students.

One revelation through this project is the extent to which LSP, and the adapted LSP activities we created for this research, shares a set of common values with student–staff partnership. The key principles and participant etiquette map closely to Healey et al.'s (2014) student partnership principles of inclusivity, community, trust, responsibility, reciprocity, empowerment, authenticity and challenge.

Inclusivity in LSP is about levelling the playing field for all participants, and as discussed, evidence strongly points to its ability to draw in inputs from quieter participants. Community and trust represent sharing, listening to others and accepting meanings, building honest dialogue in a safe environment and embracing the perspectives and experiences of all parties, who all feel a sense of belonging to and ownership of the process of building. Ownership of the learning process links closely with the notions of responsibility and reciprocity: LSP is wholly person-centred and requires full investment in the activities in a truly learner-centric way, but also requires equal investment which is necessary for the success of LSP activities (James, 2015). LSP embodies the principle of empowerment by rejecting the notion of external experts and beginning with the assumption that the answers are already in the room (Gauntlett, 2013). This closely ties in with the principles of authenticity, through both the authentic reasons to strive to improve practice, and the honest responses which LSP is able to elicit. In partnership, all parties are encouraged to constructively critique practice, in the same way that LSP allows freedom to take risks in a safe environment—in our context exploring *both scenarios and relationships to enable clearer, holistic perspectives and to question how things could be done better, to enable new ways of working.*

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7

3D Printers in Engineering Education

Atefeh Eslahi, Deoraj R. Chadeesingh, Charlotte Foreman and Esat Alpay

Introduction

The world is moving towards simpler, faster and more effective methods of chemical, component and material production, fuelled by the technological transformations of Industry 4.0 (see Lu, 2017). Accurate and precise approaches in manufacturing are revolutionising the design and operation of industry processes, with wide impact across product sectors (Despeisse et al., 2017). Within this transformation, the emergence of

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A. Eslahi · C. Foreman
University of Surrey, Guildford, UK
e-mail: c.foreman@surrey.ac.uk

D. R. Chadeesingh
Department of Chemical and Process Engineering, University of Surrey, Guildford, UK

E. Alpay (✉)
Faculty of Engineering and Physical Sciences, University of Surrey, Guildford, UK
e-mail: e.alpay@surrey.ac.uk

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3D printing (3DP), and more generally additive manufacturing (Additive Manufacturing UK, 2017; Dickens, Reeves, & Hague, 2012; European Commission, 2014; U.A.M.S. Group, 2016), has played an important role, significantly improving design (prototyping) and efficient component production (Simpson, Williams, & Hripko, 2017). Accordingly, a need has arisen for training in the use of 3DP as a design, development and manufacturing tool.

Such printers are becoming increasingly common in education, as exemplified by the UK's Department for Education report on their use in schools for "enriching the teaching of STEM and design subjects" (Department for Education, 2013). Likewise, high-impact initiatives are being reported in higher education (HE) contexts, including prototype development, design exploration and component/molecular/process visualisation. Although initial HE applications have had a natural affinity towards mechanical and structural engineering programmes, diverse and cross-discipline applications in areas such as medical and bio-engineering (e.g. tissue scaffolds), food processing (e.g. food printing) and more generally chemical product engineering are rapidly emerging. Moreover, the integration of 3DP into engineering curricula is leading to an interest in pedagogy, and specifically innovative approaches to enhance teaching quality and the student learning experience. How the technology can be used effectively in teaching and learning contexts, whilst maintaining its accessibility to students and teachers that do not have rigorous knowledge of computer-aided design (CAD) software, remains a challenge.

The focus of the research reported in this chapter is to explore literature, evidence and student perspectives on the value of 3DP in engineering education. Specifically, the following research question is being considered: what benefits do students perceive of 3DP in engineering education? A novelty of the work has been to consider 3DP use in engineering education contexts outside that of the mechanical/structural disciplines, i.e. a move away from the usual *printing of a design prototype* common in mechanical engineering design. As such, the study should be of broad relevance to educators across the disciplines.

Educational Use of 3D Printers

An extensive literature review on the use of 3D printers in education has been recently published by Ford and Minshall (2019). In addition to school and university classroom/laboratory settings, the authors also identify their growing use within library and special education settings. For example, libraries are "a logical choice to house technology that has many potential users…[and offer]…a valuable service to their organisations while raising awareness of the other services they offer as well" (Hoy, 2013). Across education levels, 3DP is allowing students to discover new interests in technology, and is similarly providing educators with new methods of engaging students. It has also provided a medium to facilitate student creativity (Bøhn, 1997; Horowitz & Schultz, 2014; Paio, Eloy, Rato, Resende, & de Oliveira, 2012; Stamper & Dekker, 2000), and empower pupils to physically create objects that aid their understanding. At the early stages of education, 3DP is also exposing children to technology, potentially changing attitudes towards study and work in science and engineering. As importantly, and valid across the education sector, 3DP can provide opportunities for low-cost component production for teaching purposes (Blikstein, 2013; Bull, Chiu, Berry, Lipson, & Xie, 2014; Bull, Haj-Hariri, Atkins, & Moran,2015; Chery, Mburu, Ward, & Fontecchio, 2015; Dumond et al., 2014; Eisenberg, 2013; Jacobs et al., 2016), providing effective replacement to real (e.g. industrial, medical, laboratory) components/equipment for demonstration and study purposes.

In response to educational needs, leading 3D printer manufacturers have developed specialised machines for such use. Nevertheless, the first step is for both teachers and students to acquire the skills needed for printing, e.g. how to convert a drawing/object into a digital format for printing, and the manipulation (modelling) of such digital formats for novel constructions. In doing so, students are also being introduced to (computer-aided) design principles, material properties and testing and developing skills in spatial awareness and visualisation (Corum & Garofalo, 2015; Huleihil, 2017). However, programme changes may be needed to accommodate the skill base necessary for projects involving

3DP and the library approach mentioned above may provide some technical support here.

Not surprisingly, the STEM disciplines are at the forefront of 3DP use (see Ford & Minshall, 2019). Success within these disciplines often requires a genuine interest in technological advancement, and there is an onus on educators to foster such enthusiasm through engaging and stimulating methods. 3DP provides one such example of stimulating technological engagement, with tangible design outputs. In engineering this has predominantly focused on design projects (Abreu et al., 2014; Bilen, Wheeler, & Bock, 2015; Butkus, Starke, Dacunto, & Quell, 2016; Carpenter, Yakmyshyn, Micher, & Locke, 2016; Reggia, Calabro, & Albrecht, 2015; Serdar, 2016). More generally, engineering concepts can be taught through physical analogues, allowing students to better grasp such knowledge through deeper engagement with the theoretical principles (c.f. problem-based learning, Chiu, Lai, Fan, & Cheng, 2015; Williams & Seepersad, 2012). Indeed, engineering students are often motivated in turning ideas to real-life objects that can be inspected, analysed and used as a springboard for further design improvement.

In the engineering disciplines, the ability to print parts for testing and as visual aids can be highly advantageous for engineering students. The relative ease of production allows rapid prototyping and modelling. Visual aids are powerful in explaining concepts and encouraging problem solving through spotting flaws, to be able to improve the designs to overcome a design flaw. This develops the students' skills in research and development in product design, but also, more fundamentally, serves as an introduction to the critical area of digital manufacturing, i.e. the use of an integrated, computer-based system comprising 3D visualisation and collaboration tools to create a product and manufacturing process (Go & Hart, 2016).

3DP brings new opportunities for a new style of learning. Studies show that students do not all respond to the same style of teaching, but rather, based on their educational needs, respond positively to several different styles of learning (Fernandes & Simoes, 2016; Minetola, Iuliano, Bassoli, & Gatto, 2015). 3DP can give rise to new and more interactive approaches to learning where it includes developmental learning, allowing students to draw their own conclusions and lessons learned, rather than theoretically teaching the concepts. This is already evident in teaching methods at university level where engineering students must carry out lab experiments and write reports on their findings. It is through designing and carrying out their own experiments that students really grasp theories and make leaps in their understanding (Loy, 2014). The use of a 3D printer can take experiments a step further where students print their own parts and carry out tests to elucidate theories and engineering laws. Furthermore, students can develop creative presentational skills through physical visualisation methods. In a related way, 3D technology can be extensively used in artistic ways (Chiu et al., 2015; de Sampaio et al., 2013), through the creation of unique and engaging pieces as a possible means of, for example, public engagement (and outreach) in STEM through an artistic (and visual) expression of underlying scientific and engineering principles.

3DP is extensively used in industry for rapid development of parts and tools. Predominant use is made in the car (and general transport) industry for rapid prototyping of mechanical and other functional components (Cunningham, 2019). Personal communication with manufacturing experts in BMW (UK) has made it apparent that 3DP technology has been revolutionary for their predevelopment models, helping to readily modify old parts for performance enhancement, and offering greater flexibility in manufacturing options. For example, one of the main issues with parts is the angles that allow a part to be made and fitted onto the vehicles and 3DP has solved this issue altogether. 3DP has also overcome tooling requirements, i.e. the tools required to fix specific parts onto vehicles can be directly printed for that specific application, opening a wide spectrum of new manufacturing possibilities. In addition, in precise-layer-by layer 3DP, the amount of waste in product manufacturing is reduced. The nature of such industrial use is of much relevance to general engineering education, related to, for example, material science, digital modelling, 3D visualisation and the "conceive, design, implement and operate" (CDIO) teaching and learning ethos that dominates in the mechanical/structural engineering disciplines (see CDIO, 2019), but much less so in the chemical and biological engineering fields.

Methodology

3DP in engineering education is a relatively new area that requires further research to explore its broad and potential uses. In this work, the research design focused on student, work placement and recent graduate attitudes towards 3DP in education (taken together as two main participant groups: students, and work placement students and recent graduates). For participants in employment, the study was conducted at BMW Group Plant (Oxford, UK), i.e. the current work-placement location of the student research partner in this study. Although the industrial location is automobile manufacturing-focused, the participants had broad disciplinary backgrounds (see below), and the study thus allowed reflection upon university education and employment preparation in the context of a sector where 3DP is being used extensively.

For university participants, the study was conducted in the Department of Chemical and Process Engineering at the University of Surrey. Similar to other chemical engineering departments, 3DP does not feature within the undergraduate curriculum, although it is anticipated that most students will have some basic awareness of the technology. The study thus allowed investigation of student attitudes on the potential use and benefits of 3DP in an engineering discipline not conventionally associated with the technology.

With reference to Table 7.1, a questionnaire was designed to explore the level of awareness and experience of 3DP (Q2–Q6) and perceptions of the value of 3DP in disciplinary knowledge and skills support (Q8–Q10). As indicated in the table, several questions employed a 4-point Likert scale to gauge perceived benefit. A qualitative response for one question (Q8) provided the main student input on potential learning value of 3DP. The questionnaire was administered electronically using SurveyMonkey. A general email with the survey link was sent to all students (FHEQ levels 4–7) across the undergraduate programmes in Chemical Engineering, i.e. an approximate cohort size of 350 students. Direct emails were also sent to relevant industry-based participants, i.e. approximately 40 individuals. The placement students are all in their penultimate year of study and thus fairly knowledgeable about their discipline.

Table 7.1 Summary of the 3DP Awareness and Benefits Questionnaire

Question	Response options
1. Choose your university degree from the options below. If it's not on the option list, please state your degree in the comment box.	
2. What's the extent of your knowledge of how 3D printing works?	4-point scale: {I know the technical details as well as applications; I do not know how it works but know the applications; I have a rough idea of how it works and general applications; I have no idea}
3. Which of the following 3D printing types do you know?	Multiple selection: {fused deposition modelling; stereo-lithograph; digital light processing; selective laser sintering; selective laser melting; laminated object manufacturing; digital beam melting; none of the above}
4. In which of these sectors do you think 3D printing is used?	Multiple selection: {automotive; medical; infrastructure and architecture; chemical; education; art; film and entertainment}
5. Have you used 3D printers at University?	{yes; no}
6. Have you used 3D printers on work placement (where relevant)?	{yes; no; not relevant}
7. Have you used computer aided design (CAD) software in your degree or elsewhere?	{yes; no}
8. Would you like to be trained on the uses of 3D printing as part of the degree curriculum? If so, please explain how 3D printing could be used to help your learning.	{yes; no; comment box}
9. How do you think the use of 3D printers might benefit the following aspects of your degree? {lecture-based modules; laboratory work; design work; computing and simulation}	4-point scale: {not beneficial; could be beneficial; beneficial; very beneficial}
10. How do you think the use of 3D printers might benefit the following skills? {team work; problem solving; analysis; creativity; technical skills; leadership}	4-point scale: {not beneficial; could be beneficial; beneficial; very beneficial}

Results and Discussion

80 participants completed the survey, 48 based at the University of Surrey and 32 at BMW. 15% of the participants were from a mechanical engineering background, 60% from chemical engineering (all university-based) and the remainder distributed across a broad range of disciplines including electrical engineering, aerospace and aeronautical engineering, industrial engineering, computer science, mathematics and sport science, product design engineering, economics, international business management and international events management. Discipline and university/employment cohort variations in response were tested for questions 4, 8, 9 and 10 in the questionnaire; however, no significant differences were noted, suggesting general positive acceptance of the value and relevance of 3DP.

80% of respondents had some awareness of 3D printers, with half reporting a "rough idea of how 3D printing works". Technical knowledge dominated amongst the mechanical engineering cohort of participants. 64% of the respondents did not recognise any specific type of 3DP. Where knowledge existed, fused deposition modelling (29%) and selective laser sintering (16%) dominated. Interestingly, sintering is a topic that most engineering students encounter in modules related to materials science/engineering, often in the early years of the degree programme. The topic could therefore act as a first (and natural) bridge to 3DP technology. Similarly, module theory could also be extended to materials analysis and stress testing on printed components. There was recognition of wide use of 3DP across different sectors (Q4), with 47% selecting all the listed sectors. The selection ranking of specific sectors (highest to lowest) was recorded as: medical (55.4%), automotive (selected by 54.2% of respondents), art (49.4%), infrastructure and architecture (49.4%), chemical (25.3%), education (32.5%) and film and entertainment (30.1%), indicating a broad appreciation of the potential use of 3DP.

81% of respondents had no university experience of 3DP; only 10% experienced 3DP in their work environment, i.e. 25% of the industry-based participants. Nevertheless, 53.6% of the respondents had experienced CAD in some form, either in their degree programme or other (e.g. school, extracurricular) use. Encouragingly, approximately 78% of the respondents reported a desire for training in 3DP as part of their degree programme, demonstrating widespread interest in the technology and its applications. Not surprisingly, particular benefit to the degree programme was reported for design and computing and simulation work (Q9). However, benefit was also reported for all teaching aspects, with mean responses (on a 4-point scale) of 2.3 for lecture-based modules (81.1% favourable response), 2.7 for laboratory work (83.3% favourable response), 2.9 for computing and simulation work (84.6% favourable response) and 3.2 for design work (94.7% favourable response).

For skills development, low 3DP benefits were reported for teamwork and leadership—an expected trend. Positive benefits were reported for (in decreasing order): creativity (3.4 mean score and 94.6% favourable response), technical skills (3.0; 97.4%), analysis (2.95; 94.8%) and problem solving (2.7; 87.2%). The widespread recognition of 3DP to promote creativity skills is encouraging, especially in (chemical engineering) curricula where creativity tasks may often be confined to paper exercises or 2D simulation software outputs, suggesting that the findings of, e.g. Horowitz and Schultz (2014) are indeed transferable to other disciplines.

A thematic analysis of the respondent comments on question 8 of the survey led to the following general categories of perceived benefits and uses of 3DP in education:

1. Prototyping of equipment in design projects/work (c.f. Bøhn, 1997; Stamper & Dekker, 2000);
2. Material selection and testing for a given application (c.f. Corum & Garofalo, 2015);
3. Physical samples for demonstrations and presentations, e.g. analogues of complex structures, equipment and chemical components, including functional items (c.f. Williams & Seepersad, 2012);
4. Demonstration of industrial additive manufacturing principles (c.f. Go & Hart, 2016; Williams & Seepersad, 2012);
5. A support tool for CAD learning through the printing and analysis of CAD models;
6. Scaled print of a chemical plant, including 3D layout.

Interestingly, with the exception of theme 4, all the themes have generic relevance to the chemical engineering discipline. Comments by students within the chemical engineering department indicated relative ease in transferring 3DP principles to their educational needs, with application examples to process equipment, overall chemical plant design and speciality materials such as column packings and catalysts being readily recognised.

Demonstration and presentation related uses of 3DP received broad mention by the respondents, i.e. alternative tactile teaching resources to complement digital and virtual content. This may be particularly beneficial for the appreciation of scale and magnitude in design components, as well as the visualisation of complex and intricate structures, including the 3D layout of equipment which is often avoided in chemical plant design, but yet can be critical to the operational optimisation and indeed feasibility of the plant (e.g. sea-based oil platforms and mobile plants on ships). Comments also included the production of functional (i.e. operational) components using 3DP that are otherwise often represented as simple schematic diagrams within lectures, or accepted with little critique or analysis within laboratory settings. Indeed, such equipment analogues, once produced, could then be scanned into an immersive virtual reality environment for widespread viewing. Whilst basic (and affordable) 3DP is currently constrained to polymer prints, material science aspects often concern material shape and thickness considerations, such as pressure vessel selection and design in the chemical industry. As indicated by some of the comments, prints of components would provide opportunities for direct, experiment-based application of such material science principles.

Although CAD education in engineering is generally viewed as favourable in supporting design and digital skills development, it is uncommon in chemical engineering curricula. This may be related to the specific output needs for such CAD models, where structural and mechanical design is less important than the identification of, for example, input streams, heat transfer areas and operating conditions. However, the advent of affordable and easily accessible 3DP would provide a relatively easy method of extending process engineering concepts to mechanical principles, fostering in turn engineers with a wider knowledge and skills base and potentially greater role pliability (see also the discussions of Alpay, 2013). The responses from the chemical engineering students in this survey indicate that 3DP would be a favoured approach in bridging (to some extent) such historic differences between engineering disciplines.

In the current job market and the increasing pressures of gaining graduate employability skills, it is important to meet the expectations of employers and industry. 3DP can enhance students' learning journeys and it can also boost valuable employability skills, including practical applications and presentation skills. Skills developed from working with 3DP to create and innovate solutions to problems through design and technology have a place in industry and engineering roles. These roles are associated with methodical and rational processes, but enhanced creativity and imagination add alternative answers and solutions, and this gives more flexibility to the field chosen by engineering graduates.

The study confirms both student and institutional desires to adopt 3DP technology, but has also confirmed relatively slow adoption outside the mechanical and civil engineering disciplines. This in part reflects discipline disparities in the knowledge and skills of 3DP, which is a greater barrier for educational applications outside mechanical and civil engineering. However, with the advent of affordable and simple-to-operate devices, the centralisation of such services within institutions seems a natural progression, e.g. the use of printers within library services as reported by Hoy (2013). Future developments in tools for the easy and intuitive translation of sketches, artefacts and even photographs to printable (and scalable) formats would further open teaching and learning possibilities. In this sense, 3DP technology may provide a readily accessible means of visualising digital lecture/design content, especially where testing is required and so virtual reality-based visualisation does not suffice.

Conclusions

The study has indicated great receptivity towards 3DP in education by students and recent graduates in areas both within and outside engineering disciplines normally associated with 3DP technology. In particular, students in chemical engineering were able to recognise a broad range of 3DP uses to support learning and creative design, supporting literature reports in this area. The inclusion of 3DP itself in teaching would open learning content in areas of CAD, real plant layout and magnitude (scale) appreciation in calculations and design. In doing so, an important bridging between mechanical and non-mechanical based engineering disciplines could be achieved, broadening the knowledge and skills base of the graduates. In a similar way, as engineering curricula evolve in digital literacy and content requirements, the study suggests that 3DP technology provides a practical, visual and engaging medium for consolidating learning across areas such as CAD and rapid prototyping.

Reflective Vignette

Student Perspective (Atefeh Eslahi)

The staff–student partnership on this project has been a great experience and there has been significant learning from this collaboration. As the first experience in this way of working it has been a truly beneficial one; the close partnership has provided much closer supervision and has been engaging in taking ownership and having the freedom to produce original work with guidance and help from the staff. The freedom of developing my own ideas and making suggestions in how to carry out the studies has stimulated creativity and has implemented better understanding on how to articulate a scientific topic in clear and concise manner. The staff experience in writing papers has been crucial for this and there has been substantial guidance and learning. Communication has been vital to the development of this project and the importance of student and staff working together has been highlighted in the gains in mutual understanding and contribution to my professional development. Overall this has been a valuable project and has given *me a significant boost in confidence to work alongside experienced academics in the future.*

Staff Perspective

The concept of staff–student partnerships in education is not new: undergraduate projects supporting academic research are a well-established example. However, such partnerships are less common on matters concerning pedagogy or educational development, especially in the science and engineering disciplines. An advantage here is the direct involvement of the recipients (i.e. students) of the intended learning and teaching initiative, providing continuous feedback into its development from the onset. The partnership also allows early and first-hand gauging of the student interest for an initiative, as well as a closer link to the student body for research evaluation purposes. The experience of this project has reinforced the value of such united educational research within discipline contexts. Perhaps an important extension of the approach however, would be to place projects within existing research project modules, thus potentially widening the scope of the research work and ultimate quality of research-informed educational development.

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