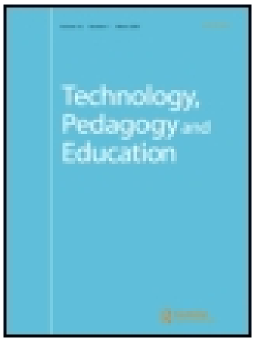

Technology, Pedagogy and Education

ISSN: 1475-939X (Print) 1747-5139 (Online) Journal homepage: https://www.tandfonline.com/loi/rtpe20

Making sense of making: critical issues in the integration of maker education into schools

Anna-Lena Godhe, Patrik Lilja & Neil Selwyn

TECHNOLOGY, PEDAGOGY AND EDUCATION
https://doi.org/10.1080/1475939X.2019.1610040

Making sense of making: critical issues in the integration of maker education into schools

Anna-Lena Godhe[a,b], Patrik Lilja[a,c] and Neil Selwyn[d]

[a]Department of Education, Communication and Learning, University of Gothenburg, Gothenburg, Sweden; [b]Department of Culture, Language and Media, Malmö University, Malmö, Sweden; [c]School of Education, Humanities and Social Sciences, Halmstad University, Halmstad, Sweden; [d]Faculty of Education, Monash University, Clayton, VIC, Australia

ABSTRACT
This article considers growing calls for the integration of so-called 'maker technologies' and associated 'maker' practices into schools and other formal education settings. Moving on from the largely celebratory literature in this area, the article seeks to further explore the tensions between the educational potential of maker technology and the realities of its use in school and classroom contexts. In particular, the article focuses on fundamental – but so far little acknowledged – tensions surrounding the social, cultural, political contexts of maker education, alongside the epistemological and pedagogical characteristics of maker technologies as tools for learning. It is concluded that maker education must not be seen as a ready fit with formal schooling. Instead, teachers and schools are likely to require sustained support to make the most of maker technologies within the demands and constraints of contemporary school contexts.

ARTICLE HISTORY
Received 22 May 2017
Accepted 27 November 2018

KEYWORDS
Schools; digital; maker education; maker technologies

Introduction

This article considers the educational implications of a relatively recent development in digital technology – so-called 'maker technologies'. In particular, the article seeks to contest current enthusiasms for the integration of these technologies and associated 'maker' practices into schools and other formal education settings. As such, the article raises questions that need to be asked of all 'new' technological developments, especially as educational technology begins to move into a 'post device' era where digital technology use diversifies beyond the dominance of laptop/tablet/smartphone use. Now, in an emerging era of the 'Internet of Things', augmented reality and others, it is important for journals such as *Technology Pedagogy and Education* to offer educationally nuanced responses to the ever-diversifying forms of 'digital' technologies that are beginning to enter schools. While many of the issues pertinent to such innovations are long-standing, these 'new waves' of technology also raise additional challenges and tensions. All told, the academic study of technology and education needs to approach developments such as maker education with fresh eyes and inquiring minds.

It is important from the outset to define what we mean by digital forms of maker technology. Recently the 'maker' label has been appropriated by all manner of classroom activities – from the teaching of computer programming through to cooking and gardening. In contrast, 'maker technology' is specifically defined in this article as: (i) the use of digital technologies to facilitate the making of physical objects; and/or (ii) the making of physical objects that incorporate some form of digital technology. The use of 3D printers in conjunction with CAD (computer-assisted

CONTACT Neil Selwyn neil.selwyn@monash.edu

design) software is an obvious example of this first type of 'making'. Conversely, the incorporation of conductive thread and programmable microcomputers into a textiles product is an example of the latter. An important aspect of all digital maker practices is a 'DIY' craft approach that emphasises experimentation and 'tinkering' both with code *and* manual production. Maker technologies are also aligned closely with open-source and hacker practices that support the free sharing of designs and code that can be re-used and improved on by others.

The educational potential of these maker technologies has been discussed widely – especially in terms of the establishment of 'makerspaces' in museums, libraries and youth centres, underpinned by growing support for the concept of out-of-school 'maker education' (Litts, Kafai, Fields, Halverson, & Peppler, 2016). Thus many commentators have welcomed the possible transfer of these tools and technologies into formal school settings as addressing a number of current educational imperatives. These include ongoing pressures to reform schools along the lines of 'twenty-first-century learning', innovation and entrepreneurial thinking (Sefton-Green, 2013). Moreover, maker technologies such as 3D printing are seen to have direct correspondences with emerging fabrication and 'additive manufacturing' industries, and what has been heralded in some quarters as 'industrial revolution 2.0' (Eisenberg, 2013). It is also increasingly presumed that classroom use of maker technologies can strengthen students' skills and knowledge in Science, Technology, Engineering and Mathematics (STEM) subjects appropriate for contemporary industry, higher education, entrepreneurship and innovation (Taylor, 2016). These technologies also chime with the growing 'maker movement' in popular culture that celebrates the craft and creativity of 'making' for oneself (see Halverson & Sheridan, 2014; Luckman, 2016).

To date, critical scrutiny of claims regarding the suitability of maker technologies for schools and other formal education settings has been limited. A handful of studies have offered examples of best practice and exemplar case studies of how maker technologies might be used in classroom contexts (e.g. Kostakis, Niaros, & Giotitsas, 2015). Such studies have tended to focus on ideal conditions for school-based maker education, and in so doing often point toward fundamental changes that need to be made within school structures and processes. These include proposals for classrooms to be reoriented around crowdsourcing, sharing and 'mash-up' practices, alongside disrupting established hierarchical classroom relationships between professionals and amateurs, experts and novices (Ratto & Ree, 2012).

While these analyses offer a useful starting point for the *long-term* rethinking of what role schools can play in an era of 'connected learning' (Ito et al., 2013), they do little to support the implementation of maker technologies in *current* school systems and contexts. Indeed, to date there is little evidence of maker technologies being taken up on a sustained basis across schools – i.e. across a broad range of subject areas and/or by diverse student groups (Taylor, 2016). At best, maker technologies have tended to be introduced into schools by enthusiastic individual teachers, leading to limited localised diffusions of practice. As such, the adoption of maker technologies in individual schools has tended to be sporadic and 'champion led' rather than the result of sustained planning and leadership (see Nemorin & Selwyn, 2017).

This article seeks to further explore the tensions between the potential of maker education and the realities of its enactment in school and classroom contexts. Of course, as with any new innovation in education there are a range of practical, logistical and organisational issues that inevitably compromise the take-up of maker technologies in schools (Cuban, 1988, 2001). These include perennial issues of resourcing, budgeting, teacher skills and/or interest. There are also a number of practical concerns specific to maker technology regarding health and safety as well as intellectual property. Notwithstanding these practical challenges, the present article explores a number of less-acknowledged *conceptual* issues that are also implicated in the implementation of maker education in school contexts. In particular, we focus on fundamental – but so far little-acknowledged – questions of pedagogy, epistemology, culture and politics. Thus the remainder of the article focuses on the three following areas of discussion:

- the challenges of teaching with maker technology;
- the challenges of learning with maker technology;
- the culture and politics of maker technology.

The challenges of teaching with maker technology

New technologies tend to be accompanied into schools with a host of pedagogical expectations. Maker technologies are proving no different, surrounded by a diversity of ideas about recasting the relationships and interactions between teacher and learner. These include the repositioning of the teacher as 'guide at the side' or even 'peer at the rear', as groups of students take collaborative control of their making activities (see Biesta, 2016). A growing number of studies describe the pedagogical shifts required from teachers to support making in the classroom. These include teacher knowledge of materials, tools and processes; strategies for supporting meaning making and the complexification of ideas; and understanding of students' prior knowledge and interests (Brahms, 2014; Gutwill, Hido, & Sindorf, 2015).

While compelling, it could be argued that these expectations nevertheless raise a number of tensions and contradictions about the use of these technologies in a school context. Indeed, these discussions of desirable teacher skills and understandings do not address the broader pedagogic tensions implicit in using maker technologies in the classroom. While popular portrayals of the maker movement often depict it as in opposition to traditional schooling (e.g. Vossoughi, Escudé, Kong, & Hooper, 2013), efforts to establish maker education in schools present a more conciliatory – yet still combative – line. Here, makerspaces are simultaneously portrayed as 'hybrid' pedagogic settings that are at once learner driven *and* arranged around pedagogical episodes such as demonstrations, workshops and feedback (Sheridan et al., 2014; Stornaiuolo & Nichols, 2018). Although taking a pride in being different to (what are seen to be teacher-directed and didactic) classroom practices, the idea of maker education plays on being sufficiently similar to classrooms to make it possible for makerspaces to become part of school practices. The caveat to such claims (as mentioned earlier) is the common argument that schools – rather than makerspaces – need to change and adapt in order to overcome such differences.

It is therefore important to be much clearer on the exact pedagogic and teacher-related aspects of these expected changes. In essence, these challenges centre on the extent to which school pedagogy is capable of being realigned around principles of 'making' rather than 'schooling'. Here, the 'maker' ethos is generally seen to consist of: '*making* as a set of activities, *makerspace* as communities of practice and *makers* as identities of participation' (Halverson & Sheridan, 2014, p. 496). Key notions are creation (i.e. making as a creative process), cooperation (i.e. makerspaces as environments where equals share and learn from each other) and agency (i.e. maker identity connected to personal traits such as innovation and entrepreneurship). Sheridan et al. (2014) reasoned that these principles and processes are an integral element of the successful educational implementation of makerspaces. Students-as-makers should be allowed to 'mess around' and 'tinker' with no finished product in mind, and with not all projects being fully realised. Thus, whereas school classrooms are characterised as spaces with a focus on the acquisition of subject-related knowledge and skills, makerspaces are characterised as spaces where knowledge is used to create things and the creations are shared with others.

A number of serious pedagogic challenges and contradictions arise from the conflation of maker principles and school classroom processes. Activities that support the ideal of the 'classroom-as-makerspace' may challenge what is considered to be a legitimate 'learning' activity since learning can be neither guaranteed nor regulated. Another important difference is that student learning in maker activities is seen to derive primarily from the voluntary nature of the activity. The open-ended, collaborative and experimental nature of making practices can clash with schools' existing curriculum, assessment and organisational priorities (Nemorin & Selwyn, 2017). Indeed, these tensions are apparent in most (non)formal educational contexts. Writing on the challenges of implementing maker technologies in day-long workshops in 'museum spaces' with students from schools where 'project-based learning was the norm', Kafai, Fields, and Searle (2014) were none-theless left to concede that 'a prescribed curriculum, an extremely limited time period, or even students who are unaccustomed to project-based learning are a few of the potential obstacles' (p. 540).

These issues are compounded by the traditional school expectation to standardise and define the learning outcomes that result from classroom processes. While maker activities are not predicated around the achievement of predefined goals, what students do in school settings will be assessed and related to curricular goals sooner or later (Sheridan et al., 2014). Specifying learning 'outcomes' and relating these to curricular 'goals' therefore often becomes a key point of tension when attempting to implement maker activities in a school setting. These tensions are most obvious in terms of assessment of student performance and achievement. In the absence of established measures to provide benchmarks of achievement, teachers and schools understandably find it difficult to account for (and assess) students' making and learning processes. These problems are compounded by the open and iterative ethos of making practices which places emphasis on the using of knowledge amongst equals. Indeed, as pointed out by Dieter and Lovink (2012), formal education relies heavily on individual assessment even though people rarely make things alone. Assessing group work is often considered a challenge for school teachers (and students) because of the difficulty in deciding who has done what. By focusing on the individual, sharing of knowledge in a classroom becomes questionable and could be regarded as cheating. So far, suggested compromises have required radically different (and time-consuming) forms of maker project assessment. For example, in order to capture classroom maker processes, Kafai et al. (2014) used video recordings and photographs of conversations and activities and complemented this with notes and interviews where the students reflected on their collaborative maker activities.

Finally, are challenges of teacher identity and shared understandings of what 'technology' is. For example, there is growing recognition that teachers need experience of being 'makers' themselves. Petrich, Wilkinson, and Bevan (2013) noted the importance of providing opportunities for teachers to experience activities and tools as 'makers' prior to and alongside engaging students in making activities. If the general teacher population is to gain such experiences, substantial professional development will be needed. This would require a substantial shift in the approach of school authorities that have tended to date to invest in technological artefacts rather than in-service training. Perhaps even more challenging is the need to shift teacher perceptions of maker technology devices and artefacts as shared and collaborative in nature. While the 1980s and 1990s supported an ethos of 'shared' computer use, current use of digital devices is avowedly individual and personal in nature. At best, any sense of 'collaborative' technology use relates primarily to online activities. Instead, maker technology use implies a shared ownership of (and control over) devices, artefacts and materials.

The challenges of learning with maker technology

Amidst these pedagogical tensions, it is important to also problematise the specific relationships that maker technologies have with learning in school contexts. Digital technologies are always accompanied into schools with expectations of new possibilities for learning. Maker technologies are no exception, surrounded by a diversity of ideas about learning that nevertheless raise a number of tensions and contradictions about the use of these technologies in a school context. There are three prominent forms of learning that are presumed to be inherent in technology-based making. These are: (i) learning through 'building' material and coded artefacts; (ii) learning through inquiry, experimentation and solving practical problems; (iii) learning through collaborative participation with others. In these ways, maker education is commonly presented as supporting two specific philosophies of education – Seymour Papert's 'constructionist' model of learning by 'building' and Deweyian theories of learning by 'doing'. While such associations add gravitas to any argument for maker technology in schools, a number of tensions remain in these philosophies of learning that perhaps limit claims for maker technology-based learning.

In the first sense, as Sheridan et al. (2014) acknowledged, much of the learning-related rationale for maker technologies derives from reappropriation of 'constructionist' models of learning. Enthusiasts of maker education have tended to reappropriate the constructionist arguments of Seymour Papert originally made for Logo programming and 'turtle' graphics. The logic of this is understandable. Papert's original constructivist agenda was strong in its revolutionary rhetoric and implied a forceful critique of classroom-based 'instructionism' – what Papert saw as dissociated 'school learning'. One of Papert's ground-breaking ideas was that Logo, through the turtle ('cursor'), could act as a transitional object, mediating between abstract domains of knowledge and the concrete activities of children. In this way, the child could be set in contact with abstract knowledge domains more or less unmediated by teachers and formal curricula.

At first glance, the extension of these ideas to maker technology is understandable. Yet the practicalities of achieving constructionist learning through digital technologies have long been questioned. The late 1980s saw considerable controversy surrounding Papert's original claims for the learning outcomes associated with Logo. For example, evaluatory work by the likes of Pea and Kurland (1984) found little sustained evidence for transferable learning arising from Logo use, even in schools that were philosophically and pedagogically matched to constructionist principles. As Pea (1987, p. 6) put it, 'finding no transfer of problem-solving skills such as debugging, planning and procedural reasoning to non-programming problems'. Thirty years later, while commentators are keen to presume the broader learning benefits of making *beyond* the actual process of making the artefact itself, such transfer of knowledge also remains largely unsubstantiated. As was said of Papert's claims for Logo programming in the 1980s, expectations for maker-related learning cannot 'rest their case … on value claims and untestable claims of varied and unpredictable good effects supported by anecdotes' (Walker, 1987, p. 10).

The applicability of Papert's description of constructionist learning outcomes to maker technologies can also be critiqued in terms of the relationship between design and knowledge domains. Here, it is easy to forget that Logo's software and hardware components were deliberately designed to result in what Papert (1980, p. 150) termed realising 'a child's value as a thinker, even as an "epistemologist" with a notion of the power of powerful ideas'. Logo was developed in close alignment with the burgeoning graphical capacities of personal computers at the end of the 1970s. It was designed carefully to provide opportunities to create, manipulate and play with code to create visual images, patterns and effects (what Papert termed turtle graphics). Thus there was an intimate association between the visual 'microworld' of Logo and particular formal conceptual domains. These forms of learning and knowledge building are not necessarily transferable to technologies such as 3D printing, microcomputing or e-textiles – all of which are very different technologies with very different types of output. Crucially, it can be argued that recent maker technologies have *not* been designed with constructionist learning outcomes in mind. If anything, maker technology might be said to have more affinity with the design-orientated iterations of constructionism advanced during the 1990s and 2000s by the likes of Yasmin Kafai and Mitch Resnick (e.g. Kafai & Resnick, 1996). This emphasis on design-based learning rather than the specific construction of 'microworlds' clearly loses much of the Piagetian-inspired domain-specific learning gains that Papert was striving to support.

Secondly, similar questions can be raised over the congruence of maker technology to commonly associated traditions of Deweyian learning by doing. The Dewey-inspired learning claims relating to maker technology are therefore compelling. For example, Alexander and colleagues pointed to the potential of makerspaces to connect the practical and the intellectual – providing 'the opportunity for students to partake in hands-on building while practicing critical thinking' (Alexander, Adams Becker, & Cummins, 2016, p. 12). This combination of 'hand' and 'head' work is also seen to stimulate the natural motivation that arises from 'a sense of playfulness or the unexpected' (Bevan, 2017, p. 76). Much of the enthusiasm linking the Deweyan tradition with maker technologies also relates to notions of 'computational participation'. For example, according to Kafai and Burke (2014, p. 124), makerspaces offer a potential renaissance for John Dewey's ideas in supporting creative online environments in which coding becomes the 'lingua franca'. Dewey is also seen to align well with maker technology in terms of his emphasis on project-based inquiry, hands-on experience and understanding of education as a social (and societal) process.

However, there are fundamental conceptual debates in the Deweyan tradition that might limit its applicability to current maker technologies. The question of how practical activity and social participation actually contributes to the educational process is one such tension. In his much-referenced 'Pedagogic Creed', Dewey stated that the 'true centre' of the child's growth lies in their social life rather than any school subject (Dewey, 1897). The connection with current references to participation in the maker literature is obvious. Elsewhere, however, Dewey offered a more complex view. In his essay titled *The Child and the Curriculum* (Dewey, 1902/1959), Dewey addressed the 'really difficult' question of 'interaction' between the child and the curriculum in educational practice. Attempting to navigate the debate between progressivists and traditionalists, he argued that the child's own experience and formal knowledge need to be understood as two extremes of the same process rather than points of departure. In particular, Dewey's thinking emphasises that informal knowledge and participation in maker activities per se will not be enough. Instead, a close reading of Dewey would suggest a need to consider how social and material experiences of making can be related to curricula in any serious attempt to introduce making in formal education. For all these reasons, then, it is clear that any attempt to apply Deweyan thinking to contemporary maker education issues is fraught with uncertainty.

The culture and politics of maker technology

Our third area of tension relates to the broader culture and politics of maker technology – not least how maker technologies are embedded within the broader 'maker culture' and so-called 'maker movement'. As such, the use of maker technology is bound up with a number of a range of claims, hopes and agendas. Perhaps the most compelling of these are the widely discussed associations between making and learner empowerment – with individuals able to take control of the means of production and engage in personally meaningful innovation and entrepreneurial activity. Thus proponents talk of maker technologies heralding 'the democratization of invention' (Blikstein, 2013), and supporting a way of learning that 'builds agency', 'develops character' and leads to 'empowerment and social justice' (Clapp, Ross, Ryan, & Tishman, 2016).

These perceived benefits often extend into ideas of equality of opportunity, with making seen as a way of engaging diverse social groups, and drawing on expertise, interest and practices that are prevalent in otherwise marginalised communities and contexts. Indeed, as Bevan (2017) reasoned, 'making is argued to be profoundly accessible because of its fundamentally interest-driven nature wherein students develop and pursue their own pathways to realizing their own ideas' (p. 76). Furthermore, are arguments surrounding the mutable personal politics of making – chiming with communitarian ideals of sustainable communities on one hand, and libertarian views of 'rugged individualism' on the other hand. Some see maker technology as chiming with countercultural interests in developing a self-sustaining 'orientation toward personal fabrication rather than blind consumerism' (Peppler & Bender, 2013, p. 23). All told, while such different priorities might appear to conflict, there is a strong strain of social utopianism attached to making practices.

Here, too, a number of challenges and tensions can be identified in terms of the enactment of these ideals in schools. In this respect, it is worth paying attention to Shirin Vossoughi and colleagues (2016), who challenged the confirmatory consensus of empowerment and equity that tends to surround maker education. The paper starts by challenging the common perception of making as community-driven and inherently democratic – juxtaposing the maker origin story of being a 'self-defined grassroots movement of backyard and kitchen tinkerers, hackers, designers, and inventors' (Vossoughi, Hooper, & Escudé, 2016, p. 210) with its historical connections to Federal government, defence research and corporate funding (see also Morozov, 2014). Belying its rebellious, alternate 'trouble-making' appearance, the maker movement could be seen as predicted upon conformist and deeply consumerist principles.

In particular, Vossoughi et al. (2016) framed making as a particularly American activity – rooted in (white, middle-class) nostalgia for a nation that is both built around 'baking apple pies' but also economic dominance in manufacturing automobiles and other advanced productive industries. This heritage, Vossoughi et al. argued, is important in making sense of the dominant economic narratives that now surround policy interest in maker technologies in schools – especially in terms of boosting national competitiveness and workforce capacity in STEM industries. Crucially, this heritage sits uneasily with some of the democratically minded discourses that have also come to be attached to maker education. In particular, Vossoughi et al. challenged the various claims made for equity-oriented maker education and growing claims around making as an education practice 'that is grounded in the histories, needs, assets, and experiences of working-class students and students of colour' (Vossoughi et al., 2016, p. 210).

It is therefore important to recognise current popular views of as 'making' as bounded by dominant values and practices that legitimise certain types of 'making' processes and practices, while other practices and understandings are marginalised, ignored or even discounted altogether. As Vossoughi et al. (2016, p. 212) observed, many social groups 'may have a very different historical and economic relationship to making and working with one's hands'. For example, working-class communities of colour possess extensive prior knowledge, skills, expertise and experience when it comes to manual labour and making things. Women also have a long history of 'mending, repairing, teaching, and caregiving' (Vossoughi et al., 2016, p. 212). These histories contrast with the common discourses of deficit and intervention that have grown up around the maker education – e.g. that girls and/or disadvantaged and disengaged students of colour need to be 'introduced' to knowledge, skills, expertise and experiences that they otherwise are lacking (see also Martin & Dixon, 2016).

In this sense, it could be argued that school-based making runs a risk of simply reproducing inequalities and reinforcing established patterns of (dis)empowerment and (dis)advantage. This relates to concerns over the ways in which maker culture is ultimately rooted in neoliberal models of the individual. Any notion of empowerment lies in the idea of being able to be self-made and re-make ourselves and situations. As Dieter and Lovink (2012, n.p.) asserted, 'it is no exaggeration to claim that the maker-as-individual is a key figure of today's neoliberal ontotheology'. In this sense, the forms of empowerment promised by maker culture are limited and limiting for those who do not (or cannot) meet these expectations. The self-determined and peer-supported forms of teaching and learning implicit in maker discourse are likely to advantage only certain groups of students (Willett, 2016). Indeed, there are obvious equity issues associated with framing making in terms of resilience, grit and a 'meritocratic, pull-yourself-up-by-your-bootstraps approach' (Vossoughi et al., 2016, p. 222). Left to their own devices, then, there is a danger that students engaging in maker practices descend into individualised (and perhaps competitive) interactions that risk reproducing raced, classed or gendered hierarchies of intelligence.

In addition, questions need to be asked of the politics of maker technology. For example, how does maker education reinforce, recode and/or ignore established norms of late-capitalist consumerism (Malewitz, 2014)? Conversely, how does the maker discourse act as a distraction from long-standing radical concerns – such as negation ('unmaking'), or even stopping making (e.g. going on strike)? As such, maker culture could be seen as limiting students' capacities to act in ways that might be of genuine benefit to themselves. As Dieter and Lovink (2012, n.p.) concluded, 'there are, indeed, complex questions of agency here'.

Discussion

There is clearly educational potential in maker technology, and many people understandably see this as an opportune moment to leverage these technologies into schools and other formal education settings. Yet, as this article has argued, attempts to integrate maker technologies into schools on a widespread and sustainable basis will face a number of considerable challenges. With school leaders and teachers under pressure to implement all manner of competing (and often contradictory) educational imperatives, many schools are unable and/or unwilling to adopt innovative but ill-fitting practices such as maker technology (Selwyn, Nemorin, Bulfin, & Johnson, 2018). As such, there is a real danger that maker technology follows the trend of many previous 'new' technological developments to be only partially adopted in schools, resulting in inconsistent outcomes and problematic 'side effects' (Cuban, 1993, 2001; Zhao, 2017).

So on the basis of all that has been discussed so far, what opportunities might exist to better integrate maker technologies into schools? To date, there has been a tendency for proponents of maker education to set making practices in opposition to formal schooling – e.g. bemoaning schools as 'quashing' the 'creativity, innovation and entrepreneurial spirit that are hallmarks of the "maker revolution"' (Halverson & Sheridan, 2014, p. 500) and framing 'the maker movement [as] an innovative way to reimagine education' (Peppler & Bender, 2013, p. 23). Similarly, Kafai and colleagues conclude defiantly that 'introducing [making] activities, like any new curricular activity, into schools is a complex enterprise that brings with it the inherent challenges of changing the status quo' (Kafai et al., 2014, p. 550).

Such arguments may well be justified and can certainly contribute to debates over the long-term nature of education provision. Indeed, maker movement proponents acknowledge an unhelpful willingness to be perceived 'as a rebellious *enfant terrible* against traditional schooling' (Blikstein & Worsley, 2016, p. 65). Yet arguments that maker technology is an inherently 'disruptive innovation' that extenuates the need to reinvent the current 'factory' model of mass schooling will contribute little to the improved introduction of maker technologies into schools in the near future. The 'status quo' is unlikely to radically alter over the next few years. In the meantime, then, the educational technology community would do well to think pragmatically and strategically about how the educational potential of maker technologies can be realised in the *current* realities of school systems and classroom contexts. In light of our preceding discussions, we can point to the following areas as being worthy of further consideration:

Rethinking 'maker pedagogies'

There is an obvious need to reconsider the pedagogical practices that might support the integration of maker technologies in schools. As discussed earlier, out-of-school maker education is entwined with learner-centred pedagogies and the notion of teachers as facilitators. Instead of denying the role of the teacher, school-based making activities need to better emphasise the importance of teachers and acts of intentional teaching. Despite the rhetoric, learning activities are rarely spontaneous. As such, school-based maker education will invariably demand high levels of pre-planning and organisation. Discussions of school-based maker education therefore need to recognise that any classroom implementation of maker technologies clearly requires a great deal of material, teaching resources and teacher time and effort to work. Teachers are also a key element of organising equitable forms of maker education. Moreover as Vossoughi et al. (2016) argued, teachers are a key element in ensuring that maker activities do not simply replicate deficit ideologies but, instead, can be something that all students experience as substantive and of 'intellectual dignity'. As such, more thought needs to be given as to how the use of maker technologies in classrooms can benefit from direct involvement of more knowledgeable others – including teachers, as well as elders and mentors from diverse backgrounds who can ensure that knowledge and assistance is readily accessible to all students.

Rethinking the alignment of maker technologies with school knowledge

Following on from these pedagogical concerns, is the need to reconsider which areas of schooling might best support making practices and knowledges. At present, many schools are turning to STEM and Digital & Technology subjects as appropriate 'home' areas for maker technologies. There is certainly logic to this approach – such as the 'design/make/evaluate' process that has long been embedded in school-based Design & Technology provision (McCormick, 1990). Yet as implied throughout this article, it may well be that other subjects might best enable the inter-disciplinary knowledge and skills implicit in maker education. While schools are not traditionally arranged to support interdisciplinary practices, it makes sense to consider all possible areas of schooling. This might suggest less-fashionable subject areas that are not part of the assessed curriculum, but are positioned around the periphery of core school activities. For example, despite the apparent inertia in terms of developing so-called 'STEAM' (STEM+Arts) agendas in school, more effort could be directed toward the integration of maker technology into arts subjects – particularly those subjects with epistemological roots in hand/mind forms of knowledge. The Scandinavian subject area of Slöjd is one such area with a pre-existing focus on handicraft-based education. Alternatively, maker technology might find a more natural fit *outside* of subject areas altogether. For example, more thought might be given as to the possibilities of 'guerrilla' making activities in the informal spaces of schools and schooling.

Reconciling 'maker learning' with 'school learning'

As has been discussed, maker technologies face long-standing tensions between what Bevan (2017) identified as 'constructionism' and 'instructionism' – echoing Papert's (1980) distinction 40 years previously between technology-based 'learning by doing' – and forms of 'school learning' rooted in a 'dissociated' model of knowledge, an emphasis on successful outcomes and avoidance of error. While it is highly unlikely that schools will be soon reconfigured around constructionist principles, it is worth considering possibilities of more closely aligning the two. As this article has implied, a number of learning-related issues need to be taken into consideration when developing school-based maker environments. First is the tension between learning through individual endeavour and learning through collective enterprise. As discussed earlier, making is not an activity that should be under-taken individually. Indeed, outside-school making is properly understood as a collective endeavour. So how might school use of maker technology be approached in this way – moving away from a spirit of 'DIY' and toward a broader notion of 'DIO' (Do It Ourselves)? Second are tensions between school requirements for 'correct' (and therefore assessable) outcomes and the emphasis within maker practices on ongoing cycles of experimentation, failure and iterative problem solving. So how might collaborative making processes be recognised as 'outcomes' to be assessed, thus shifting attention away from the grading of any final product? Third are issues related to over-estimating learner motivation and under-estimating the physical and mental demands of maker learning. There are limitations in presuming making activities to be inherently interesting or motivating – particularly in terms of the affective demands of the making process. This also raises the issue of the initial framing of any maker activity, and the motivation that stems from students being able to identify the initial 'problem' rather than school authorities pre-deciding the nature of the making activity.

Toward a better 'cultural' fit between maker technology and students

Fourth is the need for schools and teachers to be more mindful of the cultural and social limitations of currently dominant versions of the maker movement. As noted earlier, there are few grounds to presume maker technologies capable of leading to empowerment and/or overcoming injustices in education. At present, many instances of maker education are insuffi-ciently connected with the activities, practices and communities that many students are already engaged in outside of the classroom. There are obvious limitations in presuming that the practices central to 'making' are present (let alone privileged) in all communities. As discussed earlier, practices of designing, tinkering and inventing are culturally specific. So too is the assumption that collaborating in public groups is inherently desirable and motivating. In particular there needs to be better recognition of the culturally specific nature of celebrating practices of 'learning-through-failing', intellectual risk taking, resilience and confidently working through one's frustrations (Vossoughi et al., 2016). For example, these practices might not be easily reframed as desirable for young people who have had lived lives of being systematically labelled as 'failures' and positioned in terms of their deficits. Alternately, students from different ethnic backgrounds might have different historicised cultural approaches to 'making' that could be drawn upon. All told, schools need to better explore alternate ways of making that resonate with the experiences and backgrounds of all students.

Toward a better understanding of the potential beneficiaries of maker education

These latter issues relate to the broader question of who stands to benefit from the closer alignment of maker education with school processes and practices. Even if the cultural alignments described above are enacted, it is important to remain realistic of possible inclusive and/or empowering outcomes. While much hope has been attached to maker technologies as a driver for increased student engagement, motivation and learning outcomes, these benefits are unlikely to be experienced equally across all school settings and/or all student groups. We know from previous waves of digital technology use in schools that benefits often tend to accrue most with students who are already advantaged (Schofield, 1995; Selwyn et al., 2018). There is a risk, therefore, of exacerbating inequalities through framing maker education as an opt-in and/or individually driven activity. Conversely, schools are perhaps place to ensure that all students have meaningful and realistic opportunities to engage with maker education, even to the extent of positioning maker education as a mandated part of school. While this contradicts the spontaneous spirit of making, experiences from similar implementation of coding and other digital skills provision suggest that the inclusivity of such efforts is invariably compromised by the self-selecting, voluntary basis of programme participation (UNESCO, 2017).

Schools as site for a 'critical making literacy'

Finally, is the need to position maker technologies in schools as a topic of critical engagement as well as a resource for learning. This suggests that schools seek ways of supporting students in analysing the specific political, societal and cultural features of maker technology, and working out ways of challenging any disempowering/undesirable characteristics. There are plenty of aspects of maker technology and the maker movement that merit closer scrutiny as part of wider efforts to develop students' 'critical digital literacy' (see Pangrazio, 2016). For example, connections with STEM skills, employability and global competitiveness are clearly contestable. The legalities, ethics and environmental sustainability of making also merit reflection and discussion. Also worthy of critical scrutiny are heightened emphases on individual risk taking and entrepreneurial thinking, as well as consumerist-led notions of young people making 'products' and engaging in innovation. Teachers and students can therefore reflect on the extent to which dominant narratives are being reproduced in school uses of maker technology, and what opportunities might exist to challenge them. Teachers and students need to work together unpacking and problematising these associations – with time built into any maker education activity to reflect critically in terms of how these broader agendas might be shaping local experiences and activities.

Conclusion

At its heart, this article has considered a question fundamental to many aspects of educational technology – i.e. how might innovative practices (which have evolved in other settings and involve informal learning with digital technologies) be successfully received and integrated into formal education environments? In the case of maker technologies, it is clear that importing devices, applications and practices into schools, classrooms and formal curriculum plans is insufficient grounds for sustained, substantial adoption. Instead, we need to better understand the social, cultural, political contexts of maker education, alongside the epistemological and pedagogical characteristics of maker technologies as tools for learning. This implies working out ways of adjusting assumptions of teaching and learning with maker technology. This also implies exploring ways that maker technologies might be reconfigured for use within schools. For example, what would maker technology that was designed for schools look like? What principles would form the basis of 'computer-supported collaborative making'?

These are difficult questions on which to conclude – yet we raise them in the spirit of constructive criticism. Rather than arguing that maker technology is something to be resisted and ignored by schools and teachers, this article's main intention has been to begin to sketch out alternative conceptual and pedagogical frameworks that move beyond the narrow concerns of maker education as it has developed to date in mainstream education. We hope that this article offers a starting point for further experimentation, evaluation and research into how schools might realistically be supported to make the most of maker technologies within the milieu of the contemporary school context. These are technologies and practices that have considerable educational potential, but clearly involve a lot of hard work and hard thinking.

Disclosure statement

No potential conflict of interest has been reported by the authors.

Notes on contributors

Anna-Lena Godhe is senior lecturer with joint appointments at the Department of Culture, Language and Media, Malmö University and at the Department of Education, Communication and Learning, University of Gothenburg. Her research focuses on transformation processes in classroom practices and how they relate to structural aspects such as curricula and assessment.

Patrik Lilja is senior lecturer with joint appointments at the School of Education, Humanities and Social Sciences, Halmstad University and the Department of Education, Communication and Learning, University of Gothenburg. His research focuses on inquiry, problem-based learning and digital tools in education.

Neil Selwyn is a distinguished research professor at Monash University, and also a visiting professor at the Department of Education, Communication and Learning, University of Gothenburg. His research focuses on digital technology, education and society.

ORCID

Neil Selwyn http://orcid.org/0000-0001-9489-2692

References

Alexander, B., Adams Becker, S., & Cummins, M. (2016). *Digital literacy*. Austin, TX: New Media Consortium.

Bevan, B. (2017). The promise and the promises of Making in science education. *Studies in Science Education*, *53*, 75–103.

Biesta, G. (2016). The rediscovery of teaching. *Educational Philosophy and Theory*, *48*, 374–392.

Blikstein, P. (2013). Digital fabrication and 'making' in education. In J. Walter-Herrmann & C. Büching (Eds.), *FabLabs* (pp. 1–21). Bielefeld: Transcript Publishers.

Blikstein, P., & Worsley, M. (2016). Children are not hackers. In K. Peppler, E. Halverson, & Y. Kaifai (Eds.), *Makerology: Volume one* (pp. 64–79). New York, NY: Routledge.

Brahms, L. (2014). *Making as a learning process* (Unpublished doctoral dissertation). University of Pittsburgh, Pittsburgh, PA.

Clapp, E., Ross, J., Ryan, J., & Tishman, S. (2016). *Maker-centred learning*. New York, NY: Wiley.

Cuban, L. (1988). *Teachers and machines*. New York, NY: Teachers College Press.

Cuban, L. (1993). Computer meets classroom: Classroom wins. *Teachers College Record*, *95*, 185–210.
Cuban, L. (2001). *Oversold and underused*. Cambridge, MA: Harvard University Press.
Dewey, J. (1897/1975). My pedagogic creed. In *The early works* (Vol. 5, pp. 84–95). Carbondale, IL: Southern Illinois University Press.
Dewey, J. (1902/1959). *The child and the curriculum* (No. 5). Chicago, IL: University of Chicago Press.
Dieter, M., & Lovink, G. (2012) *Theses on making in the digital age*. Retrieved from http://conceptlab.com/criticalmaking/PDFs/CriticalMaking2012Hertz-Manifestos-pp15to20-DieterLovink-ThesesOnMaking.pdf
Eisenberg, M. (2013). 3D printing for children. *International Journal of Child–Computer Interaction*, *1*, 7–13.
Gutwill, J., Hido, N., & Sindorf, L. (2015). Research to practice. *Curator: The Museum Journal*, *58*, 151–168.
Halverson, E., & Sheridan, K. (2014). The maker movement in education. *Harvard Educational Review*, *84*, 495–504.
Ito, M., Gutierrez, K., Livingstone, S., Penuel, B., Rhodes, J., Salen, K., & Watkins, S. (2013). *Connected learning*. Irvine, CA: Digital Media and Learning Research Hub.
Kafai, Y., & Burke, Q. (2014). *Connected code*. Cambridge, MA: MIT Press.
Kafai, Y., Fields, D., & Searle, K. (2014). Electronic textiles as disruptive designs. *Harvard Educational Review*, *84*, 532–556.
Kafai, Y., & Resnick, M. (1996). *Constructionism in practice*. New York, NY: Routledge.
Kostakis, V., Niaros, V., & Giotitsas, C. (2015). Open source 3D printing as a means of learning. *Telematics and Informatics*, *32*, 118–128.
Litts, B., Kafai, Y., Fields, D., Halverson, E., & Peppler, K. (2016). *Connected making*. Irvine, CA: Digital Media and Learning Consortium.
Luckman, S. (2016). *Craft and the creative economy*. Basingstoke: Palgrave.
Malewitz, R. (2014). *The practice of misuse*. Palo Alto, CA: Stanford University Press.
Martin, L., & Dixon, C. (2016). Making as a pathway to engineering and design. In K. Peppler, E. Halverson, & Y. Kafai (Eds.), *Makeology – Volume two* (pp. 183–195). New York, NY: Routledge.
McCormick, R. (1990). Technology and the National Curriculum: The creation of a ‘subject’ by committee? *The Curriculum Journal*, *1*, 39–51.
Morozov, E. (2014, January 13). Making it. *The New Yorker*.
Nemorin, S., & Selwyn, N. (2017). Making the best of it? Exploring the realities of 3D printing in school. *Research Papers in Education*, *32*, 578-595.
Pangrazio, L. (2016). Reconceptualising critical digital literacy. *Discourse: Studies in the Cultural Politics of Education*, *37*, 163–174.
Papert, S. (1980). *Mindstorms*. New York, NY: Basic Books.
Pea, R. (1987). The aims of software criticism. *Educational Researcher*, *16*(5), 4–8.
Pea, R., & Kurland, D. (1984). On the cognitive effects of learning computer programming. *New Ideas in Psychology*, *2*, 137–168.
Peppler, K., & Bender, S. (2013). Maker movement spreads innovation one project at a time. *Phi Delta Kappan*, *95*(3), 22–27.
Petrich, M., Wilkinson, K., & Bevan, B. (2013). It looks like fun, but are they learning? In M. Honey & D. Kanter (Eds.), *Design, make, play* (pp. 50–70). New York, NY: Routledge.
Ratto, M., & Ree, R. (2012). Materializing information. *First Monday, 17*(7).
Schofield, J. (1995). *Computers and classroom culture*. Cambridge, UK: Cambridge University Press.
Sefton-Green, J. (2013). *Mapping digital makers*. London: Nominet Trust.
Selwyn, N., Nemorin, S., Bulfin, S., & Johnson, N. (2018). *Everyday schooling in the digital age: High school, high tech?* London: Routledge.
Sheridan, K., Halverson, E., Litts, B., Brahms, L., Jacobs-Priebe, L., & Owens, T. (2014). Learning in the making. *Harvard Educational Review*, *84*, 505–531.
Stornaiuolo, A., & Nichols, T. (2018). Making publics: Mobilizing audiences in high school makerspaces. *Teachers College Record*, *120*(8), n8.
Taylor, B. (2016). Evaluating the benefit of the maker movement in K–12 STEM education. *Electronic International Journal of Education, Arts, and Science*, *2*, 1–22.
UNESCO. (2017). *Digital skills for life and work*. Geneva: Broadband Commission for Sustainable Development.
Vossoughi, S., Escudé, M., Kong, F., & Hooper, P. (2013, October). *Tinkering, learning and equity in the after-school setting*. Paper presented at Annual FabLearn conference, Stanford University, Palo Alto, CA.
Vossoughi, S., Hooper, P., & Escudé, M. (2016). Making through the lens of culture and power. *Harvard Educational Review*, *86*, 206–232.
Walker, D. (1987). Logo needs research. *Educational Researcher*, *16*(5), 9–11.
Willett, R. (2016). Making, makers, and makerspaces. *Library Quarterly: Information, Community, Policy*, *86*(3), 1–17.
Zhao, Y. (2017). What works may hurt. *Journal of Educational Change*, *18*, 1–19.