More than a game: The participatory Design of contextualised technology-rich learning expereinces with the ecology of resources

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The development of technology enhanced contextualized educational experiences that are personally meaningful for learners is an essential research goal, which is enabled by the ever-increasing wealth of networked, pervasive, mobile technologies. The developments in the rich variety of technologies is not however matched by the development of a rich variety of models and frameworks that can support the contextualized design process. These models and frameworks are essential for the adoption of contextualized technology enhanced education. Methods to support these design frameworks and evidence of their usefulness are essential if the potential of progressive technology development is to make contextualized technology enhanced education a reality. We describe the Ecology of Resources approach, which offers a model and a framework to support the design of Technology Enhanced Education (TEE). Participatory design is embedded in this approach and offers a key contribution to the development

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of TEE by enabling researchers and designers to tap into the complex and subtle circumstances in which and through which people learn. The case study that we present demonstrates this participatory process and provides evidence that its combination with the Ecology of Resources approach effectively supports the development of TEE.

1 Introduction

The theme of this special issue is an important one for researchers and practitioners interested in the best ways in which technology can support and enhance learning through offering 'contextualized educational experiences'. The focus upon experience and context recognizes the importance of these issues for learning and is far removed from the Behaviorist traditions that motivated the design of the early machines for teaching (Skinner, 1968). These Behaviorist traditions have been superseded by a series of more modern and broadly framed approaches to learning and education, and yet they still ground important aspects of the ways in which institutions and education systems operate. One reason for this continuing influence is that Behaviorist approaches and techniques can be clearly articulated, are quantifiable and controllable, whilst approaches that acknowledge what happens beyond observable outcomes, and recognize the influence of the circumstances of the learner and the subtleties of their subjective engagement, offer far less tangible products and processes. The onus is therefore upon those of us who are developing models and frameworks that attempt to capture important aspects of this broader learning landscape to work together and to communicate clearly why what we are doing is important, what it can offer and what clear evidence there is of its benefits. This journal special issue is an important contribution to that collaboration and communication.

In this article we focus upon the concept of context, which is at the heart of the development of 'contextualized educational experiences'. We present a case study that uses a model and a framework of context in order to ground a participatory design process. We offer a learner-specific definition of context in an attempt to pin down this complex concept in a way that enables it to be used as the basis for constructing a model and a design framework. We briefly present the Ecology of Resources model of context and its associated design framework. We then focus our attention upon a case study that exemplifies the manner in which the model and framework can be used to develop 'contextualized educational experiences' and in particular how the model enables the participatory process that we believe to be fundamental to the development of robust designs.

1.1 Context

Context is talked about in different ways within different disciplines and is acknowledged to be complex. Michael Cole's (1996) text on cultural psychology is particularly helpful with respect to learning and context. He distinguishes between 'two principal conceptions of context that divide social scientists' (Cole, 1996, p. 131): the first conceptualization is as 'that which surrounds'; the second conceptualization is one that builds on a metaphor of weaving, which requires that we interpret mind in a relational way: 'as distributed in the artifacts which are woven together and which weave together individual human actions in concert with and as part of the permeable, changing, events of life' (Cole, 1996, p.136). Cole draws our attention to the distribution of mind across connected artefacts in the world and this view is echoed in the situated approaches to cognition and learning (for example, Brown, *et al.*, 1989) and the Legitimate Peripheral Participation thesis (Lave, 1988; Lave & Wenger, 1991). A key influence, both for Cole and for Lave and Wenger was the work of Vygotsky (1978; 1986). Vygotsky's socio-cultural psychology resonates with a conceptualization of context that adheres to the notion of a weaving of mediated experiences. The basic ideas of Vygotsky's approach are presented in the 'general law of cultural development', which makes explicit the link between the external activity of the 'interpsychological' activity of the individual's culture, and the 'intrapsychological' processes within the mind that allows the internalization of the higher mental processes from their social origins. Critically, this law recognizes that learning begins in social interaction.

1.2 The Zone of Collaboration

This diverse and inter-disciplinary literature, whose surface we have barely scratched in this article, grounds the learner-specific definition of context that we adopt. This definition conceptualizes context as a dynamic entity that is "associated with connections between people, things, locations and events in a narrative that is driven by people's intentionality and motivations" (Luckin, 2010). There are not multiple contexts to which the learner is exposed in a serial fashion, but rather the learner "has a single context that is their lived experience of the world; … that reflects their interactions with multiple people, artefacts and environments" (*ibid*). These interactions offer the learner partial descriptions of the world that provide the ingredients and mechanisms for meaning making through the process of internalization (Vygotsky, 1986). This process of internalization is crystallized in the Zone of Proximal Development (ZPD), which can be thought of as a context of productive interactivity: the interactions between people that lead to learning. We interpret the ZPD to formulate The

Zone of Collaboration (Luckin, 2010), which is integrated with the definition of context outlined above in the formulation of the Ecology of Resources model of context (see Figure 1). The Zone of Collaboration involves two constructs called: the Zone of Available Assistance (ZAA) and the Zone of Proximal Adjustment (ZPA). The ZAA describes the variety of resources within a learner's world that could provide different qualities and quantities of assistance and that may be available to the learner at a particular point in time. The ZPA represents a sub-set of the ZAA that is appropriate for a learner's needs. The important point about the constructs of the ZAA and the ZPA is that they offer a way to describe learning in terms of the assistance that a learner's interactions with the resources of their context can afford them.

2 The Ecology of Resources Model and Design Framework

The Ecology of Resources model of context (see Figure 1) describes the people, artefacts and environments with which the learner interacts as resources. These resources have the potential to offer the learner the assistance required by the Zone of Proximal Development: they offer the partial descriptions of the world that need to be connected and built into a meaningful learning narrative through the process of internalization. One resource that is of particular importance is that of a More Able Partner, there may be multiple More Able Partners who can both act as a resource themselves, and who can help the learner make best use of the other resources available to them. Each of the resources, which are divided into the categories of Knowledge and Skills, Tools and People, and Environment in Figure 1, are interconnected to the learner and to each other. These connections represent important influential relationships for learning. For example, consider a child learning arithmetic (a resource in the Knowledge and Skills category) and working with a peer to complete a worksheet (resources in the Tools and People category) in a school classroom (a resource in the Environment category). In this example, the worksheet needs to be designed in a manner that reflects the arithmetic that the learner needs to understand: this is the relationship between the Knowledge and Skills resources, the Tools and the People resources, and the learner. The interactions between the learner and their peer need to support their successful completion of the worksheet activities: these are the relationships within the resources of the Tools and People category; and the classroom needs to be organized in a suitable manner for pairs of learners to work collaboratively on an arithmetic worksheet, as opposed, for example to the organisation that would be better suited to a learner working alone, or to the organization that would be suitable for learners completing sports activities. These are the relationships between the resources in the Knowledge and Skills category, the Tools and People category,

the Environment category and the learner. As designers and practitioners we can investigate the relationships between resources and the learner for opportunities to enhance these relationships. For example, could the arithmetic worksheet be designed in a manner that built on the relationships between it and the classroom environment, by asking questions about features of the classroom perhaps? Could the relationship between the learner and their peer be strengthened through collaborative scripts (Dillenbourg / Hong, 2008), or through supportive interventions provided by technology (Kerawalla *et al.*, 2008)?

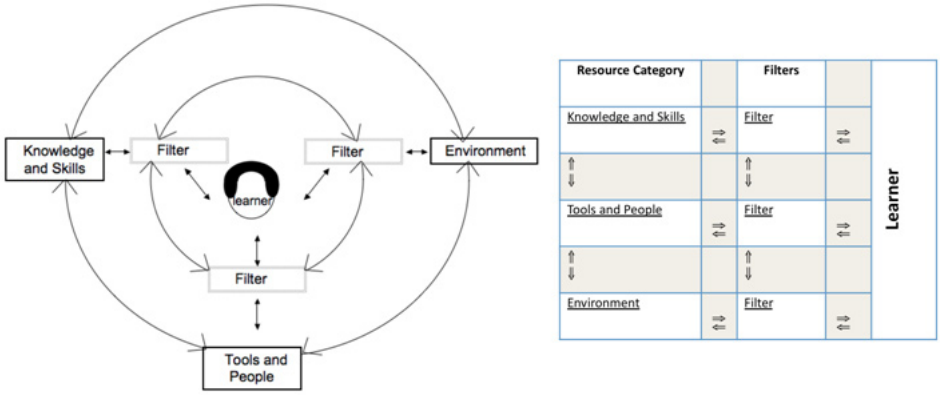

Fig. 1 - The Ecology of Resources Model (Luckin, 2010) and its tabulated representation, used in the design process

The resources categories within the Ecology of Resources are not intended to offer definitive bounding for the resources. Their purpose is to aid the identification of resources and inter-resource relationships to support the design process. A resource's categorization is based upon the role that it is playing for the learner and the focus of attention of the design activity. For example, if the arithmetic worksheet in the example presented above were to be presented via the walls of the classroom, the decision as to whether those classroom walls should be categorized as an Environment resource or a Tools and People resource would be decided through consideration of the role the worksheet plays for the learner. It may be that when the learner and peer are completing the worksheet and that activity is the focus of their attention, then the worksheet wall is categorized as a Tools and People resource. If the wall worksheet is a persistent feature of the classroom once the learner has moved on to a different activity, then at this point its role has changed and it may be re-categorized as part of the Environment.

The resources in their categories are illustrated in the outer ring in Figure 1 and sitting between the learner and these resources are Filters. These Filters represent the manner in which a learner's access to the resources with which they interact is rarely unconstrained. In the example of the arithmetic worksheet discussed above, the teacher who designs the worksheet is filtering the arithmetic concepts to which the learners are introduced, and the rules and regulations of the classroom environment filter the manner in which the learner can interact with their peer. Filters are often positive features of a learner's context, but they can be negative, for example when the school timetable dictates that a lesson must end, just as the learner reaches a crucial stage their arithmetic understanding. All of the resources and filters, known collectively as elements, in any Ecology of Resources model are inter-connected, and all bring with them a history that defines them, as well as the part they play in the wider cultural and political system. Likewise, the individual at the centre of the Ecology of Resources has their own history of experience, which impacts upon their interactions with each of the elements in the Ecology.

The Ecology of Resources model is the basis for a design framework to support the dynamic participatory process of developing contextualized technology-rich learning activities. The aim of the Ecology of Resources approach is to identify the resources that comprise a learner's ZAA and to develop the best means by which the learner's ZPA can be tailored to meet their needs. The framework maps out the design process so that it can be conducted with an enhanced awareness of the complex nature of the learner's context. The process is iterative and has three phases, each of which has several steps. A full account of the model and framework can be found in Luckin (2010); here we explain it relatively briefly to ground the case study. The Ecology of Resources framework has three phases, each of which has multiple steps.

1. Phase 1: Create an Ecology of Resources Model to identify and organize the potential forms of assistance that can act as resources for learning.
   Step 1 – Brainstorming Potential Resources to identify learners' ZAA;
   Step 2 – Specifying the Focus of Attention;
   Step 3 – Categorizing Resource Elements;
   Step 4 – Identify potential Resource Filters;
   Step 5 – Identify the Learner's Resources;
   Step 6 – Identify potential More Able Partners.
2. Phase 2: Identify the relationships within and between the resources produced in Phase 1. Identify the extent to which these relationships meet a learner's needs and how they might be optimized with respect to that learner.

3. Phase 3: Develop the Scaffolds and Adjustments to support learning and enable the negotiation of a ZPA for a learner. Phase 3 of the framework is about identifying the possible ways in which the relationships identified in Phase 2 might best be supported or scaffolded. This support might for example be offered through the manner in which technology is introduced, used or designed.

3 The Ecology of Resources Design Framework in use

The Ecology of Resources approach has been used in a variety of projects. The example we draw upon for the case study discussed in this paper was completed with learners and mentors at a learning centre in the South East of England. The learning centre, from here on referred to simply as the Centre operates a self-managed learning (SML) process with 11-16 year old learners in an 'out-of-school' environment. Aspects of the work we conducted with the learning centre are reported elsewhere (Luckin, 2010). Here however we focus upon the iterative participatory design of a card game, the detail of which is not reported in these other publications. The objective of the game was to help learners and mentors at the Centre make the best use of their technology resources to support them when they made trips outside of the learning centre.

3.1 The Learning Centre and the participatory method

Within our discussions of this case study we concentrate upon the participatory method of the Ecology of Resources. We therefore draw examples from different steps in Phases 1 and 2 of the framework, rather than reporting the step-by-step detail of each and every step in the framework.

The start of the design process is crucial and complex and requires careful engagement between researchers and participants, in this case the learners and mentors at the Centre. The participatory process of the Ecology of Resources was initially conducted through observation, informal discussions, interviews and group discussion with learners and staff at the Centre. The SML approach to learning adopted at the Centre provides a structure within which learners can plan, organise and carry out learning activities. The activities at the Centre are supplemented by a range of external activities such as trips and visits, which are identified, planned and organised by the learners themselves. Our initial explorations revealed that learners have access to a wide variety of technologies – at home, as well as at the Centre. The kinds of activities learners engage in with these technologies fall broadly into four categories: communication, learning, entertainment and leisure. However, despite good access, learners did not find it easy to make connections between the technologies available to them, their

learning activities and the learning environment.

The specification of a Focus of Attention in Step 2 of Phase 1 of the Ecology of Resources framework offers a way of narrowing down the resources with which the design team (researchers, learners and mentors in this case) concern themselves in future design steps. The specification of a Focus of Attention is rarely obvious and there may therefore be several iterations between Step 1 and Step 2 of Phase 1 of the design framework, before the point where a preliminary Focus of attention can be identified is reached, and the process can continue through the ensuing design steps. Table 1 illustrates the steps that were taken with participants at the Centre in order to generate an initial explicable Focus of Attention.

TABLE 1
Iterations to Identify a Focus of Attention

Iteration	Potential Focus of Attention	Design Activity	Impact upon Resources Identified at Step 1
1	Characterising learner and their context, including available technologies	Exploring the Centre using informal chat, observations, photographic data, documentary data	General overview of spaces, people, tools, practices, technologies and activities
2	Linking learners, environments and technologies	Exploring multiple learning environments drawing on more detailed participant perspectives through focused individual interviews	Focus on multiple environments for learning and use/non-use of technologies for learning
3	Linking learners and technologies to trips and visits outside the centre	Exploring specific learning environments, learner practices & perspectives on technology through focused discussion	Focus on external learning environments & learner perceptions of learning technologies
4	Linking learners and technologies to specific trips	Exploring learner perceptions of relationships between trips, technologies and learning through targeted group discussion (semi-structured interview technique)	Focus on practices and learner's 'internal' resources Distinctions made between learning as studying, leisure, interests

These design iterations enabled the specification of an initial Focus of Attention:

How can we support the learner to make appropriate selection and use

of available technologies to learn about the Milky Way whilst on a trip to the London Planetarium?

Once this initial Focus of Attention had been identified, the key challenge for continuing with the participatory design was to get learners to talk about their resources, and in particular their technologies without directing them inappropriately and losing the opportunity to elicit their perceptions and influences. In order to address this challenge a card game to support learners in their selection and use of technologies for a field trip was developed with learners.

3.2 The Card Game Design method

An initial simple set of game cards were developed based upon the data collected from interviews and discussions held with learners and mentors at the Centre. Each card simply suggested a function that technology might perform for example Storage, Retrieval, or Capture. Learners were asked to identify by writing on the front of each card which of their technologies might be used for this function. They were also asked to describe possible types of use on the back of the card. They were told that they could change the words used to describe a technology function if they disagreed with them or didn't understand them. The aim of this activity was to develop a learner-generated lexicon of technologies and descriptors to address the lack of common linguistic ground between learners and researchers. After the initial iteration, these annotated cards were collated and all technologies and uses identified by them were placed into a list. This list was then used to produce a second set of playing cards that were shown to learners as a focus for further discussion. When the discussion turned to the subject of game play, learners found the suggestion of a 'game for learning' difficult to understand, as evidenced in the following dialogue example that reflects learner responses to a question which asked whether they would play a game like this:

> Learner b: "How long would it take to play?"
> Learner c: "You, like, ask… not questions like 'how old am I'… but like 'Yes', 'No' and maybe… and you have to guess…"
> Learner d: "You've got to win!"
> Learner c: "Maybe two people could play… and they could be against each other…"
> Learner e: "The most you can learn about each technology."
> Learner c: "Just something educational, like who gets the most answers…"
> Learner d: "You pick a place and everyone has to name as many techno-

logies as possible and the person who gets the most wins."

These discussions informed the next iteration of the game and involved learners in the design, format and rules of the game. The shift in iteration also generated a shift in learner awareness to a more abstract appreciation of the technologies available to them and the potential for these technologies to support their learning needs. For example, learners suggested the introduction of a new card to cater for technologies not included in the existing set of specific technologies.

The game became increasingly complex, but remained playable. In the development of the cards, and to address the original aim of applying game play to a real world scenario, learners also introduced an activity pad to record the results of their game play as a form of planning for their trip. This activity pad also went through a re-design process when the early pad design proved insufficient for the complexity of the rules of game play.

3.3 Results and Discusssion

There were 5 iterations in the game design process and the game that was developed is illustrated in Figure 2. The rules for its play were as follows:

Order of play and rules of game

- Each player takes an Activity pad sheet and writes the name of an activity they wish to complete and its goal;
- First player is the Player and selects an appropriate ACTION card to start their game;
- Player annotates the Activity pad to record ACTION;
- Player selects MEDIA card to go with ACTION and annotates Activity pad;
- Dealer deals each player a hand of 6 TECHNOLOGY cards;
- Players will find some cards useful, some not;
- Player tries to find a TECHNOLOGY card in dealt hand that matches the ACTION and MEDIA cards selected at start of play. Match is identified via colour coding between TECHNOLOGY card and ACTION card;
- If player has a suitable TECHNOLOGY card, they place it with the ACTION/MEDIA card and place this card set to one side and continue to play;
- If player does not have a suitable TECHNOLOGY card, they show their ACTION/MEDIA cards to the other players and seek a suitable card.
- If another player has a suitable TECHNOLOGY card they are willing

to 'deal'… they must describe ways in which their card is appropriate and useful;

- Once they have a suitable card, the player spins the QUESTION WHEEL and matches the word from that to their MEDIA selection, e.g. AUDIO and WHERE, writing the response on the Activity pad, next to the question word;
- Next, the player selects an ISSUES card to identify any considerations that might affect their use of the selected technology and writes these in the ISSUES section of the Activity pad;
- Finally, before play switches to the next player, the current player connects the MEDIA card with the QUESTION WHEEL word and any relevant ISSUES and looks for another ACTION card for the next round. Each player can only take one turn (based on an ACTION card) at a time.
- Play passes to the next player.

Fig. 2 - The card game after 5 design iterations

The five design process iterations that were competed in the development of the game can be summarised in the following manner from the participatory design perspective:

Iteration 1 – learner generated vocabulary about available technologies

(filtered by researcher-generated processes).
Iteration 2 – co-designed technology cards: a combination of researcher-generated categories and learner-generated technologies.
Iteration 3 – learner-generated revised cards with introduction of colour matching. Activity demonstrated an increased level of abstraction in learner thinking, separating out technology from process and modeling relations between Knowledge content and Knowledge environment. For example, linking technologies to processes using a 'Capture' card category.
Iteration 4 – learner-generated revised card set, including a revised notepad. Learners start to track multiple issues and questions, demonstrate theoretical awareness of processes, relationships between tools, and needs and activities. For example, capturing an image using a mobile phone and sending it to a blog using a laptop connected to the Internet.
Iteration 5 – learners take greater charge of the activity and demonstrate increased awareness and understanding of the resources available to them. They apply and reapply resources in different scenarios, going beyond the immediate context, for example, carrying forward game play suggestions to the real world setting and adapting from sending mobile phone pictures to a blog, to engaging with photo storage, sharing and mapping with google maps.

These iterations demonstrate the manner in which learner's awareness of their resources was enhanced through a process of identifying, classifying, negotiating, applying and reflecting. This enabled them to verbalize details of their resources and the relationships between them in a manner that permitted the completion of the Ecology of Resources design steps. Figure 3 illustrates the development of the Ecology of Resources model for a learner at the Centre at the end of the first iteration of the card game activity (top) and at the end of iteration 5 (bottom). These models demonstrate the rich data about the learners' resources that has been captured through the participatory game design activity.

The card game methodology ensured that data from one design iteration was analysed and used to develop the game materials used in the next iteration. There is insufficient space in this article to offer a detailed account of the analytical methods used for the data collected during the study. We can however offer an outline: the main data sources for the game design activity were the learner annotations to the game materials and the transcripts of the discussions between researchers, learners and mentors: the design team. These transcripts were subjected to a themed content analysis based upon the resource categories in the Ecology of Resources and the particular stage in the design framework.

A full account of the analysis, complete with data examples, can be found at http://eorframework.pbworks.com.

Resource Category		**Filters**		
Knowledge and Skills Knowledge of Technology includes: Mobile phones Digital Cameras Video Camera Voice Recorder MP3 players Analogue camera (disposable) Headphones Flickr account, Flickr maps, blog Interactive exhibit (touch tables, touch screens, video walls) Interactive simulations (game play) Digital cinema wall Audio narratives	⇉ ⇇	Filters Using appropriate technologies on a trip to the London Planetarium The constituent parts of this informal 'curriculum' include a negotiation of the following: Identify appropriate technologies Identify any issues/challenges in using them Find appropriate solutions Capturing and storing data Retrieving and processing data Sharing and communicating data Interacting with *in situ* digital opportunities	⇉ ⇇	**Learner**
⇑ ⇓		⇑ ⇓		
Tools and People – Human Resources: mentors, parents, peers, researcher, Planetarium staff – Physical Resources: buildings, exhibits, shop, transport (train, tube), café, activity spaces, learning spaces, benches, yard area, park, pen, notebook, leaflets, books (*see also Environment category*) – Digital Resources: see above for list of available technologies; music files, games, Internet, text messaging	⇉ ⇇	Filter – Human Resources: mentors, parents and researchers constrain learner activity (health & safety) staff/rules constrain learner activity – Physical Resources: space constraints in café, shop and exhibit areas; access to Planetarium controlled in terms of time & allocation of seating – Digital Resources: use of technologies constrained by Planetarium staff, limited photography, no recording in some areas	⇉ ⇇	
⇑ ⇓		⇑ ⇓		
Environment The constituent parts of the environment include: - Public spaces (streets, train stations, tube stations, park) - Planetarium (indoors, outdoors – exhibits, shows, cinema, café, shop, activity spaces, learning spaces, seating areas, stairwells, lifts, planetarium, telescope room) - Centre: House, lounge Sofas, coffee table, chairs, walls, shelves French doors - Other objects/artefacts (television/video player, etc.)	⇉ ⇇	Filter Timescales for travel, visit and return – Physical environment constraints include: Rules, timetables, other visitors/community relations Prohibited activity relating to technology use in some areas of Planetarium Space around activity areas, space to interact with exhibits, number of visitors, ambient surroundings, proximity Availability of appropriate artefacts Weather – rain constrains outdoor activity Concerns for health and safety of learners in public spaces and respect for other visitors.	⇉ ⇇	

Resource Category		Filters		
Knowledge and Skills Knowledge of technology includes: Text Video Audio Data Links Image	⇉ ⇇	Filters Identifying technologies Capturing and storing data Retrieving and processing data Sharing and communicating Data through transfer or presentation	⇉ ⇇	
⇑ ⇓		⇑ ⇓		
Tools and People – Human Resources: mentors, peers, researcher – Physical Resources: blank cards, pens, example cards, batteries, wall charts – Digital Resources: mobile phones, digital cameras, laptops, voice recorders, television, video camera, mp3 players	⇉ ⇇	Filter – Human Resources: direction/pace of activity regulated by researcher and, sometimes mentors, learners constraining time available, rules – Physical Resources: allocation of material resources designed by researcher, accessibility, availability – Digital Resources: digital voice recorder used to record talk, other technologies present but not used, focused on paper-based activity;	⇉ ⇇	Learner
⇑ ⇓		⇑ ⇓		
Environment The constituent parts of the environment include: The Centre House, lounge Sofas, coffee table, chairs, walls, shelves French doors Other objects/artefacts (television/video player, etc.)	⇉ ⇇	Filter Constraints on the learning environment include: Activity focus, timetable, community rules, community relations Constraints on the physical environment include: Space, ambient surroundings, proximity Availability of appropriate artefacts (e.g. something to lean on)	⇉ ⇇	

Fig. 3 - Tabulated Ecology of Resources model for a learner at the Centre, at game design iteration 1 (top) and at game design iteration 2 (bottom).

4 The Trip

The focus of this paper is upon the participatory design process and the manner in which it, in combination with a model and framework, such as the Ecology of Resources, enables researchers to capture the rich data about learner experience and context that will ensure the rigour of the design process. We can also confirm that the card game was used to support the trip to the Planetarium and was considered by both learners and mentors at the Centre to have been useful, both in terms of the end product of the game, and in terms of the process of its design.

During the trip, students used technology for communication, music, texting and taking snapshots of the day to help them remember things. They cited the following reasons for their technology use:

1. Excitement and interest: for example, the 4.5 billion year old meteor
2. Amusement and fun: for example, the interactive exhibits inside the Planetarium
3. Entertainment and information retrieval: for example, about films or stories
4. Social: for example, for group photos

An extract from the trip diary describes the first of these technology uses and an associated filter that was not initially clear:

"The first thing to grab students' attention at the Planetarium is 4.5 billion year old meteor. All of the students, who had mobiles with them, used them to take a photo of the meteor, with the exception of Student 1, who used his digital camera. Mentor 1 also used her digital camera. Interestingly, we were later informed that it's not permissible to take photos inside the Planetarium building but there were no signs to this effect inside the building and staff only objected when they felt we were taking too many."

The following were identified as the key foci for the students' technology related activity on the trip to the Planetarium:

a. Greenwich clock
b. Meteor
c. London skyline
d. Meridian line
e. Millennium dome
f. Planetarium
g. Space mission
h. Galaxies beyond our own

The card game process also enabled reseachers to identifiy some of the scaffolding and adjustment potentials for future development. For example, Table 2 describes these possibilities for a learner who is interested in astronomy and decides to use a digital camera to capture some data about galaxies whilst on a trip to the Planetarium.

TABLE 2
Scaffolding and Adjustment Potentials

Step	Actions to be completed by learner and More Able Partner (MAP)	Actions to be completed by design team to adjust and scaffold
1	Represent and communicate their mutual current understanding of the learner's EoR, in particular in terms of the knowledge or skill to be learned.	Provide facilities to enable the learner and MAP to represent and communicate their understanding. Astronomy example: Learner and learning advisor can compare and discuss learner's prior engagement with astronomy with available resources in the context of the trip.
2	Negotiate a shared representation of the goal or sub-goal of potential interactions (identify the recognition-production gap).	Provide facilities to enable the learner and MAP to represent and communicate their understanding. Astronomy example: Learner and learning advisor can compare and discuss learner's prior engagement with astronomy with available resources in the context of the trip.
3	Explore the resources identified in the learner's EoR model. In particular the filter elements and the extent to which these need adjustment.	Provide accessible descriptions of available resources. Astronomy example: Learner consults with museum staff to establish rules of engagement with setting; local signage also contributes to this; researcher-designer and learner discuss functionalities of technologies.
4	Select the resources most suitable for the learner and identify at what levels of difficulty and in what way these should be introduced.	Provide specifications of the range of resources, e.g. level of difficulty or range of locations. Astronomy example: learner and researcher-designer discuss opportunities for in situ transfer of data using mobile phone and Flickr.
5	Make decisions about who or what will be able to share the representation of the learner's Ecology of Resources.	Provide facilities to share/limit access to the evolving Ecology of Resources model of the learner. Astronomy example: learner and learning advisor discuss knowledge-sharing, audience and communicative purpose and transfer of information from Planetarium visit to Flickr or newsletter.
6	Access and activate the selected resource/s.	Provide facilities to enable resources to be accessed. Astronomy example: museum staff member gives learner permission to use digital camera to capture data/information about Galaxies.
7	Return to step 1.	-

Conclusion

The participatory process of the game design offered learners, mentors and researchers a focus for their conversations about the resources within the Ecologies of Resources of the learners at the Centre. Each step enabled a more sophisticated and refined identification, mapping and understanding of these resources, as required by the Ecology of Resources design framework. This refinement process can be summarised and generalised for use with other situations and participants as follows:

1. Provide opportunities to enable the learners and mentors to represent and communicate their understanding, for example, the Blank Card activity at iteration a of the game design.
2. Provide opportunities to enable the learners and mentors to negotiate the available resources and filters. For example, situating the game within learners' personal contexts of game play and technology use and only then proceeding to a shift to consideration of learning needs.
3. Provide accessible descriptions of the Resources available. For example, by considering the influences, limitations and potentials of available resources by category, and by introducing a sense of purpose – as with the trip activity.
4. Provide flexible specifications for the available range of resources. For example, co-design of rules of game play and aesthetics of game components.
5. Provide facilities to share access to the evolving Ecology of Resources model of the learner. For example, making connections between game play and a real world scenario.
6. Provide opportunities to enable resources to be accessed. For example, a real world scenario.

The researcher perspective alone can only produce a surface view of a learner's available resources and participatory working is essential to engage the social practices that can provide a wider perspective on contiguous environments. The continuing process of iterative participatory engagement at different times with participants whose experience and knowledge is diverse can help to sharpen the design focus. Rigorous models and frameworks are essential to the enterprise of developing TEE. The participatory process makes an key contribution to this rigour by enabling researchers to gain insight into some of the subtlety and richness of the interactions that comprise learners' experiences and contexts. The participatory process is embedded within the Ecology of Resources model and design framework. The growing body of empirical evidence about the use of the Ecology of Resources, such as that discussed in this

paper, support the contribution it can make to the important task of developing rigorous and testable models and frameworks that attempt to capture important aspects of the broader learning landscap of TEE.

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