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Visual forms of mediating artefacts: A research-intervention in engineering education

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Abstract

This paper describes a research-intervention to change technology-enhanced learning (TEL), in a setting of engineering education. It examines how participants used visual forms of mediating artefacts, that is, the means by which the group came together, examined and changed their own TEL activity. Engineering education, an arena that is highly dependent on visualisation and the promotion of visual literacy, largely constrains visual representations to instrumentalist and work-related applications, for the mental rehearsal of engineering solutions. This paper instead describes an activity theoretical perspective, where visual representations of social activity became mediating artefacts, sitting between a collective subject (of learners, lecturers and managers in engineering education) and the object of their activity (to change their TEL activity). In the study described, participants identified, curated and engaged with visual forms of mediating artefacts: stimulating their need and potential for change; assisting their questioning of social conditions and knowledge; and mitigating the reversal and regression of their endeavours. The research-intervention used the Change Laboratory methodology, engaging them in collaborative and agentic double-stimulation tasks through a process of expansive learning. The core claim is that visual forms of mediating artefacts played a crucial role in the group's qualitatively meaningful change to TEL, and in engendering their transformative agency.

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1. Introduction

This paper contributes to research of change to technology enhanced learning (TEL), specifically in engineering education where visualisation has a long history of influence (see e.g. Dickens & Arlett, 2009; Heywood, 2005; Nguyen & Khoo, 2009). Visualisation and visual literacy in education have been debated since the latter term was coined by Debes (1968). Contemporary researchers in education have adapted working definitions of visualisation to suit the increasing use of digital media and platforms (summarised by Baylen & D'Alba, 2015). The majority of researchers focus on visualisation and visual literacy for teaching and learning interactions, recognising a growing need for "evaluation of images and sources, the design and creation of meaningful images and visual media, ethical, legal, social, and economic issues" (ibid., p. xiv). Turning specifically to engineering education, visualisation is one of six "Engineering Habits of Mind" (Lucas & Hanson, 2016), used in education to conceptualise "how successful engineers think and act when faced with challenging problems" (p. 7). Engineering projects are highly visual endeavours in work and learning, and are described as "situated, collective practices which create a visual culture" (Henderson, 1999, p. 26). And yet in the current literature, there is a shortfall of research examining visual forms of mediating artefacts, engaging people in envisioning and enacting visible and agentic change (Engeström & Sannino, 2012). Research of engineering education tends to analyse visualisation in direct instruction, preparing learners for the workplace. Visualisation is thus crucial in engineering education yet is seldomly valorised for mediating agentic change, or to critique the "nature, methods, limitations, and validity of knowledge" (Kirschner, 2009, p. 144).

Visualisation and visual literacy are commonly framed by researchers of engineering education as providing instrumentalist, outcome-driven, cost and time benefits for mental rehearsals: relatively low consequence "venues for virtual experimentation" (Harrison, 2012, p. 24); expedient schemata for people and technologies to "interact, perform and adjust for accuracy" (MacKenzie, 2018, p. 360); and means to compare proposals with "physical space and practical design solutions" (Lucas & Hanson, 2016, p. 6). In engineering education visualisation is promoted, valued and exhibited across all components of visual literacy theorised by Avgerinou and Pettersson (2011): visual thinking; visual communications; visual perception; visual language; and visual learning. Yet visualisation is less valorised in *change* to TEL; where visual techniques and representations of social activity allow people to question the nature and validity of knowledge and its meaning. In the study described in this current paper, these visual representations of social activity were used as *mediating artefacts*: sitting between people and the attainment of social motives; being controlled by people to influence social conditions; and being imbued with markers of their own development (Kuutti, 1996).

This current paper describes research in education for built infrastructure engineering. Cultural and historical activity theory (CHAT) guides a research-intervention using the Change Laboratory methodology (Engeström et al., 1996). Assisted by visual forms of mediating artefacts, a group of learners, lecturers and managers collaboratively engaged in understanding, critiquing and redesigning their own TEL activity. Visualisation informed their collective, agentic and problematic endeavours, with change originating in "simple modifications in the way groups of people argue with one another using paper, signs, prints and diagrams" (Latour, 1986, p. 3). During the research-intervention visual representations were used as cultural tools and signs, sitting *between* the collaborative subject of activity, the learners, lecturers and managers involved in TEL, and the object of their activity—to change their unsatisfactory and sub-optimal experiences of TEL. Mediating artefacts played crucial roles in double-stimulation tasks, through which the group changed activity in a process of *expansive learning*. They reconceptualised their activity, leading to its "radically wider horizon of possibilities" (Engeström, 2001, p. 137). Expansive change engendered the group's *transformative agency*, a term depicting how people "break away from the given frame of action and take the initiative to transform it" (Virkkunen, 2006, p. 49). The core argument of this current paper is that mediating artefacts used in double-stimulation tasks enabled the group to undertake expansive change, engendering their transformative agency, through the exposure and aggravation of problematic social conditions of their TEL activity.

In engineering education, there are pragmatic reasons for the dearth of researching agentic engagement. Firstly, as an educational arena which prepares learners for a 'profession', engineering contends with historically embedded expectations where societal access to knowledge and information is controlled by unquestioned, formally appointed institutions (Rueschemeyer, 1983). This impedes the research of democratised and agentic engagement, which could "make knowledge visible so that it can be better accessed, discussed, valued or generally managed" (Eppler & Burkhard, 2004, p. 3). Secondly, in the "hard applied field" of engineering education (Becher, 1989) research agendas tend to prioritise visualisation for work-related outcomes, which in recent decades has driven the commercialisation of knowledge transfer in computer aided engineering, digital modelling and spatial

ability (Heywood, 2005). These agendas hamper research of agentic interactions with visualisation—irrespective of how they enhance learning—where epistemic and social relations do not directly translate to work (Winberg, 2012). Thirdly, the success of engineering education is persistently measured in economic terms (Brookfield, 2018). This means that educational managers are more likely to request and resource research which prioritises the business gains of education, directly and measurably "pertinent to the needs of employers" (Tennant et al., 2009, p. 111).

These drivers to prepare work-ready engineers are compelling, and they often direct research of visualisation with instrumentalist gains; preparing learners for known work yet eroding society's ability to meet unexpected challenges (Giroux, 2011). Instrumentalist gains of research with visualisation compress the time and cost of engineering projects, reducing errors to enhance products and services. These are important capabilities for students of engineering, characterising the historically embedded "visual culture of the engineering profession" (Henderson, 1999, p. 25). Yet the result is that more agentic interactions with visualisation are unexamined, or perceived as an obstruction to efficiency and profit. In a seminal piece of research for visual learning design, Winn (1982) describes the pursuit of visual learning experiences for engineers to the point where "anything more elaborate than telling learners what is expected of them would be a waste of time" (p. 21). In their examination of knowledge visualisation, Cañas et al. (2005) describe how research opportunities are dependent on quantifiable benefits to the business community, who "carefully analyse how better elicitation, representation and administration of their knowledge can give them a competitive advantage" (p. 205). In researching visualisation tasks in virtual laboratories and the design of virtual internships for engineers, Alekseev et al. (2019) describe primary benefits in terms of cost, time and closer alignment with the professional practices of workplaces and government departments.

In some contrast, a burgeoning body of researchers study visualisation in engineering education through more agentic and critical perspectives, often following the path of social sciences: examining how "insignificant people working only with papers and signs become the most powerful" (Latour, 1986, p. 30); studying how "visualisations facilitate reflexivity in the research process" (Löfström et al., 2015, p. 193); and using visual techniques to "foster awareness and reflection about learning processes or changes in them" (Klerkx et al., 2014, p. 801).

In a study to increase critical thinking amongst engineering students, Shatri and Buza (2017) investigate visualisation for "self-directed, self-corrective thinking in learning" (p. 73) to move away from conceptions of learning as limited to memorisation and recall. In researching the challenges faced by students in their scientific visualisation, reasoning and problem-solving, Chaudhury et al. (2015) examine how agentic engagement can "make concrete that which is not apparent to the naked eye and thereby engage and inspire learners" (p. 197). In examining visual techniques for digital collaborations amongst interdisciplinary groups of engineers, Kerosuo (2017) comments on the need for models to be sufficiently accessible to identify potential for change "through the participants' collective constitution of the problems and tensions to be solved" (p. 345). These researchers share interests in participant agency, a notion which also guided the study in this current paper.

Subsequent sections describe a study of change to TEL in engineering education, with CHAT as its theoretical framework and the Change Laboratory methodology guiding the research-intervention (Bligh & Flood, 2015). In this paper, I respond to the research question:

> How can visual forms of mediating artefacts, in a research intervention in TEL for engineering education, inform expansive learning and engender participants' transformative agency?

Visual forms of mediating artefacts were used by participants to enhance their understanding of the problematic circumstances of learning activity, engendering and tracing their agentic change endeavours. The project that I analyse was motivated to address persistent practice dilemmas in TEL. The site was an undergraduate engineering programme, where participants had experienced the top-down implementation of digital technologies, with little regard for broader social implications. As a teaching-focussed lecturer in the setting, I led the project as an insider researcher. The overall description of the project, with detailed accounts of the constellations of mediating artefacts and the participants' eventual solutions to practice dilemmas are described elsewhere (Moffitt, 2019). This paper focuses on the visualisation-oriented aspects. Subsequent sections describe the theoretical and methodological aspects of the study.

2. Theoretical framework

CHAT (Engeström, 1987/2015) is a specific form of activity theory which foregrounds temporal context and cultural mediation; activity cannot be understood or changed without awareness of its historical evolution and the culture in which it occurs. CHAT takes human activity (as discrete

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from stimulus-response associations) and represents it as an activity system where a subject, an individual or group, is oriented to an object (Yamagata-Lynch, 2010). This subject-object relationship is mediated by a constellation of artefacts. An activity system represents this mediational relationship along with the activity's rules, community and division of labour, making it useful for studies of collaborative TEL. CHAT allows the examination of internal and external relationships of these elements as contradictions, advantageous in researching complex situational dynamics such as changing TEL (Bligh & Flood, 2017). The Change Laboratory methodology was originally designed by activity theorists to be commensurate with CHAT, enabling researchers to analyse the interactions between different perspectives of shared situations. Key concepts are described below.

1. *Artefacts* are technological and conceptual tools, which mediate between people and the object of their activity. Artefacts are products of cultural and contextual requirements (Kaptelinin & Nardi, 2006), as tools (shaping the world) and signs (shaping the mind). They carry traces of their own cultural and historical development which influence their use. Artefacts can be digital or analogue, see examples in Figure 1: an interactive whiteboard, a smartphone, and a pencil sketch on paper.
2. *Activity* describes collaborative and sustained human endeavour, mediated by artefacts, regulated by rules, with roles differentiated by specialisation and authority (Blunden, 2010). Activity is motivated toward and defined by its object; the object gives activity meaning. Relationships between elements commonly focus studies of activity in educational settings (Bligh & Flood, 2017). The visualisation of activity can be represented as an activity system, an example in Figure 2 showing typical TEL activity.
3. *Contradictions* are historically emergent systemic problems, originating in tensions between use-value of activity's production (for direct application) versus exchange-value (for trade with another commodity) (Engeström & Sannino, 2011). Contradictions are not merely more-or-less attractive dilemmas; they are mutually oppositional, interdependently defining, and potentially negating of each other. Their resolution will drive further contradictions. They exist in various forms within and between activity systems, as illustrated in Figure 3.
4. *Ascension* from the abstract to the concrete is a Marxist concept describing progression from theorizing and observing activity, towards exhibiting transformation and change to activity (Bligh & Flood, 2015). An abstract notion is one which is undeveloped and "thin in content", whilst a concrete notion has developed connections and is "rich in content" (Blunden, 2010, p. 62). Of note, the term ascension may imply a vertical datum, although it encompasses horizontal and relational expansion (Engeström & Sannino, 2016).
5. *Expansive learning* is a process of cyclically reconceptualizing a developing activity, reconsidering and expanding its object, overcoming contradictions to reach "wider horizons of possibilities" (Engeström, 2001, p. 137). Expansive learning has a recognised, relatively stable and iterative cycle which is shown in Figure 4 with expansive actions: questioning; analysing (historical-genetic and actual-empirical); modelling; examining the model; implementing and concretising the model; reflecting and evaluating; and consolidating and generalising. These have empirical and theoretical validity for interventions, as a predictive tool and as a guide for design (Engeström, Sannino & Virkkunen, 2014). Expansive learning is intrinsically related to the intervention's provocation and study of transformative agency.

Figure 1. Examples of visual forms of mediating artefacts in use to change TEL

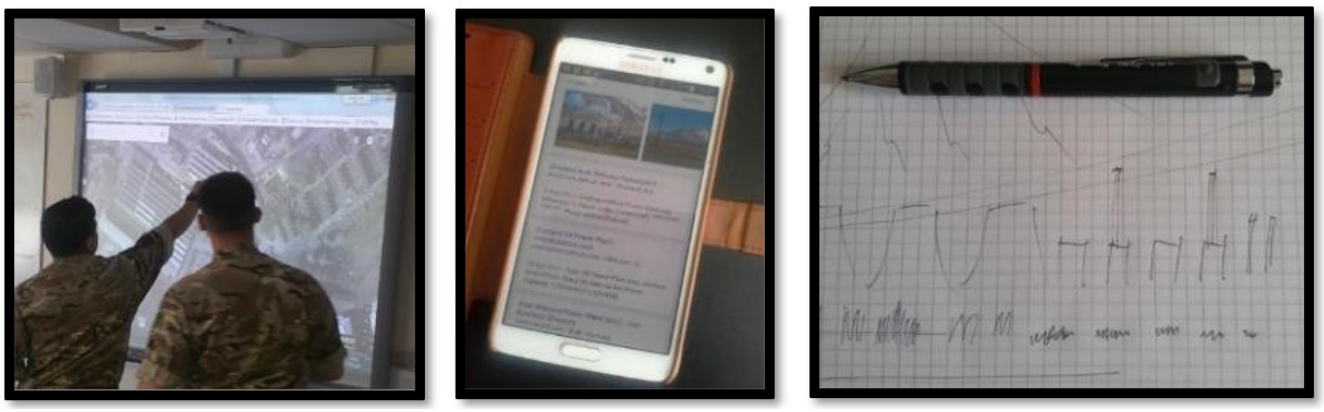

Figure 2. An activity system for TEL, adapted from Engeström (1987, p. 78)

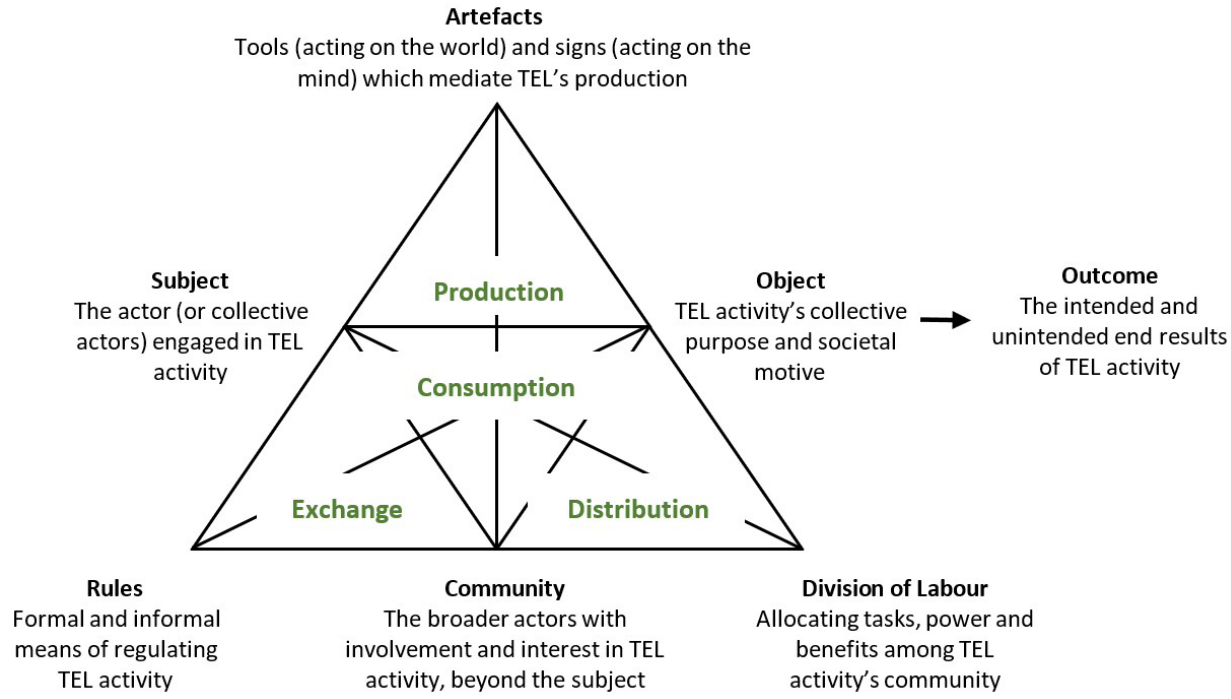

Figure 3. Examples of contradictions, adapted from Yamagata-Lynch (2010, p. 24)

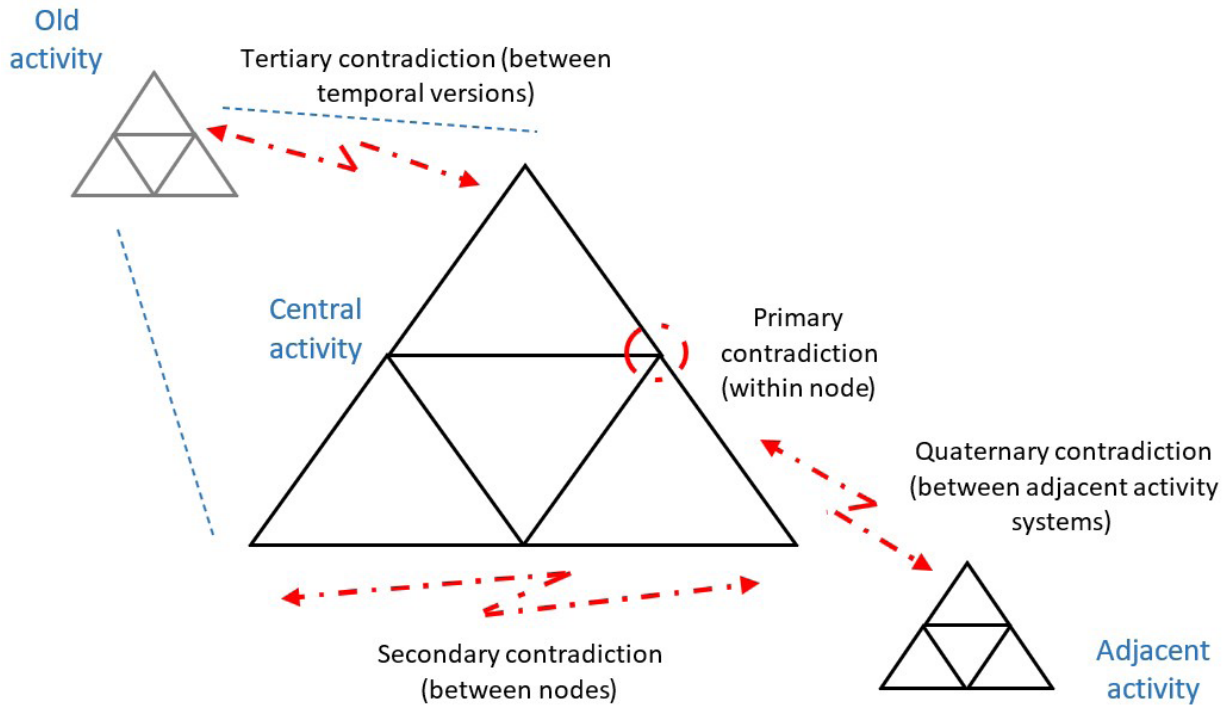

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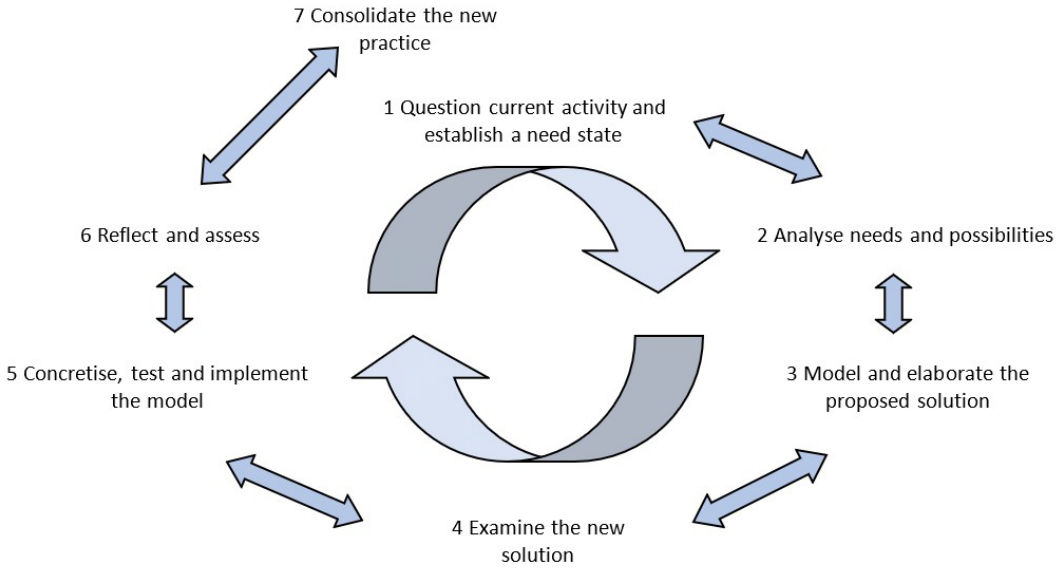
Figure 4. Actions in expansive learning, adapted from Engeström (1994)

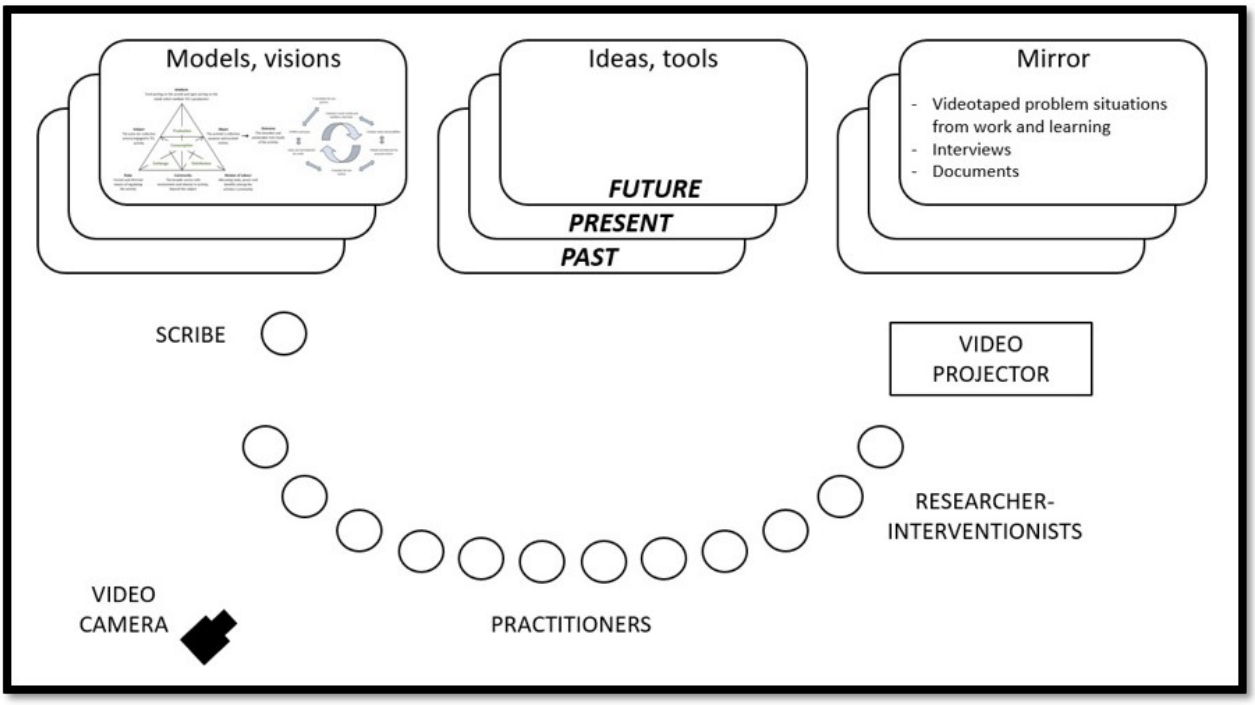


6. *Transformative agency* is a collective characteristic of a group undertaking expansive learning. It describes a level of shared subjectivity, where they negotiate and enact collaborative and future oriented decisions. It requires the destabilisation of social, cultural and structural norms typically through six exhibited expressions (Haapasaari et al., 2016): resisting; criticizing; explicating; envisioning; committing; and taking action. Resisting means opposing the change, new suggestion or initiative. Criticizing describes identifying problems in current working and learning. Explicating is the explanation of new possibility and potential for change. Envisioning means exhibiting future-oriented observations and visualisations. Committing to action describes self-obligating and specific details of concretisation. Lastly, taking action describes accounting for consequent concretisation
7. *Double-stimulation* (or dual-stimulation) is a Vygotskyan method and principle, which inspires task designs for Change Laboratory sessions (Sannino, 2015). Double-stimulation task designs are visualisation-intensive, requiring consideration of conflictual aspects of change; without conflicting motives and volition to work through them, attempts at double-stimulation will revert to general mediation of activity (Sannino & Engeström, 2017). The first stimulus comprises the task specification with conflicting motives for participants. The second stimulus is the analytical tool or method which participants are invited to think with whilst they address the first stimulus. In undertaking these tasks, participants refer to mirror-data; materials used by researchers and participants to visually represent their practice problems and contradictory situations, "provoking visceral reactions within sessions and conveying that problems exist *undeniably*" (Bligh & Flood, 2015, p. 156, original italics).

3. Methodology

The Change Laboratory methodology is theoretically aligned with CHAT, applying the methods and principles described above in ways developed by activity theorists for collaborative interventionist-research (Engeström et al., 1996). Its aim is to foster engagement of a group in expansive learning; they engage in double-stimulation tasks to change activity, developing their transformative agency (Sannino & Engeström, 2017). The methodology takes as its developmental starting point activity's contradictions, felt by participants as dilemmas in their activity's daily reality. Through multi-voiced negotiation, they take charge of changing activity by exposing, aggravating and developing solutions to contradictions. Participants use cues such as modelled expansive cycles, historical and future visions of activity, images and documents "couched in terms of CHAT which they can then use to analyse the contradictions, tensions and dilemmas that exist" (Daniels et al., 2007, p. 131). The means for the group to facilitate, trace and re-present their generation, critique and testing are provided in a dedicated space with surfaces for visualisations through time and at varying degrees of concretisation: models/visions; ideas/tools; and mirror-data (Cole & Engeström, 2007). Examples are shown in Figure 5.

Figure 5. Configuration of surfaces, adapted from Cole and Engeström (2007, p. 484)



The participants of the study comprised ten learners, six lecturers and three managers of an undergraduate degree in built infrastructure engineering. The research-intervention took place in fourteen 90-minute sessions across a period of 18 months, in separate sub-groups for some particularly problematic stages and plenaries of all participants for the majority of sessions. Plans and intentions for sessions were negotiated during cessation of the prior session, with time between to reflect and prepare.

Task stimuli were communicated on surfaces and in workbooks known as "Disturbance Diaries" (Virkkunen & Newnham, 2013, p. 239). These encouraged personal notes and visualisations to record: observed dilemmas in activity; proposals for collaborative examination of problems; and personal concerns for the intervention in general. It was in these fourteen sessions that the results in the next section were generated.

4. Results

The results below provide evidence of how the intervention's visual artefacts mediate activity, provoking the participants' expansive learning as they undertook change to TEL. Firstly, tabulated and graphical data summarise the emergence of transformative agency across the research-intervention. Then selected visual evidence and related speaking turns exemplify how the intervention's constellations of artefacts, including visual stimuli, were identified, used and adapted to foresee and enact change to TEL activity.

In double-stimulation tasks, visual stimuli invited participants to understand and engage in their conflictual social circumstances; the results highlight the qualitatively impactful role of visualisation. Table 1 shows a total of 750 turns of speech expressed in the research-intervention. Each session is listed, with the expansive action that primarily focused its double-stimulation tasks, and with co-occurrences of expressions of transformative agency. The most frequent expressions were those explicating possibilities, evident in 192 turns of speech. The least frequent were expressions of having taken consequent action, evident in 82 turns of speech. Figure 6 graphs the emergence of expressions across the intervention.

The visual surfaces in use during a typical session are shown in Figure 7, with a double-stimulation task taking place in the "interplay between emotional involvement and theoretical-genetic reflection" (Virkkunen & Ahonen, 2011, p. 237). Using these surfaces, participants collaboratively accessed, created and curated visual forms of mediating artefacts. The models/visions surface to the left illustrates two persistent mediating artefacts; an expansive cycle and

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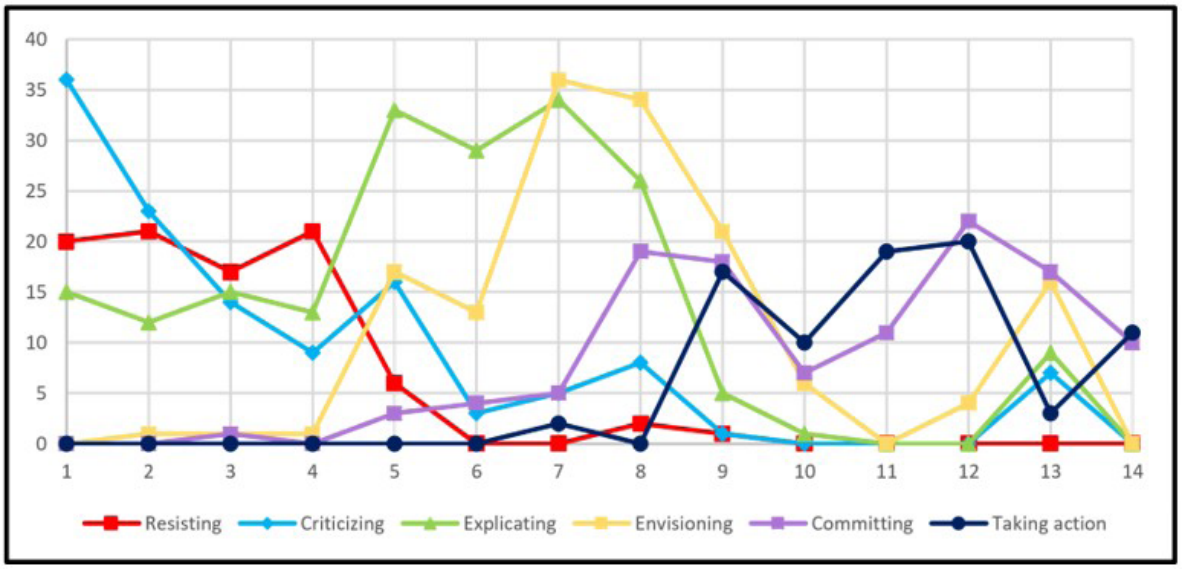
Table 1. Turns of speech relating to expressions of transformative agency in sessions

Session	Resisting	Criticizing	Explicating	Envisioning	Committing	Taking action
1. Questioning - learners	20	36	15	0	0	0
2. Questioning - lecturers	21	23	12	1	0	0
3. Questioning - managers	17	14	15	1	1	0
4. Questioning	21	9	13	1	0	0
5. Historical analysis	6	16	33	17	3	0
6. Actual-empirical analysis	0	3	29	13	4	0
7. Modelling	0	5	34	35	5	2
8. Examining	2	8	26	34	19	0
9. Implementing - learners	1	1	5	21	18	17
10. Implementing - lecturers	0	0	1	6	7	10
11. Implementing - managers	0	0	0	0	11	19
12. Implementing	0	0	0	4	22	20
13. Reflecting / consolidating	0	7	9	16	17	3
14. Reflecting / consolidating	0	0	0	0	10	11
TOTALS	**88**	**122**	**192**	**149**	**117**	**82**
PERCENT OF TOTAL	**12%**	**16%**	**25%**	**20%**	**16%**	**11%**

Figure 6. Turns of speech with expressions of transformative agency (Y axis) in sessions (X axis)



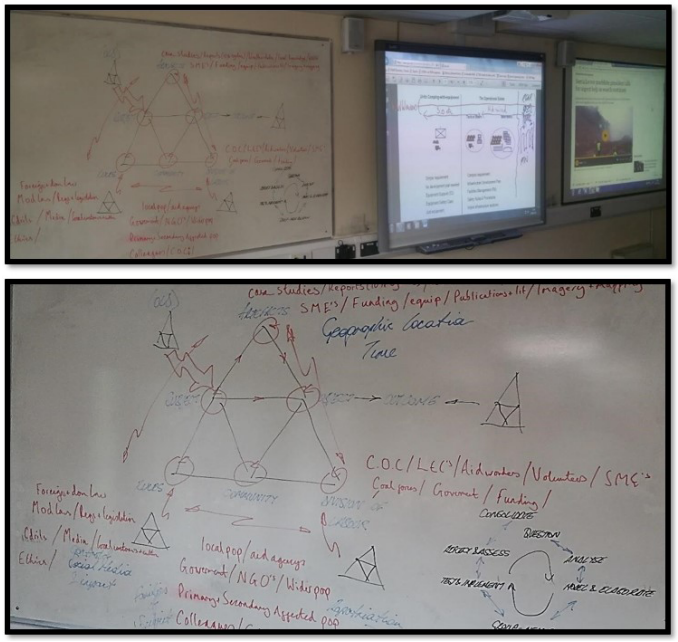
an activity system. The ideas/tools surface in the centre shows illustrations in a policy document for engineers being imbued with questions and queries. The mirror-data to the right shows video footage of previous engineering projects involving the participants, highlighting irrefutable evidence of the problems being discussed. These surfaces show how participants expansively modelled and examined new activity, during an iterative double-stimulation task entitled "examining the redesigned activity", which invited participants to consider how proposals for change might aggravate contradictions in TEL activity.

The examples of speaking turns below are from the same double-stimulation task as the one on the surfaces in Figure 7, emphasising the role of mediating artefacts for expansive collaborative interactions and for engendering transformative agency. Participants refer to and modify the elements of their visual activity systems as they expose and aggravate contradictions within and between them, engaging with their visual expansive cycles as they recognise the actions that they have undertaken, are undertaking and have yet to undertake. These turns of speech were troublesome, visceral and appropriate in the context of the group's examination of conflictual social circumstances; they convey the qualitatively impactful role of mediating artefacts and double-stimulation tasks.

> We've always done it like we've always done it, and we pretend we're keeping up with the rest of the world [motions to old activity system, *criticizing*] … we've got to do it to suit the future us, whoever the [expletive] that is … it was us we made it work here [motions to mirror data] and we can again [motions to ideas /tools, *explicating*] but it'll be with IT you don't like [motions to artefacts] and people you don't like [motions to division of labour] and shove your rules up your [expletive] [motions to rules]. (*Carlton, session 5 – historical analysis*)

> We can [expletive] it off [motions to model and elaborate] but then absolutely nothing will change, instead we need to think about all the good stuff and put it in here [motions to new activity system, *explicating*], so it kind of focuses you … these [motions to old activity system and expansive cycle] help you [identify] things you wouldn't have the [expletive] to just say, but it's hard to avoid when this [expletive], well, when it's staring you in the face … here's our own bosses [circling community] … so that's between here and here I reckon [drawing contradiction lines between community and division of labour, and between artefacts and division of labour] [*envisioning*]. (*Gerard, session 6 – actual empirical analysis*)

Figure 7. Typical surfaces in use during sessions



The quotes summarise how participants problematically engaged with visual task stimuli and mirror data to deliberately envision, represent and preserve their progress, exposing and aggravating contradictions in activity. They convey the importance attributed to their visual mediating artefacts while examining proposals for new activity and understanding its historical evolution; by this point the object had eroded to the point where "the existing conceptualisation of the object and the tools available no longer match with it" (Virkkunen, 2004, p. 43). In these circumstances the object of activity demanded reconsideration prior to proposing new mediating artefacts—*the object of activity gave activity its purpose*. Carlton's quote exposes the futility of incremental and additive changes to technologies, until the group had reconsidered the object *prior* to activity's mediation (c.f. "it'll be with IT you don't like and people you don't like and shove your rules up your [expletive]"). Similarly, Gerard's quote acknowledges historically embedded contradictions, through dilemmatic conditions where strategists had implemented change to digital artefacts without changing social and cultural mediation by examining the division of labour and rules (c.f. "absolutely nothing will change … it's staring you in the face").

These data show participants' agentic engagement with visual forms of mediating artefacts, and the importance for social and cultural mediation of rules, community and

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division of labour. In double-stimulation tasks, transformative agency was engendered as participants developed their task stimuli, by either: modifying and using visual artefacts provided to them by the researcher-interventionist (such as partial models of activity in TEL and expansive cycles); or using visual artefacts identified by participants themselves, when "the subject spontaneously involves some artefact as an instrument in the problem-solving process" (Virkkunen & Newnham, 2013, p. 47). As examples of the latter, second-stimuli such as disturbance diaries, activity systems, expansive cycles, and more locally familiar mediating artefacts were iteratively imparted with qualitative meaning by participants, as increasingly expansive double-stimulation tasks engendered their transformative agency. Table 2 summarises notable examples; this format allows comparison with other interventions in Virkkunen and Newnham (2013, p. 213). The table exemplifies how participants engaged with these visual mediating artefacts to confront problems, "visualizing and documenting collective thinking" (ibid., p. 10).

5. Discussion

The research-intervention's participants called upon, modified and shared constellations of diverse artefacts in changing TEL, yet this paper's research question focuses specifically on *visual* forms of those mediating artefacts, how visual stimuli inform expansive learning and engender participants' transformative agency. In the introduction, pragmatic reasons are described for the preclusion of agency in much research in engineering education. The results highlight how the status quo was confronted and rejected by participants in expansive endeavours, often with emotive and visceral reactions. They identified, curated and engaged with visual forms of mediating artefacts to focus on problems and to change the social and cultural conditions of their TEL.

Visual artefacts were identified, adapted and shared by participants, allowing them to collaborate in ways that

Table 2. Examples of imagery as created second-stimuli for problem-solving

Notable phase of development	First-stimuli	Central internal contradiction	Created second-stimuli
In turning from questioning to analysing, participants took control of identifying, curating and re-presenting their own mirror data and second-stimuli.	Questions in workbooks asked about experiences of problems with old activity. To plan the collaborative journey, the group annotated an expansive cycle for the intervention.	Identifying old activity's historically embedded forms of secondary contradictions: rules / division of labour; rules / artefacts.	Live disturbance diaries were published by participants, with sub-groups responding to other sub-group's accusations as a plenary to identify and further aggravate contradictions.
In moving from examining to implementing, group experiences of aggravating secondary contradictions resulted in the need for remote trials of change.	Questions examined the group's competing obligations: on one hand, compliance with rules on communication and security; on the other hand, the need to complete given tasks.	Informal reality of TEL's horizontal division of labour, versus formal rules denoting a vertical division of labour in teaching / learning.	Participants' new model of TEL activity, resulting from iteratively resolving and generating secondary contradictions and redefining the object of activity.
In reflecting, consolidating and follow-up work, participants proposed and concretised visual media for use as second-stimuli in future interventions.	Questions to extract concerns for sustenance postintervention, specifically risks of regression and reversion to historically established rules and divisions of labour.	Potential for change to revert, driven by TEL's historically embedded contradictions of new rules / old divisions of labour.	Participants curated imagery of changed TEL activity to legitimise, normalise and consolidate in corporate media and social network accounts. Used as future mirror material.

fostered their transformative agency. Participants appropriated and adapted artefacts "in order to empower themselves and fulfil their objects" (Kaptelinin & Nardi, 2006, p. 248). Their transformative agency emerged as they confronted complex problems and engaged in systemic change (Haapasaari et al., 2016). Their visual second-stimuli were imbued with meaning, as participants identified ways to use visuals forms of mediating artefacts to assist them in confronting and changing problematic conditions of TEL activity. The use of mediating artefacts, to elucidate and overcome what were previously irresolvable problems, is a defining feature of double stimulation (Virkkunen & Schaupp, 2011, p. 634).

In the first example in Table 2, visual stimuli in disturbance diaries legitimised participants, at very different hierarchical levels, to challenge one another and allocate responsibility for problems. These visual forms of mediating artefacts became instruments for change, offering a solution to challenges described by Eppler and Burkhard (2004), where "communication between different stakeholders and experts with different professional backgrounds is a major problem" (p. 5). In the second example in Table 2, visual models of activity and expansivity enabled participants to propose and model change, exposing and aggravating contradictions to redefine the object of activity. They used visual stimuli to confront notions of TEL as solely preparation for work, with cultural sensitivity for "what engineers do at work to show the relevance or otherwise of education" (Heywood, 2005, p. 28). In the third example in Table 2, participants further embellished these visual models, incorporating imagery of their redesigned activity into routine corporate publications and social networking, seeking to mitigate regression of change due to historically embedded contradictions between new rules and old divisions of labour. This ongoing challenge and enduring commitment to confront embedded divisions of labour relates to the observation made by Kerosuo (2017) where "collaboration is challenging because the players stick to old, routine practices that are difficult to change" (p. 332). Learners in particular used visual stimuli in expansive and agentic ways, disproving Tennant et al.'s (2009, p. 129) framing of a passive "Google-eyed YouTube generation, no longer the people our educational system was designed to teach".

In contrast with the visual forms of mediating artefacts summarised in Table 2, which became enduring instruments of change in the local setting, other problematic conditions proved to be stubborn barriers to consolidation, providing further research opportunities. Persistent problems include: visual media for TEL which prioritise fidelity over contextual value; complex hardware and software which proves materially unmanageable for spontaneous visualisation; and novelty of media and platforms being prioritised to the detriment of enhancing learning. These encapsulate broader problems of agency, visualisation and TEL, noted in Henderson's (1999) seminal work on the visual culture of engineering: "Because of the glamorous aura of high technology, we often forget the human agency that is required to fit the new technology into settings and practices" (p. 197). The results illustrate valuable perspectives for agentic change by participants themselves, with visual stimuli used in a research-intervention for "challenging conventional wisdom and reconceptualising activity" (Bligh & Flood, 2015, p. 142). And yet the consolidation will *never be complete*; there is an enduring need to intervene, otherwise these artefacts may revert to merely being "new visualisations of current socioeconomic conditions" (Avis, 2010, p. 169).

6. Conclusions

This paper contributes to research of change to TEL in engineering education, a field where visualisation has a long history of influence. The paper seeks to shift prevalent conceptions in engineering education, which limit visualisation to its instrumentalist benefits for mental rehearsals of engineering solutions. The research-intervention examined in this paper took a different perspective, illustrating CHAT's ability to assist people in exposing and aggravating their activity's contradictions, enabling them through visual task stimuli to undertake expansive change. They took control of visual forms of mediating artefacts for themselves, to examine, understand and change the social and cultural conditions of their TEL, engendering their transformative agency. Without such agency change may have continued against their will, in forms which were regressive as discrete from progressive (Hardman & Amory, 2014).

Löfström et al. (2015) describe commonly encountered challenges of research with visualisation: participant hesitancy; inter-rater reliability; and "dependability, ethics and issues of ownership and interpretation" (p. 194). In this study, visualisation was instead designed and curated in the form of mediating artefacts for change to TEL: participants themselves owned decisions about selection and use; mirror-data provided them with irrefutable evidence of problems in activity; they used visual cues to engage with the first-stimuli and its conflicting motives; and they developed second-stimuli for themselves, to expose and aggravate contradictions, developing ambiguous and partial tools and signs into qualitatively meaningful instruments of change. As they did so, they "developed and used external artefacts to

control their own actions, not as isolated individuals but as members of a community" (Virkkunen, 2006, p. 49)

The core argument I make is that visual forms of mediating artefacts, a special application of visualisation, engendered transformative agency during this group's expansive change to TEL. A caveat is that the consolidation of expansive change is never complete, and further interventions are required in ways which will not simply transpose the researcher-interventionist agendas in place of those problems which are being confronted. The dilemmas of expansion and regression for change to TEL relate to the "two-edged sword" of expansivity for the Change Laboratory methodology itself (Virkkunen & Newnham, 2013, p. 235). Ongoing consolidation of change to TEL ought therefore to be mitigated, as it is for the methodology itself, by committing to further research to expose and aggravate persistent contradictions in TEL activity; a long-term collaborative project with crucial roles for visual forms of mediating artefacts.

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