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What could Learning Analytics learn from Human-Computer Interaction theory?

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The design of Learning Analytics tools is an example of the general problem of designing interactive tools, which is the focus of Human-Computer Interaction (HCI) research and design practice. LA as a field must understand how to embed LA into organisations and the design of effective, trustworthy human-computer systems is where HCI theory and practice have much to offer. Consequently, this chapter argues that LA can learn from (i) the way that theory has evolved in HCI, (ii) the field's methods for evaluating interactive systems at different scales, and (iii) HCI debates how established *scientific* theories and methods relate to *design* theories and methods. As a highly interdisciplinary applied field, LA (like HCI) faces the challenge of maintaining academic standards in the conduct and review of research from many disciplinary traditions. I propose that HCI offers inspiration for researchers seeking rigorous methods to design and evaluate LA in authentic contexts, including principles to maintain their intellectual rigour, which will also be of interest to LA journals and conferences seeking to maintain peer review standards.

Keywords: Human-Computer Interaction (HCI) Theory , Design Theory, Evaluation Methods, Peer Review

1 Introduction

In this chapter, I consider how the Learning Analytics (LA) community, not yet in its teens, could learn from the 40+ years experience in the Human-Computer Interaction (HCI) community grappling with the role of theory in response to the digital revolution since the 1980s. As we will see, HCI frames human interaction with technology in diverse ways, that certainly includes individuals interacting with software tools to perform discrete tasks (LA's currently dominant paradigm), but extends well beyond this.

For some, the attraction of LA as a field is the prospect of affordable sensors and data-intensive tools to research learning or teaching in ways that were previously impossible, or too expensive. Improving our foundational understanding of these forms of human activity is of course important, and just as advances in instrumentation have revolutionised science, data science is now transforming fields such as genetics, astronomy, and high energy physics, in what some have called *The Fourth Paradigm* [30]. But if LA only refers to the data science revolution for highly trained researchers, why would we look to HCI for insights? The answer is, of course, that since its earliest days [64], what has differentiated the LA community from its more technical sister communities (such as educational data mining, or artificial intelligence in education) is an interest in designing effective *sociotechnical* systems that make more effective use of data and analytics. Specifically:

> "The new possibility is that educators and learners — the stakeholders who constitute the learning system studied for so long by researchers — are for the first time able to see their own processes and progress rendered in ways that until now were the preserve of researchers outside the system. [...] So, for *educators and learners*, the interest turns on the ability to gain insight in a timely manner that could improve outcomes." [36]

Framed thus, we need to design effective systems that can be used not only by data-literate researchers or institutional analysts, but by learners, educators, student support teams and others as part of their everyday lives [68]. For these users, LA tools are data-intensive instances of educational technology tools. Consequently, LA as a field must understand how to embed LA into their targetted organisational entities [8, 29]. I will argue in this chapter that the design of effective, trustworthy human-computer systems is where HCI theory and practice have much to offer LA theory and practice.

2 The historical roots of the HCI/CHI communities

Detailed accounts of the history of HCI are available to those interested [26, 62], but for this chapter's purposes, a brief account suffices. The first conference on *Human Factors in Computing Systems* was convened in 1982 in the USA, under the auspices of the Association for Computing Machinery (ACM), catalysing the *Computer-Human Interaction (CHI)* community as it came to be known, which was a helpfully pronounceable acronym. This led to the formation of the ACM Special Interest Group (SIGCHI), now one of the largest of all ACM SIGs. CHI/HCI built, in turn, on fields such as Human Factors (as it was best known in North America) and Ergonomics (Europe), both of which had for decades been researching and informing the design of safe and effective working equipment and environments, addressing the many factors other than software that shape quality of working life (e.g., furniture; lighting; noise; shift-work; cognitive load; instrumentation; allocation of function between humans and machines). The software revolution, catalysed by the work of pioneers such as Douglas Engelbart on "augmenting human intellect" [19], foregrounded new subfields with names such as cognitive ergonomics and cognitive systems engineering [18, 31, 39]. Complementing this 'turn to the cognitive', notably in Scandinavia since the 1970s, was research and practice around the *participatory design* of work systems, with particular attention paid to politics — the asymmetric power between management and (often unionised) employees. With increasing automation and the personal computer revolution in the 1980s, Kristen Nygaard, for instance, was prescient in advocating for "data shop stewards", meaningful staff consultation, and attention to how staff social networks could be impacted by automation [46]. Christiane Floyd and colleagues published a landmark paper in *HCI* journal in 1989 [22], bringing this tradition to the attention of the wider international community, and the Participatory Design Conference has continued to run bi-annually since 1990.

As will be detailed later, HCI research greatly expanded from these initial roots, drawing on, and developing, diverse theories in response to the technological revolution in interactive, social computing since the first days of personal computing in 1980s. It was because of this rich history in HCI that since 2012 when the second *International Conference on Learning Analytics & Knowledge (LAK)* was held, LAK has been formally "in cooperation" with the ACM SIGCHI with archival proceedings in the ACM Digital Library.

3 HCI's first contribution to LA: giving a voice to end-users

To date, arguably the most impact that HCI has had within LA has been in design and evaluation methodology, through efforts to adopt and adapt processes and tools that make it possible to bring non-technical stakeholders into the design process. As summarised in a 2019 journal special issue dedicated to *Human-Centred Learning Analytics*, a number of established methods from user-centred design (UCD) and participatory design (PD) are beginning to be used by LA researchers and vendors [9]. Such approaches seek to give a meaningful voice to students [3, 15] and educators [32, 71]. The rich array of methods and processes developed in these traditions attends to how one can cultivate productive design conversations among diverse people, through various strategies including:

- attending to the intelligibility, malleability and accessibility of design representations and artifacts (using "low-tech, high-touch" physical media for prototyping; or using design-oriented playing cards to help articulate viewpoints);
- addressing the power-imbalances between technical experts and less technical stakeholders;
- opening up the earlier stages to stakeholders to influence the conception of a future system, not merely testing late stage software.

While these processes are far from embedded practice in LA system design, UCD/PD are arguably the most clearly understood HCI contribution to LA so far, with new examples being published on a regular basis [2, 44, 55]. Accordingly, the remainder of this chapter is devoted to facets of the LA/HCI nexus that have received far less attention, namely, the role of *theory* in designing interactive systems, and since theory must translate into practice, *research methods* and *evaluation methods* that bring theoretical assumptions, and which may also help to advance theorising and making evidence-based claims about the human experience of LA.

4 Learning from the evolution of HCI theory

The first interactive personal computers became available to the public in the early 1980s, and the HCI design challenge then was to establish a closer coupling between how non-technical citizens thought and acted, and how software behaved. The technological landscape has of course undergone a revolution since then. Reflecting in 2011 on the field's 30th birthday, a distinction made by CHI veteran Ben Shneiderman [61] was between *micro-HCI* and *macro-HCI*. Micro-HCI is perhaps how many of the LA community might first intuit HCI's relevance to LA:

> "Micro-HCI researchers and developers design and build innovative interfaces and deliver validated guidelines for use across the range of desktop, Web, mobile, and ubiquitous devices. The challenges for micro-HCI are to deal with rapidly changing technologies while accommodating the wide range of users. [...] Micro-HCI researchers can take comfort in dealing with well-stated requirements, clear benchmark tasks, established measures of human performance, and effective predictive models." ([61], p.11)

In LA, we certainly seek good micro-HCI design, to deliver the kind of user experience that we all appreciate when we use software that 'just seems to work right', whether on our phone, laptop or other device. However, Shneiderman points to how the agenda has expanded with the explosion in interactive technology:

> "Macro-HCI researchers and developers design and build interfaces in expanding areas, such as affective experience, aesthetics, motivation, social participation, trust, empathy, responsibility, and privacy. [...] Macro-HCI researchers have to face the challenge of more open tasks, unanticipated user goals, new measures of system efficacy, and even conflicts among users in large communities." ([61], p.11)

Accompanying the micro/macro distinction is the story of the *kind* of theory that emerged in response. In her insightful book, *HCI Theory: Classical, Modern, and Contemporary*, Yvonne Rogers [51] characterised the evolution of three epochs in HCI theory, using terms borrowed from the history of art. 1980s HCI theory is termed *classical*, followed in the 1990s-early 2000s by *modern* theory, with *contemporary* theory from the mid-2000s to the book's publication in 2012. These epochal transitions reflected key drivers including:

- modelling beyond individual users' mental states to *cognition as embodied, social and distributed*;
- the need to move from the lab to the *complexity of real use contexts*;
- and the pressing need to *inform design on realistic design timescales*, rather than the timescale of the academic psychology experiment or many research projects.

Unlike HCI's 40 year journey, of course, the youthful field of LA is not following these epochs in a linear manner, but has had to grapple from the start with the pervasive computational infrastructures that emerged from these epochal shifts. Table 1 summarises the HCI paradigms marked by each epoch, and provides examples of how they can be seen playing out in LA.

Table 1: Three epochs of HCI theory from 1980 – 2012 as characterised by Rogers [51], with illustrative Learning Analytics examples.

HCI Epoch	Theories	Learning Analytics examples
"Classical" **(1980s)**	*Usability for the individual, non-technical user using a personal computer for solo work* Cognitive psychology was considered the scientific basis for understanding the user. Cognitively-based predictive models of users worked for expert performance of routine actions which could be modelled in sufficient detail. *The Psychology of Human-Computer Interaction* was a landmark cognitive science text in this paradigm [12], although *User-Centered System Design* introduced broader perspectives [45].	*Designing usable, insightful LA tools, primarily for the single user, to help people teach and learn as efficiently as possible.* Learning Sciences and Education are considered the scientific basis for understanding the learner. In longstanding research within the AI education community, pre-dating the emergence of LA, it is noteworthy that cognitively-based intelligent tutors had their roots in the same HCI research at Carnegie Mellon University that underpinned pioneering cognitive models of the user [4] Predictive models of student risk prove valuable when integrated into organisational processes,

		but depend on stable curriculum and learning design (poor transferability across contexts).
"Modern" **(1990s – Early 2000s)**	*Extending cognition from single to multiple minds, and to the cognitive resources in the environment* Diverse theories introduced to reflect social phenomena, reflecting also the emergence of the sub-field of Computer-Supported Cooperative Work (CSCW), e.g., External Cognition [56], Distributed Cognition [33], Ecological Psychology [25], Situated Action [65], Activity Theory [6], Ethnography [5]	*LA for collaborative learning, embodied learning, social learning* Computer-Supported Collaborative Learning (CSCL), the associated learning sciences and more social/constructivist pedagogies require theory to tackle more complex, collaborative, open-ended learning contexts. LA for collaborative processes [53, 58, 70] and specifically student discourse [21] are examples. LA remains dominated by formal learning, but efforts are now underway to extend into professional/workplace learning [10, 38]. Embodied learning is beginning to be addressed with multimodal LA [41, 47]. Relationships with the teaching environment and practices are being addressed via e.g., orchestration theory [49] and proxemics theory [42]. Deeper integration between qualitative and quantitative paradigms begins to be addressed by quantitative ethnography [60] enabling new kinds of LA [23].
"Contemporary" **(Mid-2000s onward)**	*From tools we use, to artifacts we live with, and are immersed in. Critical reflection on the ethics of HCI research methods, values, and how HCI creates a more equitable society* Critical reflection on how HCI design processes and digital artifacts/infrastructures shape, and are shaped by, culture, politics, equity, sustainability, aesthetics, wellbeing. Recognition that HCI is entering a "third wave/paradigm" [7, 27]. Developments include calls for more reflective design practice [40] and phenomenological accounts [43]. Methodologies for more authentic 'in-the-wild' analyses of technology use in situ [52]. HCI analysed through the lenses of critical theory, film theory, gender theory.	*Growing focus on lifelong learning, and deeper critiques of the ethical, political dimensions of LA as its infrastructures go mainstream.* Critiques of LA infrastructures informed by critical theory, critical data studies [59, 69], data ethics [14, 50] and methods such as value-sensitive design [15]. Few examples to date of longitudinal LA studies [29, 37]. Few examples of work on culturally-sensitive LA design [67]. Preliminary work on LA and intersectionality [66]. Little or no LA research using theory from the arts.

It should be noted that the epoch's dates reflect when these theories emerged and are not meant to indicate that they only had relevance in those periods. The approaches are doing very different theoretical work, although as Rogers documents, the field also learnt that assumptions underpinning some approaches proved unfounded, and for others, while providing interesting research framings, the practicalities of applying some of them within the constraints of real life design timescales proved unrealistic. There is, therefore, no suggestion that LA should focus only on "contemporary" HCI theories, as though these have eclipsed and made redundant all predecessors.

LA is wielding theories from all three epochs at once, given its interests in how we design effective sociotechnical systems for LA. The scope spans the single user making sense of LA feedback delivered via a task-oriented tool (the driver for classical theories), to studying multiple users engaged in collaborative work in authentic work contexts (modern theories), to recognition of the ethical/cultural dimensions to LA as it embeds into digital and human infrastructure (contemporary theories). However, LA is weakest in its use of contemporary approaches, only just beginning to study systems 'in the wild' since there are to date very few examples of LA in longitudinal use, given the young age of the field. Aesthetically-focused perspectives from the arts have also yet to appear,

since LA is (at least currently) a very work-centric field, compared to the diversity of human experience with digital artifacts at large, studied by HCI.

Surveying these epochs, Rogers identified the diverse roles played by theory in HCI over the years, as summarised in Table 2, reflecting the transition from early psychological theory in the predictive, empirical scientific tradition, to theories capable of making sense of the sociotechnical complexity that is the hallmark of authentic contexts of computer use.

Table 2: The multiple roles played by theory in HCI, summarising Rogers [51] (p.16-17)

Role of HCI theory	Description
Descriptive	Clarifying terminology and guiding inquiry
Explanatory	Explicating relationships and processes
Predictive	Testing hypotheses about user performance
Prescriptive	Providing guidance on how best to design and evaluate
Informative	Importing relevant findings to ground understanding of HCI
Ethnographic	Providing detailed descriptions arising from a field study
Conceptual	Eliciting frameworks for informing design and evaluation
Critical	Couching HCI in a cultural and aesthetic context
Wild	Developing new theories of technology use in situ

I suggest that this broader, richer definition of "theory" in HCI is a stimulating provocation for the LA community. We are seeing a growing chorus of calls for LA tools to be "theory-driven", and many of this book's chapters add weight to this agenda. The critique in such calls is typically that too few LA tools, not only commercial products but also most research prototypes, have been grounded in theory. Notably, such arguments are framed in the "classic" paradigm, defining "theory" in terms of education/learning sciences to improve formal teaching and learning. Thus, when Paul Kirschner challenged the LA community in his LAK16 keynote [35] to attend more to the *L* in *LA*, he unequivocally meant the learning sciences.

The evolution of theory in HCI invites the LA community to think more expansively, because as LA becomes embedded into mainstream infrastructures and lifelong learning apps, (i) we will need to theorise about more than learning in formal contexts; (ii) we will need theory that can inform insight and action on practical design timescales in product lifecycles; (iii) LA will expand beyond the execution of work-related tasks, to an experience infused into our lives; (iv) compared to the scientific paradigm currently dominating LA, design disciplines generate different but equally important theory. The next section introduces three examples to illustrate these points.

5 Researching LA through designing and deploying

Working with the above characterisation of the many roles that theory has played in HCI, a key contribution of HCI theory to LA is in helping us frame *what it means to rigorously study LA systems in use, and to make robust claims about their fitness for purpose*. After all, we cannot analyse or evaluate a phenomenon in a vacuum — what we value, what we think education is about, what we judge to be desirable experiences, the roles that we assume digital tools could/should play in the lives of their users — all determine how we frame the design challenge, the methods we adopt, the data we gather and the arguments we make.

LA design processes and evaluation methods are, therefore, inextricably tied to testing theory, and as we will see next, contribute distinctive kinds of knowledge and evidence by which we warrant our claims. I introduce a second book at this point. *Ways of Knowing in HCI* by Judith Olson and Wendy Kellogg [48] is an edited collection of chapters by leading HCI researchers, each introducing theory, design and evaluation methods they have adopted,

adapted, and in some cases invented, specifically to research and/or design HCI systems. The book reflects the response to the aforementioned micro/macro challenges that HCI was facing as computing changed at an astonishing rate in the period spanning 1980–2010. Research methods were adapting as fast as possible, but academic reviewers in such a diverse field were struggling to know how to judge the quality of work. We can recognise that similarly, LA as a field draws its strength from a diversity of well-established disciplines, but reviewers are often confronted by work using unfamiliar theories, methods and unarticulated assumptions.

Approaches covered in the book include Ethnography, Action Research, Surveys, Crowdsourcing, Sensor Data Streams, Social Network Analysis and Retrospective User Interviews, with discussion of their academic roots, strengths and weaknesses, practical guidelines, and case studies. I consider three of the approaches described in the book to illustrate how they connect to LA.

- We start at the micro-HCI level with *Retrospective Cued Recall*, a specific technique for evaluating the user experience with a digital artifact, which could confirm or challenge theoretically inspired assumptions about the kind of user experiences that an LA tool/artifact should evoke.
- We then move to macro-HCI with *Field Deployments as Research*, as a response to the challenge of reflecting critically and academically on the gradual scaling of novel platforms in increasingly authentic contexts.
- We conclude with a meta-level question, from the HCI community's debate around what counts as 'theory' or 'knowledge' when designing and researching interactive digital artifacts. *Research Through Design* is an approach developed in response to the HCI reality — also playing out in LA — that in the tech industry (indeed most design domains) theory lags behind design, yet a conventional science worldview values theory over design innovation. Can LA learn from how the HCI community has negotiated this challenge?

5.1 Retrospective Cued Recall for User Interface Evaluation

Guided by theory, an LA team may have designed an app and user experience that reflects their aspirations for LA-augmented work practice. For instance, inspired by a theory of student belonging and attrition, the researchers' intent might be that student success advisors will *gain insights* from visual analytics about student activity and sentiment, and *take appropriate actions* that the theory predicts should be effective. Or guided by a sociocultural theory of knowledge negotiation, the researchers may predict that students will a text analytics-powered prompt will help students *pause*, *reflect on their ideas,* and *compose a more thoughtful forum post*. But is that *actually* what these users experience, or why they act as they do? Perhaps other factors have unexpectedly intruded and disrupted the theory-driven workflow and analytics? In short, how can we know what's going through a user's mind as they encounter our LA tools?

This is a "micro-HCI" question (to borrow Shneiderman's terminology introduced above [61]). One approach that may be familiar is the think-aloud protocol [20], whereby the user is asked to talk about (for instance) what they're noticing, thinking and feeling as they use a system, motivations and goals, what they want to try doing next in the software, whether they are surprised or reassured by the software's behaviour. Since such information is invisible in behavioural log data, qualitative self-report data can be immensely useful. However, a limitation of this approach is that this places extra cognitive load [17] on the user, since it is unnatural to think-aloud, and the cognitive, social and attentional burden of doing so, plus any anxiety the user may be feeling as their voice, facial video (often) and screen activity are recorded, can combine to produce unnatural behaviours that are not representative of a typical user. Pairing users up may help make it more natural to voice one's thoughts in discussion with one's partner, but if using the system in pairs is not really an authentic use case, that too has limitations. If the authentic use environment is not conducive to thinking aloud, this further limits the use of the method.

Retrospective Cued Recall (RCR) is summarised by Russell and Chi [54] as a way to avoid this in-situ load by presenting the user with visual cues after their session with the software (e.g. from minutes to days later), in order to elicit their reflections. The risk of reconstructing false memories is mitigated by cueing the user with screenshots and/or video clips from their screen activity, a particular window or whole desktop. Users are then interviewed to elicit their recollections around each cue, with a range of specialist research tools developed to assist the logistics of running RCR studies [34]. Russell and Chi provide helpful guidance on the pragmatics of running RCR studies, including the kinds of cues to use, cautions around using RCR with children, different delay periods before interviewing, and the different ways to ask the cued recall interview questions that minimise the risk of participants over-rationalising accounts of their behaviour. The questions are entirely up to the design team to formulate,

ranging from focused usability questions, to the social or cultural implications of a technology, potentially implicating privacy, emotions or trust.

When we consider the challenge of evaluating LA tools in authentic use contexts, RCR is attractive in not burdening the user with any additional tasks while they use the tool, especially in potentially complex, socially sensitive, noisy, 'in the wild' environments (such as classrooms, offices, streets, or small public spaces) with many potential distractions — these are after all how many tools are used in real life, especially mobile devices, and we can expect LA apps to pervade life well outside the formal classroom.

To summarise, LA research and development needs practical ways to evidence whether theoretically motivated design aspirations were successfully translated into the cognitive, social and emotional experiences intended. RCR is one candidate method for LA researchers to consider as a way to understand a user's experience, scaffolding recall, and avoid disrupting the naturalistic experience they want to understand.

5.2 Field Deployments as Research

If we want to understand how LA embeds into an authentic context, we need not only to deploy in the field, but also find ways to understand the ripples that result from inserting new technology into those activity ecosystems. The HCI community has of course been wrestling with this "macro-HCI" challenge far longer than LA, and Siek, et al. [63] provide a helpful overview of the methodological considerations for what they term *Field Deployments as Research (FDR)*. They clarify the different scales of "field" one can deploy to, starting from a *convenience deployment* with the design team testing on themselves or immediate colleagues, to *semi-controlled studies* at a larger scale involving stakeholders who are early adopters, but still permitting qualitative data analysis, to *in the wild* with possibly tens of thousands of users, unknown to the team, comparable to a product beta release.

In LA research, *convenience deployments* are a common first step, in which researchers 'eat their own dog food', for instance, introducing an LA tool or other intervention into their own teaching. *Semi-controlled studies* mark a milestone as the project matures, and educators outside the research/design team are willing to deploy the tools with their students. At this point, a critical challenge for researchers is to develop their software to be sufficiently usable that others can use it without such difficulty that they give up, while the researchers must also develop their own capabilities and infrastructure to handle the interaction and data from potentially hundreds or thousands of students. Integration with other platforms may also be a challenge, since students and staff expect to login seamlessly using their university credentials, introducing concerns around software performance and security.

Field deployment in the wild is the aspiration of LA researchers who seek to develop tools that will reach sustained adoption, e.g. within a whole university. At this stage, "LA systems" cannot be limited to just LA software systems, but the *overall work system* in which we seek to embed LA. For example, as the LA field has matured we have come to understand that a predictive model of student outcomes should not defined only in terms of statistical algorithms able to classify students with an acceptable level of precision and accuracy (the data science lens). Nor are we done when it has an intuitive user interface that provides insightful data visualizations (the micro-HCI lens on user experience and sensemaking), critical though these are. The boundaries of "the system" must extend to the professional context in which this software is introduced and scaled: this implicates the *competency of the staff* expected to use it effectively, which in turn requires *training*, *integration with other institutional technologies*, *workflows*, *workload planning*, and alignment with *organisational strategy*. Moreover, no matter how good the design is by the above criteria, if for some reason students or staff lose *trust* in the software, "the system" has failed. It is thus a co-evolution of human and machine capabilities which may seem daunting, but this is entirely possible. In LA, this has been documented, for instance, by the UK Open University's embedding of predictive modelling of student outcomes into their student support teams, and studying their responses to, and uses of, the dashboard [28, 29].

What kinds of contributions does FDR make? A range of considerations arise, which should help the LA community conduct better, more ethical research, and judge the quality of such work, using criteria such as those in Table 3.

Table 3: Considerations in HCI of Field Deployments as Research [63] and LA examples

HCI Field Deployments as Research	Learning Analytics examples
Generalisability of the knowledge gained about an interactive system is of less concern than *transferability* of the design ideas, because the researchers document the design rationale and process in sufficient detail for others to contextualise to their work. FDR is thus distinguished from the everyday work of professional practitioners, who have little or no incentive to be so diligent.	In LA, as in all educational research, there is a temptation to report only the success stories, but in this regard the LA community is healthier than some. The "LAK Failathon" workshops [16] have helped to legitimise the sharing of failures.
Early user groups may be legitimately incentivised to use the tool in order to answer research questions, but this must be declared in order to moderate claims about the readiness for wider, voluntary adoption.	In LA, while it is rare to reward academic colleagues for using experimental LA tools, students may be rewarded for participating in interviews. However, given the scale at which education works, it is rare for students to be rewarded simply for using the tool.
Semi-controlled deployments are often with the researchers' colleagues, who are often themselves 'early adopters' ready to try new technologies, and who may be reluctant to criticise the work, so claims about success should be moderated accordingly.	In LA we need to be alert to this, and can mitigate against the risks by giving permission to colleagues to be 'brutally honest'. However, they may be more tolerant of software errors and disruption to their teaching than other colleagues, and this issue should be reported in research papers (it is very rare for pilots of interactive LA tools to go flawlessly).
There are ethical issues to working with practitioners, who are placing significant trust in the team that the software will not disrupt their work and reputation.	In LA, we need to be extremely sensitive to the fact that educators have a duty of care with regard to their students, as well as a responsibility to deliver the curriculum, often to a tight timescale. The extra effort required to deploy LA should be valued by the research team, who must invest greater support in pilots than could be sustained were the tool be eventually mainstreamed.
If the field deployment will end, how is this managed ethically? Stakeholders may expect that if the deployment was a success, then the tool will continue to be available. What are the resource implications?	In LA, we aspire to create tools that provide insight to different kinds of stakeholders. While companies are equipped to sustain products, academic research groups rarely are [11, 57]. How are realistic expectations established with stakeholders?

5.3 Research Through Design

In my view, LA should be approached as a *human-centred design discipline.* It has drawn on academic theory (to date, primarily from education and the learning sciences) to some degree. However, it is a mistake to imagine that "theory-driven design" will alone guide a team to the creation of a good LA tool. There are so many other factors that determine whether, in the end, it works functionally, culturally, aesthetically. So, how should the LA community think about the relationship between theory and design? Does design in fact contribute theory? Should design become more "theory-driven" in order to advance science, or is this in fact a misguided notion? These are significant questions that the LA field could be asking, and this brief section can provide only a few pointers for further reading.

These questions confronted the HCI community as it tried to figure out how to integrate the design community into its academic community, and how to judge the quality of work that was unapologetically driven by design problems, rather than a scientific research question. The reality was that technological advances and design innovations preceded HCI theory, they did not flow from it. We see exactly the same thing in LA, which as noted earlier, some regard as a serious problem. The debate in the HCI field may suggest otherwise.

In their overview of *Research Through Design (RtD)*, Zimmerman and Forlizzi [72] trace the history of the field, as interaction designers (coming originally from physical artifact design) migrated their approaches to designing digitally-enabled artifacts. They propose that in designing an interactive system, there are four important types of knowledge (Table 4).

Table 4: Four types of knowledge integrated in HCI *Research Through Design* methods [72] and LA examples

Type of knowledge	Learning Analytics examples
"How" knowledge provided by engineers regarding what is technically possible.	In LA we can see this community as including both researchers and engineers in data, statistics, machine learning, multimodal analytics, etc.
"True" knowledge provided by behavioural scientists regarding how people think and act.	In LA the learning sciences and education tend to be the authority disciplines in asserting how people teach and learn, but new perspectives are emerging, e.g., to account for professional/workplace learning
"Real" knowledge provided by anthropologists and other qualitative researchers who provide 'thick descriptions' of how the world works.	In LA, we see design-based research, ethnography and sociology providing accounts, and critiques, of technology in use.
"Right" knowledge as the synthesis of the above by design researchers, in order to make the optimal decisions about an artifact to improve the world in a use context: the "right thing".	In LA, we see various flavours of human-centred, participatory and interaction design expertise, seeking to combine the above knowledges by engaging non-technical stakeholders meaningfully to conceive "the right LA" for a given context.

Frameworks such as this recognise the distinctive contributions of different knowledges to the development of digital artifacts. Zimmerman and Forlizzi provide case studies of systematic design that are carefully documented in order to help others understand the above interplay. In one case study, they emphasise the role of RtD in *reframing* a design problem through iterative cycles of prototyping in authentic contexts, through which the team came to understand the role of the digital artifact they were designing in a completely different light. To my knowledge, LA has yet to see such examples, possibly because, as noted earlier, in LA we are not yet thinking about our digital creations as more than tools to perform well-defined tasks. Possibly, it is because we simply do not have many creative designers in the LA community. Encouragingly, we are starting to see members of the LA community who also work in HCI presenting narrative design case studies [1].

Other researchers have also concluded that *design artefacts* constitute an important form of knowledge in HCI, since they encapsulate myriad judgements brought together in a harmonious manner, to perform a function in a social context. They are a "theory-nexus" who user interfaces and functionality make "psychological claims" about what users need to know, do, and how [13]. The resulting Claims Analysis approach can be seen as an example of the kind of rigorous RtD methodologies and documentation that Zimmerman and Forlizi call for elsewhere [73], in order to strengthen and legitimise the academic knowledge it produces. In this chapter they conclude that RtD can make at least two key contributions to HCI: "1. the reflective practice of reframing the underlying situation and goal of the project during the design process; 2. a shift to investigating the future as a way of understanding the world that should be brought into being" [72], p.178). However, a different perspective is presented by Gaver in a sister chapter, *Science and Design: The Implications of Different Forms of Accountability* [24]. Gaver cautions against calls for design researchers to strive for theoretical contributions that move towards science's standards of *epistemological accountability*, arguing that design is a distinctive and legitimate form of knowledge production that answers to *aesthetic accountability:* "how satisfactory the composition of multiple design features are (as opposed to how 'beautiful' it might be). The requirement here is to be able to explain and defend—or, more typically, to demonstrate—that one's design *works*." (p.147).

To summarise this brief introduction to RtD, I suggest that one direction that LA theory could take as the field matures is to recognise that, as a design-intensive field seeking to create digital artefacts whose design *really works*, the scientific methods and theory currently dominating the field could come into fruitful dialogue with design methods and theory, just as it has done in HCI. Epistemological debates such as this are critical, determining what counts as a contribution to the field. A consequence is that the CHI conference recognises the distinctively different criteria for judging more conventional scientific work compared to design-led submissions.[1]

[1] ACM CHI 2022 guide: https://chi2022.acm.org/for-authors/presenting/papers/contributions-to-chi

6 Discussion and conclusion

The opening premise was that the design of LA tools is an example of the general problem of designing interactive tools, which is the focus of HCI research and practice. However, unlike HCI in its early 1980s days of the personal computer used by a solitary user, LA is now confronted by the challenge of designing increasingly pervasive analytics infrastructures across diverse platforms, accessed via myriad devices and user interfaces. It was precisely this explosion in data, computing power and mobile communications that demanded new ways of theorising HCI and studying systems in use.

In this chapter, I have drawn on two major HCI books to argue that LA can and should learn from the way that theory has evolved in HCI. I propose that Rogers' characterisation of the different roles that "theory" has come to play in HCI expands the discourse on "theory-based LA" beyond the theories from education and the learning sciences. Her analysis of the three epochs of HCI theory that unfolded since the 1980s (namely, *classical*, *modern* and *contemporary*) offer an historical lens to make sense of the diverse range of theories now appearing in LA, or which may soon appear. The examples from the *Ways of Knowing in HCI* book illustrate how LA might consider enriching its repertoire of techniques to study LA systems at micro and macro scales, and consider how established *scientific* theories and methods may need to come into dialogue with *design* theories and methods. As a highly interdisciplinary applied field, LA (like HCI) faces the challenge of maintaining academic standards in the conduct and review of research coming from many disciplinary traditions. I propose that HCI offers inspiration for researchers seeking rigorous methods to design and evaluate LA in authentic contexts, including principles to maintain their intellectual rigour, which will also be of interest to LA journals and conferences seeking to maintain peer review standards.

Looking forwards, HCI points us to futures in which LA may be experienced in myriad ways. Firstly, user interfaces will continue to evolve, shaping when, where and how we encounter, interact with and interpret information. LA's digital artifacts may extend their interfaces to provide embodied, social and distributed experiences. Feedback may be tangible to other senses, and take on new aesthetic qualities. There remains huge scope to invent more engaging ways of interacting with LA visualizations and feedback beyond the very traditional forms we currently see.

Secondly, as we develop long-term 'relationships' with artifacts such as our phones and apps, it seems likely that we will develop qualitatively new ways of relating to 'lifelong LA'. We will be accompanied by software agents with varying degrees of intelligence, whom we will consult with varying degrees of trust. HCI theories should help us design for this. While the focus of this chapter has been on LA, the boundary with artificial intelligence is increasingly blurred as LA increasingly uses machine learning, multimodal sensing, and user interface technologies such as conversational agents become readily available. As AI becomes increasingly mainstream, *Human-Centred AI* is growing rapidly as an HCI research stream. This is a rich community for the LA community not only to draw on, but hopefully also contribute back to, since the LA community brings distinctive strengths in the theories we can offer on what it means to *learn* — via, from and about — computers.

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