Theory-Led Design of Instruments and Representations in Learning Analytics: Developing a Novel Tool for Orchestration of Online Collaborative Learning

Nick Kelly

Australian Digital Futures Institute, University of Southern Queensland, Australia
Science and Engineering Faculty, Queensland University of Technology, Australia
nick.kelly@usq.edu.au

Kate Thompson and Pippa Yeoman

Centre for Research on Computer Supported Learning and Cognition (CoCo)
The University of Sydney, Australia

ABSTRACT: This paper describes theory-led design as a way of developing novel tools for learning analytics (LA). It focuses upon the domain of automated discourse analysis (ADA) of group learning activities to help an instructor to orchestrate online groups in real-time. The paper outlines the literature on the development of LA tools within the domain of ADA, and poses an argument for conducting tool development based upon first-principles. It describes first principles as being drawn from theory and that these principles can subsequently inform the structure and behaviour of tools. It presents a framework for this process of theory-led design. The framework is substantiated through the example of developing a new tool for assisting instructors with the orchestration of online groups. A description of the tool is given and examples of results from use with real-world data are presented. The paper concludes with a call for intent on the part of designers to connect the design process explicitly to theory on the basis that this has the potential to yield innovation when developing tools as well as the prospect of outcomes from tools connecting back to theory.

Keywords: Automated discourse analysis, collaborative learning, orchestration, learning analytics, topic detection

1   INTRODUCTION

Learning analytics (LA) has in recent years moved from early successes in predictive analytics (Campbell, DeBlois, & Oblinger, 2007; Macfadyen & Dawson, 2010) to include more fine-grained uses, in particular in the move towards lecturer- and student-facing analytics aligned with design for learning (Lockyer, Heathcote, & Dawson, 2013). This movement has seen much progress within LA to achieve its goals of evidence-based improvements to learning, teaching, and the environments in which they occur (Siemens & Long, 2011). Part of this progress has come through novel sources of data and novel ways of acting based on analytics. A further part of this progress, and the focus here, comes from the development of new tools for obtaining evidence. We consider the development of new tools for LA to be an example of design activity. One approach to designing tools is through abduction following the establishment of first principles (Gero, 2000), what we refer to here as *theory-led design* where these first principles are grounded in established theory. The claim that we make in this paper is that theory-

led design has the potential to yield innovation in the development of LA tools and, in turn, that the development of LA tools and their use may contribute to learning theory.

In this paper we present an example of theory-led design within one particular area of LA, the automated discourse analysis (ADA) of online collaborative learning. Collaborative learning can now be observed in synchronous or asynchronous learning environments (Garrison & Kanuka, 2004), as part of a physical, online, or blended modality (Bonk & Graham, 2012) and can range in group size from the small (i.e., two participants) to the very large (e.g., Kop, 2011). A commonality between these different forms of collaborative learning is that the discourse between participants can be analyzed to reveal information about the learning that is occurring (De Liddo, Buckingham Shum, Quinto, Bachler, & Cannavacciuolo, 2011; Mercer, 2007). As a result, discourse analysis has become "an important theoretical perspective for those concerned with the study of learning in social settings [in order to] examine ways which knowledge is socially constructed in classrooms and other educational settings" (Gee & Green, 1998, p. 119). In recent decades, many instruments have become available for conducting ADA to allow the natural language of group interactions to be parsed computationally and reveal aspects of the learning occurring, e.g., in the *productive multivocality project,* which identifies many different approaches to the analysis of group interactions (Suthers, Lund, Rosé, Teplovs, & Law, 2013). Any tool for analyzing group interactions necessarily makes ontological and epistemological assumptions about which phenomena are worth studying and the ways in which we may know about them (Lund & Suthers, 2013, p. 22). In the development of many tools for LA such assumptions may remain tacit. Theory-led design is one way of developing tools that allows for such assumptions to be made explicit and upfront.

The paper is structured by first synthesizing a framework for theory-led design of LA tools based upon the literature. This framework is then used in a demonstration of the development of a novel tool to analyze a real life dataset from a group learning situation that has previously been analyzed manually. This real life dataset is in a subdomain of ADA that has received recent attention, for instruments that can aid instructors in the real-time orchestration of groups during learning through topic detection (e.g., Oshima, Matsuzawa, Oshima, & Niihara, 2013; Trausan-Matu, Dascalu, & Rebedea, 2014). Finally, in the discussion and conclusion we show that by developing the analytic technique from first principles, rather than applying an off-the-shelf tool, there is the potential to add to the theory of small group cognition and orchestration through the design of new instruments.

2   BACKGROUND

2.1   Frameworks for Learning Analytics

A number of frameworks have been proposed to guide the design and use of instruments and representations in LA. What follows is a brief review to portray current thinking on how the development of instruments and representations is conceived. The terminology of *instrument* is used

15

here to refer to individual methods of analysis (e.g., sentiment analysis, topic detection) and the term *representation* is used to refer to the way that the results of analysis/analyses are presented (following Greller & Drachsler, 2012). We will use the term *tool* to refer to the combination of both instrument and representation. Any new developments of instruments and representations are open to ethical debate (Lund & Suthers, 2013), by asking questions of "who is defining the measures, to what ends, what is being measured, and who gets to see what data?" (Buckingham Shum & Ferguson, 2012, p. 5). Such questions can have more profound answers by first considering the question: Where do novel tools for LA come from?

The design of instruments for analytics is often construed as having an intention to answer the questions of users so that decision making and action can take place (e.g., van Barneveld, Arnold, & Campbell, 2012; Verbert, Duval, Klerkx, Govaerts, & Santos, 2013). This is an implicit design philosophy of *user-centred design* (Abras, Maloney-Krichmar, & Preece, 2004) in which the needs of the user are the dominant consideration during development. The users provide the impetus for developing novel instruments; and if the instrument is useful for allowing the users to take positive actions then it has been successful. Whilst this is a valid and proven approach to developing novel tools, there are considerations outside of user needs that can enhance tool development. Two variations are proposed within the Information, Representation, Affordance, Change (IRAC) framework for LA (Jones, Beer, & Clark, 2013). The first is to suggest that any instrument for analytics ought to be continually developed and changed in response to user needs following implementation. This is "change," the C in IRAC, and it refers to the need for analytics to evolve over time based upon user and institutional needs. The second is to call for "mindful innovation" (Jones et al., 2013, p. 447) in developing tools, explained as a "nuanced appreciation of context" (p. 447), a call found elsewhere in the literature (Macfadyen & Dawson, 2012). However, much ambiguity remains as to how to achieve mindful innovation; and how user-centred design, continual change, and ethical concerns fit together.

Another framework for LA is useful for establishing terminology. A *general framework for LA* was proposed by Greller and Drachsler (2012) that critically considers LA from the perspectives of stakeholders, limitations, objectives, instruments, and data. In this framework *stakeholders* are those who will make use of the representation resulting from the analytics, and are identified as learners, educators, institutions, and researchers. *Objectives* are identified through the broad aims of reflection and prediction. Many types of *data* can be utilized and *instruments* are used in conducting the analysis of these data with an acknowledgement of both intrinsic and extrinsic *limitations*. The framework identifies the need to have clear objectives, especially with respect to stakeholders, in determining which instruments will be used and appropriate representations.

2.2 Automated Discourse Analysis and Topic Detection

This section provides a brief overview of Automated Discourse Analysis (ADA) and topic detection, areas where significant innovation in tools has occurred over recent decades. This background will be drawn

upon in the example of developing a novel instrument in Section 4. Discourse analysis has been shown to be of significant utility to researchers, to learners, and to educators (Gee & Green, 1998). Over the past two decades a number of methods for automating discourse analysis through computation have been introduced to the study of learning, often through techniques originating in the field of computational linguistics (Chiu, 2008; Rosé et al., 2008). Methods of ADA, when used to improve teaching and learning, form a part of the field of learning analytics (LA) when these methods are used for "the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs" (Siemens & Baker, 2012, p. 1). ADA has the potential to aid researchers to study learning, learners, and learning environments (Thompson, Ashe, Carvalho, et al., 2013); aid students by developing student-facing LA for meta-cognitive feedback and formative assessment (De Liddo et al., 2011; Lockyer & Dawson, 2011; Buckingham Shum & Ferguson, 2012; Wise, Zhao, & Hausknecht, 2014); and aid educators with educator-facing analytics, some of which can help facilitate orchestration (De Liddo et al., 2011; Trausan-Matu et al., 2014). Researchers utilizing ADA techniques for LA are concerned not just with mining data for analysis, but with using this analysis to enhance learning or learning environments in the subsequent redesign of learning tasks or for learner-facing analytics (e.g., Scheffel et al., 2012).

Thus far, much of the work in ADA has focused on the analysis of learning events after they have occurred — a focus on making claims about the learning (Lund & Suthers, 2013) rather than upon utility for in-class orchestration (Dillenbourg & Jermann, 2010). There is significant potential for further developing the use of ADA in the orchestration of classroom environments whether face-to-face or online in real time (Trausan-Matu, 2013; Trausan-Matu et al., 2014). The introduction of technology into face-to-face environments and the removal or distancing of the instructor in online collaborative settings has resulted in a complex web of challenges to the traditional management of these groups. As such, a tool that could give instructors a quick overview of discussions in progress, and track transitions through expected phases of group collaboration would be valuable. An example of such a tool is seen in *KBDeX* (Matsuzawa, Oshima, Oshima, Niihara, & Sakai, 2011; Oshima, Oshima, & Matsuzawa, 2012), which builds a network from group interactions and provides a visualization of group activity based upon social network analysis.

Automated topic detection is concerned with the discovery of key topics, themes, or concepts from within a body of text (Blei, Carin, & Dunson, 2010). Topic detection takes a corpus of text as an input, performs automated analysis, and returns a set of themes as an output. An early example is the "word cloud" approach, a simple listing of the words most repeated within a discourse (Cui et al., 2010). Far more advanced tools have been developed since, such as Latent Dirichlet Allocation (LDA), keyphrase extraction algorithms (Witten, Paynter, Frank, Gutwin, & Nevill-Manning, 1999), and hierarchical LDA models (Wallach, 2006). Recent research in computer supported collaborative learning (CSCL) has utilized these approaches for the analysis of collaborative problem solving (Trausan-Matu & Rebedea, 2010), classification of online discussion (Mu, Stegmann, Mayfield, Rosé, & Fischer, 2012; Trausan-Matu, Dascalu, & Rebedea, 2012), visualization of chat (Trausan-Matu, Rebedea, Dragan, & Alexandru, 2007),

marking participation in online chat (Rebedea, Dascalu, Trausan-Matu, Armitt, & Chiru, 2011), evidence of metacognition (Chiu, 2013), and the extraction of scientific concepts from student interviews (Sherin, 2013). These examples use a probabilistic approach (most typically LDA) to build a model from the text that can then be used for analysis (Blei, Ng, & Jordan, 2003).

One limitation of this approach is the need for a large corpus of text from which to build an initial statistical model. A more recent approach to topic detection that does not have this limitation is the graph analytical approach. Topic detection in this way proceeds by constructing a graph from utterances in discourse, which can then be mined to give information about the topics (Sayyadi & Raschid, 2013). The advantage of the graph analytic approach is that it can identify relevant text from small samples of the discourse. A second advantage of this approach is that the salient features of the resulting graph can then be represented in the output (e.g., Oshima et al., 2012). Recent work has begun to combine the two approaches (Teplovs & Fujita, 2013).

2.3   CSCL in the Context of ADA

This section provides some background on the theory of CSCL in the context of ADA, which we will draw upon in the example of developing a novel instrument in Section 4. The example in Section 4 involves design for instructors orchestrating online group cognition tasks. Analysis of collaborative learning has been built upon several seminal theories including, amongst others, the sociocultural theory of Vygotsky (1930/1978), communities of practice (Lave & Wenger, 1991), conversation analysis (Sacks, 1972), and the role of computers in cognition (Winograd & Flores, 1986). Many of these theoretical perspectives (Stahl, Koschmann, & Suthers, 2015) identify cognition as being "distributed across people and tools, situated in contexts, within small groups, involved in larger activities and across communities of practice" (Stahl, 2012, p. 1). From these foundations, theory has been developed to support the research of individuals working in groups, small group cognition, and community cognition (Stahl, 2012). One area of recent focus has been group cognition (Stahl, 2006), which assumes that knowledge emerges from the interaction of social organization, tool use, and epistemic factors (Goodyear & Carvalho, 2014), which are beyond that of the influence of any particular individual. In addition to the theories of CSCL, two other bodies of research are important to this work: 1) the role of time and order in analyzing the activity of learners (Goodyear, Jones, & Thompson, 2014; Reimann, 2009); and 2) classroom orchestration (Dillenbourg & Jermann, 2010; Mazzolini & Maddison, 2003). The term *classroom orchestration* is widely taken to refer to "the design and real-time management of multiple classroom activities, various learning processes and numerous teaching actions" (Dillenbourg & Jermann, 2010) and it brings together many of the theoretical perspectives mentioned above. Educators, tasked with the responsibility of orchestrating learning across multiple online or in-person groups, in open, flexible and digitally enabled learning environments, face numerous challenges at multiple scales that require a form of omnipresence to provide timely and effective intervention — intervention that is often critical to the successful completion of group work (Mazzolini & Maddison, 2003). Whilst there is debate about the nature, role, and scale at which orchestration should be

deployed, there is general agreement about the need for technologies that support those who teach in technology rich environments (Roschelle, Dimitriadis, & Hoppe, 2013), with a focus on functionality that enables those who use it to monitor activity and adapt elements of the design accordingly, in real time (Dillenbourg, Nussbaum, Dimitriadis, & Roschelle, 2012; Martinez-Maldonado, Clayphan, Yacef, & Kay, 2015).

In this paper, we concentrate on the perspective presented by group cognition, using a conversation analysis approach in order to use learning analytics in tools to support orchestration. The speech produced within a group is influenced by factors such as the other members of the group, the nature of the task, and the tools, both digital and physical, in the learning environment.

3 THEORY-LED DESIGN OF ADA TOOLS

3.1 Designing from First-Principles

What then, given this background, is the role of theory in the "mindful design" of new tools? In many cases, new tools come to be developed from existing tools. Consider that an LA practitioner (henceforth "researcher") has clear objectives, data, stakeholders, and limitations. In most situations, many available instruments could be used to address these objectives. Whilst researchers will often adopt an existing, validated tool from the existing corpus, there may also be potential to design a new tool based upon existing methods and first principles. If researchers are designing tools, then the processes by which novel methods are developed are of considerable interest. Such activity to produce novel methods is termed *innovative design* in that it requires researchers to move beyond the grammatical application of existing designs (Gero, 2000).

Innovative design can be described through one or more of five processes, and the category of theory-led tool design fits into the first of these. Processes that rely on *first principles* involve the use of abduction from a set of "causal, qualitative, or computational knowledge" (Gero, 2000, p. 194). Processes of *analogy* involve the transfer of elements of structure or behaviours from one problem or domain into another problem or domain. *Combination* involves the "addition of two sets of ideas or some subset of them" (p. 191). *Transformation* is the "alteration of one or more structure variables by an external process" (p. 191). This involves altering a method to make it suit the objectives. *Emergence* is the process whereby "extensional properties of a structure are recognized beyond its intentional ones" (p. 193).

Some of these processes for innovative design can be demonstrated by discussing the recent example of the PolyCAFe system (Trausan-Matu et al., 2014). The PolyCAFe model automates the analysis of unmoderated chat conversations, aiming to assist educators in orchestrating and assessing groups engaged in potentially hours of chat dialogue. In this model, the researchers cite Bakhtin's discussion of the dialogic imagination and evocation of polyphony (e.g., counterpoint in music) (Bakhtin, 1981/2010) as the basis for their choice of how to analyze and represent the arguments that participants are making

within a dialogue. This is an example of the use of *first principles*, beginning with the theory and using this to suggest function, structure, and behaviours of the tool. Trausan-Matu et al. also use *analogy* in drawing upon the experiences of tutors described in Stahl's study of virtual maths teams (Stahl, 2009) and set the task of making an automated analog of what the tutors were doing. They use *combination* in combining the existing techniques of Social Network Analysis (SNA) and Latent Semantic Analysis (LSA) in developing a composite metric and representation.

3.2 Mindful Design from Theory

Theory-led design is defined as a form of innovative design that begins with the use of theory to establish first principles, and proceeds towards the development of a tool through an abductive process. To be useful to practitioners, however, a more pragmatic description than this is required: For example: What are these first principles? How are they developed and how are they used? These questions are addressed by proposing a general framework for the design of new tools. The framework refers to the distinctions of *function, behaviour,* and *structure* (Gero, 1990), and first principles fit into this framework in establishing function during the design of the tool.

The function of an artefact is its constructed teleology — the intentional purpose for undertaking the design activity (Dorst & Vermaas, 2005; Gero & Kannengiesser, 2004). For example, the function for designing an office chair could be described as "supporting a human at rest whilst they work at a computer workstation." This function then forms the basis for establishing the *expected behaviours* of the artefact. These are the ways in which the artefact's satisfaction of the function can be measured. For example, an office chair might have behaviours that relate to safety, ergonomics, cost, and aesthetics. A structure is then developed as the elements composing the artefact and their relationship, e.g., size, shape, material, and relationships of parts. This designed structure can then be evaluated to determine the extent to which the expected behaviours are satisfied — these are the *actual behaviours*. Each of these steps — establishing function, expected behaviours and structure — may be revisited in the process of *reformulation*, showing design to be an iterative process*.*

The utility of this description of the design process is to allow for distinction between cognitive tasks that take place during design (Gero & Kannengiesser, 2004). For example, there is nothing in the description of function that directly suggests structure; it is only through behaviours that function influences the structure. This description of design is not intended to be prescriptive nor to suggest that design occurs in a linear way, but rather be a useful ontology for discerning, analyzing, and studying the different processes involved in design (e.g., Williams, Yoon Suk, Gero, & Paretti, 2012). Figure 1 captures this process of design as it relates to the theory-led design of tools for ADA of group learning.

3.2.1 Establishing Function
Design of LA tools from first principles requires that time be spent establishing the function for the tool being developed. In this step an engagement with theory influences the design process and is the

foundation for innovation. There are five domains in which theoretical decisions are made during analysis of group discussion (Wise & Paulus, in press): 1) ontological and epistemological foundations; 2) the way that learning is conceived; 3) the kinds of claims expected to be made; 4) data sources; and 5) data analysis methods. Each of these presents an opportunity to influence the function in the direction of innovative design. A designer can undertake an interrogation of their assumptions by engaging with the literature that relates to their understanding of the world, the nature of knowledge, the nature of learning, the outcomes that will come from the use of their tool, the sources from which their data will be drawn, and ways to analyze that data.

In this paper we are concerned with the development of tools for ADA. In ADA the theory that informs first principles pertains to the way that groups learn together, the language used by groups during collaboration, and what that language signifies. The function relates to the objectives for the tool (what can be done with this tool that could not be done previously?) and to the stakeholders (who will be using this tool?). An example of this process, and specific relevant theory, is detailed in Section 4.

3.2.2. Establishing Behaviour and Structure

The expected behaviours of the tool are developed from an understanding of function grounded in theory. An example in the domain of LA serves to illustrate the use of function to develop behaviours and structure. If the function of the Course Signals learning analytics tool was perhaps to "use available data to support students in their learning" then the expected behaviours of the tool are those things that the designers consider relevant to measure in order to establish the achievement of this function (Arnold & Pistilli, 2012). One indicative measure might be an increase in student retention (Arnold & Pistilli, 2012). An example of another expected behaviour could be indicators of engagement by lecturers (e.g., number of views) with the Course Signals tool. The expected behaviours established do not specify structure; rather they specify the way in which structure will be measured.

In the context of ADA of group learning, behaviours relate to measures of the tool's use and operation and of its impacts upon those who will be using it (e.g., researchers, academics and students). The use of theory in developing the function for the tool allows for the designer to challenge pre-existing and often implicit beliefs about behaviours for the tool.

The structure of the tool is developed in an attempt to create an artefact that will satisfy the expected behaviours. In a tool for ADA of group learning this involves decisions about data sources, methods of analysis, and methods of representation (Wise & Paulus, in press). The use of theory in developing the function may again serve the designer in opening them up to the potential for developing novel elements of structure. There is much potential for innovation within ADA that comes from novel sources of data and from the development of new forms of analysis and new modes of representation.

3.2.3 Iterating through Evaluation and Reformulation

In this framework for design, iteration occurs through one of three types of reformulation: 1) where structure is revised; 2) where expected behaviours are revised; and 3) where function is revised (Gero,

1990). A trigger for reformulation is evaluation, where expected behaviours of the structure are compared to actual behaviours. In some cases the designer can change the structure to produce the desired behaviours. For example, in reformulating structure, the designers of the Course Signals software might change their algorithm or their data sources to improve performance of the tool. In other cases, the behaviours of the design might be changed through reformulation. For example, in reformulating behaviours, the designers of the Course Signals software might decide that the behaviour of student retention is not appropriate for achieving the desired function and other behaviours could be introduced. Finally, the function of the tool can be revised — perhaps with what has been learnt through the process of designing, the original intent is no longer a good description of the purpose of the design activity and is reformulated.
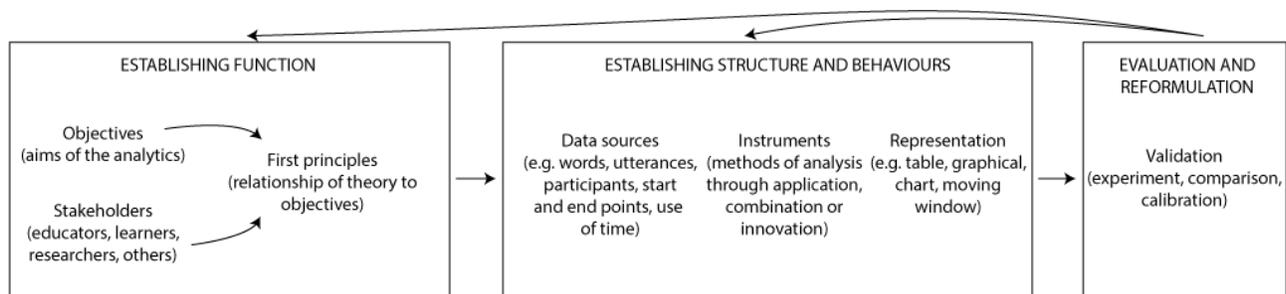
Figure 1. A general framework for design of ADA instruments and representations from first principles.

4   DEVELOPING AN INSTRUMENT FOR TOPIC DETECTION IN ORCHESTRATION

This section describes the development of a tool for topic detection through ADA as an example of theory-led design. Referring to the framework developed in Section 3, it describes the processes of establishing function, establishing structure and behaviour, and evaluation and expected reformulation. The design produced can be summarized as a tool for instructor-facing topic detection using graphical modelling, where heuristics for parsing natural language are used to construct a graph that is then mined for data.

4.1   Establishing Function

The function of the tool developed was to aid instructors in the orchestration of online collaborative learning tasks. The process for arriving at this function is described here, including the theory informing first principles. Two overarching theories supported this work. *Group cognition* recognizes that learning can be observed at the level of small groups and communities (Stahl, 2006). Adoption of the theory of group cognition shifts the conception of learning away from individual minds towards the way that small groups or communities work together to create shared understanding. The focus is upon the

development of the constructs adopted by the group as they develop a "joint problem space" revealed through the sequence and semantics of their discourse (Stahl, 2006). Within this understanding of group cognition, Reimann's theoretical work informs the understanding of data analysis in terms of the importance of time (Reimann, 2009; Reimann, Markauskaite, & Bannert, 2014). Many types of automated analysis of discourse (especially techniques based on probabilistic models) ignore vital information about the timing and process. A contribution of this theory was to question whether further use might be made during analysis of the sequence in which the words and utterances of group discussion occur.

The initial impetus for developing the tool occurred whilst carrying out a number of studies using manual discourse analysis. The objective of the manual studies was to understand the complex interplay between aspects of the learners' social and epistemic activity and the activity associated with the tools and physical and digital learning environments. Two streams of data were related to the discourse. The first was the *Design Ideas* code (Thompson, Ashe, Yeoman, & Parisio, 2013), which was the identification of ideas important to the development of each group's design; the second was the CPACS code (Kennedy-Clark & Thompson, 2013a). CPACS (the Collaborative Process Analysis Coding Scheme) is a multi-level coding scheme based on coding systems used by Mazur and Lio (2004), Sawyer (2006), Nivre, Allwood, & Ahlsén (1999), and Soter et al. (2008), focusing on features of speech and macro (action and content) and micro (attitudinal, tense, modality, and pronouns) elements of turn taking (Kennedy-Clark & Thompson, 2013b). The CPACS code includes social (phatics, salutations, leave taking), planning, topic, task, tool use, and off task (Kennedy-Clark & Thompson, 2013a). Other related work examined the presence of oscillation between consecutive corresponding points of the same phase of a problem in the contents of discourse as an indicator of successful collaboration (Kennedy-Clark & Thompson, 2013b; Thompson, Ashe, Yeoman, Parisio, 2013). These studies provided a basis for further investigation into 1) the potential for using language in group discourse to aid in detecting successful collaboration; 2) the role of turn taking, in particular, during collaboration.

It was observed that the key concepts in the *Design Ideas* study that participants referred to were primarily nouns, and that there was a repetition of words (echoing) between participants around key topics. These nouns were mapped to the *content* codes: social, tools, planning, topic, and task. In the original, manual studies, the identification of these nouns and subsequent mapping allowed the authors to identify patterns of collaboration that mapped to phases in the group's design work (orientation, idea generation, social interaction, and technology failure) (Thompson, Ashe, Yeoman, Parisio, 2013). Continual referral to the keywords concerned with the *topic* and the *task* indicated that students were integrating specific content knowledge in the generation of ideas for the design task. The identification of any of these phases, be they of progress (orientation and idea generation) or a lack of progress (negative social interactions and technology failure) is of interest to an instructor.

Further, the observation was made that repetition of words is a key indicator of importance. This was supported by further reading of the literature, with Tannen (1987) suggesting that repetition serves

many purposes in speech, both within an utterance and in the interplay between participants. For interplay, "repeating the words, phrases, or sentences of other speakers (a) accomplishes a conversation, (b) shows one's response to another's utterance, (c) shows acceptance of others' utterances, their participation, and them, and (d) gives evidence of one's own participation" (Tannen, 1987, p. 61). These are valuable indicators of which words might correspond to important topics and provides an indicator of a technique that may supplement or extend existing measures that are commonly used, such as LDA. A feature of human language in conversation is that segments of the previous utterance are often repeated, to confirm common ground and establish or alter meanings (Norrick, 1987; Tannen, 1987). This is highlighted by Norrick who recognizes that "speakers not only repeat their own words and phrases at the level of the turn, and their own turns at the discourse level, but they also echo the wording, rhythms, and turns of their interlocutors" (Norrick, 1987, p. 245).

These underpinnings informed the function for the design task. Assumptions can be made explicit: that the tool is concerned with groups collaborating online; who use language whilst learning collaboratively; in the presence of an instructor. The concepts that the group members make reference to are likely to be of interest in determining whether the group is discussing the task and the topic. Further, the turn-taking of participants likely reveals something about which parts of the discourse are important.

Given this basis, the instructor was identified as the key stakeholder. The objective was to create a tool that could assist the instructor in knowing which groups are on or off task. A reading of existing tools showed that there is much potential for innovation in this area in the data displayed to instructors and the way that it is represented.

4.2   Establishing Behaviour and Structure

Having established this function of enabling instructors to quickly understand the status of multiple group collaborations in real-time, the expected behaviours of the tool could be developed as the measures that would indicate that this function had been achieved by structure. An important behaviour was that the tool had to be perceived as useful by instructors in revealing something about the status of groups. This behaviour cannot be measured directly from the structure (from the tool itself) but rather requires measurement of how it is used by the stakeholders.

A behaviour that did not require measurements of stakeholders was that the tool would show the current group constructs relating to the task and to the process of designing. This behaviour can be considered a measure of "how well does the tool reveal the current status and phase of design of the group?" If this behaviour were satisfied, the tool could assist orchestration by suggesting which phases of design each group was in "at a glance." During the process of design, this behaviour was decomposed into smaller behaviours as a method for establishing the behaviour. A further behaviour was that the tool could be used by non-experts and this required that the visualizations created by the tool would enable a non-expert to make decisions on-the-fly during orchestration of online groups — that the

visualizations should show change over time and that the tool would reveal something about group dynamics through the language, in particular through word repetition.

Data visualization was deemed important due to the complex nature of the task (a design task about a specific topic), the tools and unique setting, and the requirement to work collaboratively. There is much in the literature about the ability of non-experts to interpret representations, which lies outside the scope of this paper. In this case, we followed Trausan-Matu et al. (2014) in utilizing visual representations of words in the discourse to aid non-expert comprehension, and Oshima et al. (2013) in using a graph structure to make explicit the relationships between words. For classroom orchestration occurring in real-time, the discourse from different groups makes up a continuous data stream. An educator would need to focus on comprehending the most recent data in the context of the entire discourse (rather than simply on the entire discourse). Making a decision about structure, a sliding window was deemed to be an appropriate representation, in which results from the most recent x number of utterances or time period is displayed, and changes to this over time can be observed. From the manual studies it was estimated that the window in this type of task should span approximately 50–100 utterances to show where negative social interactions and off-topic work was taking place.

Given these behaviours, the structure was developed through a process of *synthesis*: the cycle of developing structure, evaluating actual behaviours and *reformulating* the structure. Some behaviours were challenging to measure (e.g., how useful the tool was to instructors) and were not included in the cycle of synthesis. Other behaviours were used: the perceived ease of at-a-glance understanding of the visualizations produced; the perceived value of the concepts picked up by the tool for revealing the status of the group and the variables that went into this. Pragmatically, this latter required the most innovation, with many variables to consider, such as size of the window of utterances, the analysis of language to utilize, the relevance of sequence of utterances. A detailed description of the structure is useful both for allowing others to replicate the tool but also for understanding how these behaviours were developed into a working, innovative prototype for a tool.

4.3   Describing the Structure of the Tool

The structure of the technique was established through this cycle of synthesis. The tool is described with sufficient detail that it could be replicated. The tool adopts a graph-based approach to representing group dynamics, in which the relationships between words (in particular repetition between members) are used in drawing the graph. The resulting visualizations are then used by instructors for orchestrating group activity. Whilst the idea of using a graphical, heuristics-based approach to topic detection is not new, the desire to include repetition in the analysis meant that appropriate technology was not available, and the technique to do so would have to be developed. The technique will be described in three parts: 1) the NLP pipeline in preparing the natural language and extracting the nouns for processing; 2) drawing the graph based upon relationships between nouns; and 3) analyzing the graph and developing a representation based upon the relationships between words. The example provided

here is being conducted using real-world data from a study of learners engaging with design tasks (described in Thompson, Ashe, Yeoman, & Parisio, 2013).

4.3.1 The NLP Pipeline

Many NLP approaches have in common a pipeline of automated preparation of the natural language data prior to analysis (Manning & Schütze, 1999). In this work, an NLP pipeline was established to clean the data and move from a natural language utterance to a list of nouns from those utterances for further processing, shown in Figure 2 of the pipeline. These techniques have been used previously in analysis of CSCL (Mu et al., 2012; Rebedea et al., 2011; Trausan-Matu, Dascalu, & Rebedea, 2012). The process was implemented in the Python language using a combination of the Natural Language Toolkit (Bird, Klein, & Loper, 2009) and the pattern.en natural language module: 1) data preparation, 2) tokenization, 3) parts of speech tagging, 4) stopword removal, and 5) word stemming. The outcome from the NLP pipeline is a list of nouns from the text. An example of outcomes from the NLP pipeline is shown in Table 1. As the pipeline has an input of natural language, there are likely to be frequent instances of typographical errors, which can lead to an output with the same errors.
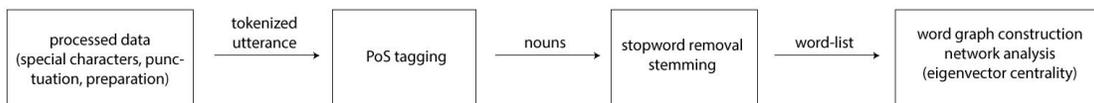
Figure 2. Natural language processing pipeline of utterances

Table 1. Utterances and outcomes from NLP pipeline graph construction

Line	Author	Utterance	Outcome from NLP pipeline
68	Alfred	I've got a plain book, we've got the science syllabus, the geography syllabus…	book, science, geography, syllabus
69	Bronwyn	Put the music on, see it works fine.	music

4.3.2 Graph Creation

The technique functions by creating a graph within which words are nodes and relationships between them are edges. In drawing the graph the relevant questions are 1) which connections are meaningful? and 2) how much weight should be given to these connections? The resulting graph can subsequently be mined for information using a suite of algorithms from the field of network theory (Wasserman & Galaskiewicz, 1994).

In this work, the graph (Figure 3) is constructed using the words extracted from the chat dialogue. Edges are drawn between these words based on 1) co-occurrence and 2) adjacent occurrence by different actors. Co-occurrence refers to the identified words that occur within the same utterance. Their relationship is indicated by having been uttered within the same sentence. Adjacent occurrence refers to words in proximal utterances. A further criterion is that only adjacent occurrences by different actors are considered.

The resulting graph produced by this process is a representation of the relationships between the pruned words. Edges in the graph are weighted to capture information about the frequency of connections. For example, if the same extracted word occurs within three separate utterance times then it means that this has occurred more than once. Equation 1 shows the calculation of weighting of the edge, as term frequency (the number of times the same extracted word has been used in the utterance), over the number of terms in the utterance (the total number of extracted words in the pruned list). Two distinct benefits are derived from this weighting. First, it prevents the length of each utterance from having excessive influence on the final graph; second, it allows for the additive development of weights on connections as new utterances are processed.

These rules can be formalized as a group chat Γ made up of a number of utterances U, Equation 1, where each utterance consists of a number of extracted words k:

$$\Gamma = \{U_1, U_2, U_3, \ldots, U_n\} \tag{1}$$
$$U_x = \{k_{x,1}, k_{x,2}, k_{x,3}, \ldots, k_{x,m}\} \tag{2}$$

Each extracted word, k, becomes a node within the graph. An edge $e_{i,j}$ is drawn between every pair of extracted words $k_{x,i}^a$, $k_{x,j}^a$ that co-occur within the utterance U_x made by actor a:

$$k_{x,i}^a \cap k_{x,j}^a \rightarrow e_{i,j} \tag{3}$$

The weighting given to each edge is inverse to the number of terms within the utterance U_x which will be referred to as p:

$$w_{e_{i,j}} = \frac{1}{p} \tag{4}$$

An edge is also drawn between extracted words where an adjacent occurrence occurs and there is a different actor b such that $a \neq b$:

$$k_{x,i}^a \cap k_{x+1,j}^a \rightarrow e_{i,j} \tag{5}$$

In the case of these adjacent utterances this takes the number of terms in the subsequent utterance multiplied by the previous weight:

$$w_{e_{i,j}}^{adjacent} = \frac{1}{p^{current}} \times p^{previous} \tag{6}$$

Weights are summed where more than one connection is being made, as occurs where a word has more than one edge joining it, such as in cases where the same word appears in multiple utterances throughout the conversation.

The two phrases in Table 1 can be used to provide an example of the construction of the graph. The two utterances are adjacent and are uttered by different actors. The resulting nodes, edges, and weightings are represented in Figure 3. The utterance in U_{68} results in the creation of weighted links between the words, "book," "science," "geography," and "syllabus." As there are four extracted words in the utterance, each link has a weight of 0.25. In the second utterance in U_{69} there is one word identified, "music." As the second utterance was adjacent and uttered by a different actor, links are created between the two sets of words with weightings of 0.25.
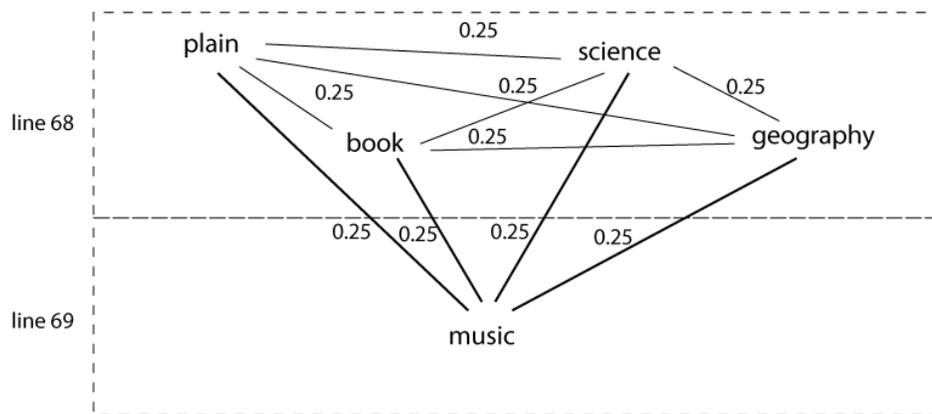
Figure 3. Construction of weighted graph of extracted words and relationships from the utterances in Table 1

The composition of the graph resulting from this construction of CSCL data is then analyzed to determine topics, using the centrality of each word within the graph as an indication of its importance (Wasserman & Galaskiewicz, 1994). Due to the way that the graph has been constructed, the importance of the word as indicated by centrality incorporates factors of frequency of the word, its relationship to other words, the importance of *those* words, and the relationship between actors.

The centrality measure used in this work is eigenvector centrality which is typically used to measure influence within the network (Bonacich, 1972). This algorithm is more widely known as the technique upon which the Google PageRank is based (Page, Brin, Motwani, & Winograd, 1999). This measure finds the influence of each node upon the entire network, where the importance of a node is affected by the importance of each other node that connects to it. In our model the eigenvector centrality measure is used to indicate the words most influential in the graph.

4.3.3   Representation

The representation of the data provides the reader with information about how the key concepts relate to one another. In this demonstration, the most recent 50 utterances were used. The key concepts used by each group are shown as nodes, with the width of the edges representing the strength of connections, Figures 4–9. This provides an intuitive understanding for the viewer (in practical use, the

instructor), where a richness of words indicates significant activity, whilst a paucity of words indicates parsimonious contributions.

Figures 4–13 below are the representations generated using the graphical analysis technique for a sample of the utterances generated by Group 1 and Group 2 (from utterance 300 to utterance 449). During the period represented in what follows, the group is undergoing a phase of idea generation prompted by the presence of the facilitator. The analysis of the processes of idea generation and collaborative discussion in Group 2 has also been reported on in previous papers (Thompson, Ashe, Wardak, Yeoman, & Parisio, 2013; Thompson, Ashe, Yeoman, Parisio, 2013). During the collaborative design task, Group 2 underwent a period where the processes of collaboration broke down due to a failure in the technology they were using, and which was preceded by negative social interactions. It is this point, as the group is fracturing, that is represented by the selection of utterances below. There are five graphs for each group. While each graph represents 50 utterances, there is an overlap of 25 between each graph. This is done to show the gradual change in the discourse over time (i.e., the idea being that in practice this would be a moving window of 50 utterances that the educator can view at any time). First we will use a rich description, based on the video data, of what was happening in each group at this time. Then we will show how this relates to the graphs. Finally, we will provide a comparison between the two groups.

Group 1 spent much of their time negotiating ownership of tools and space. The facilitator attempts to move them from the phase of negotiation and orientation to idea generation before they have resolved the roles of the group members and the rules of the group. Each time the facilitator leaves the group, they revert to this negotiation and orientation phase. In Figure 4, the key concepts with strong connections between them are *Facebook*, *game,* and *guy*. The group is in the middle of a period of ideation in which the facilitator is leading them through the development of ideas for the game. He is asking them to empathize with the future users of the learning resource, with reference to *guy* and *person* and asking them to find *connections* to other *ideas*.

In Figure 5, the discussion about ideas for the game continues, mainly led by the facilitator. However, as can be seen in utterances 350–399 (Figure 6), the network of key concepts is highly decreased. It is at this point that the discourse slows as the students are recording the idea in their shared document, and having minor technical difficulties with the mouse. Conversation is stilted as the facilitator tries to evoke responses from the students as to how they envision their learning resource, as their concentration is on the technology.

Figure 7 shows the beginning of the group discussing their own ideas that have come from the conversation with the facilitator. There are many different ideas being thrown around, as evidenced by the many key concepts without strong connections between them. Figure 8 shows the connections becoming stronger as the group comes to a shared understanding of the proposed idea.
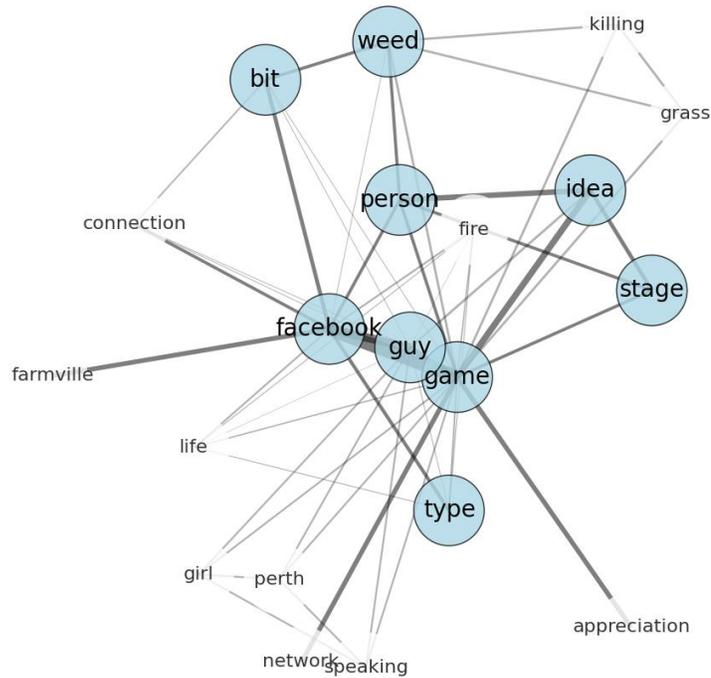
Figure 4. Representation of group 1 collaboration, utterances 300–349
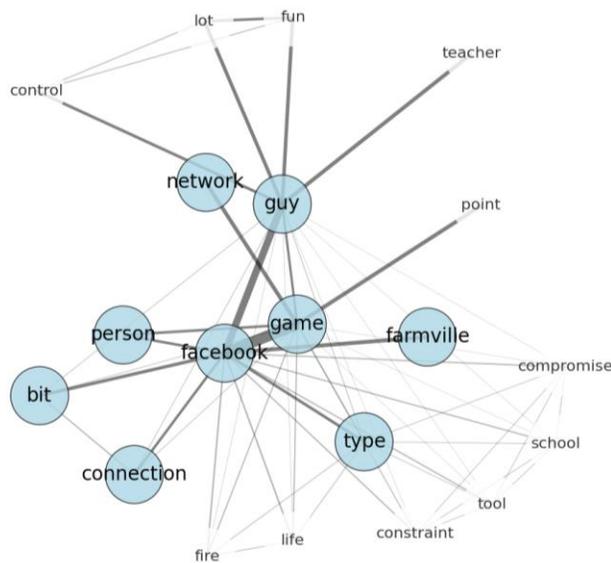
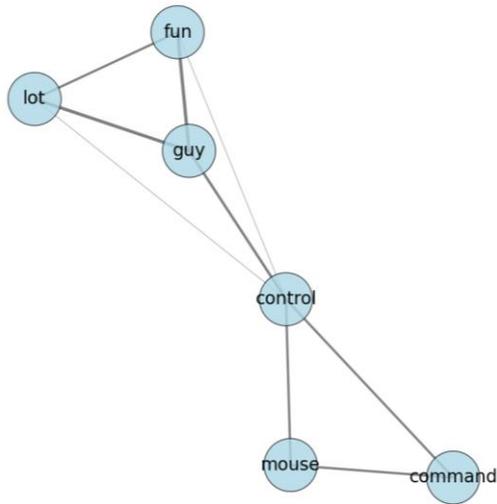**Figure 5. Representation of group 1 collaboration, utterances 325–374**

Figure 6. Representation of group 1 collaboration, utterances 350–399
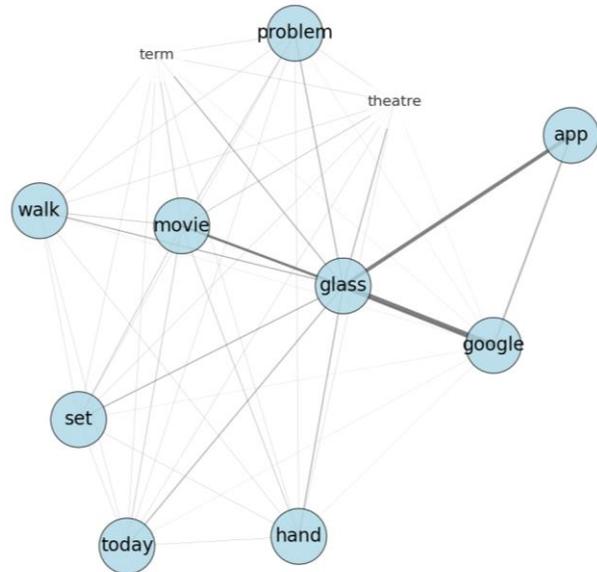

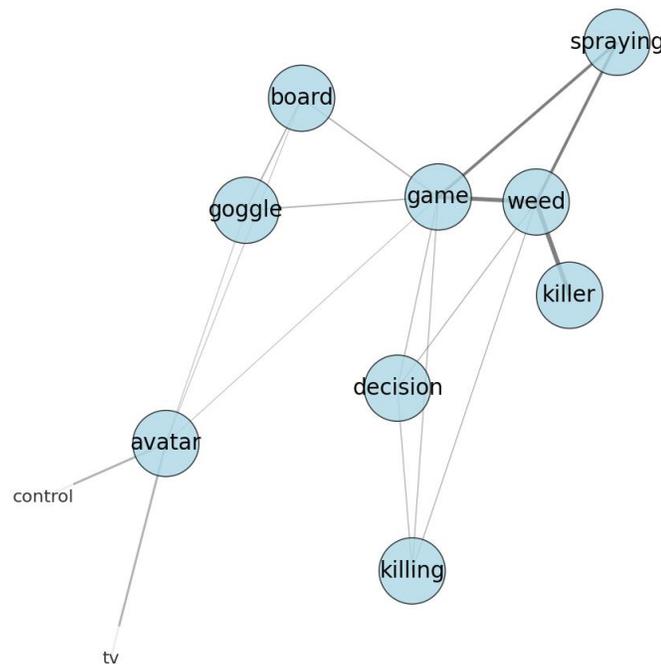**Figure 7. Representation of group 1 collaboration, utterances 375–424**

Figure 8. Representation of group 1 collaboration, utterances 400–449

At the same time as the idea generation phase could be observed in Group 1, Group 2's discussion was characterized by negotiation of the rules and roles within the group of five boys (e.g., *smarty, pants*) and reference to the creation of a Word document in which one member catalogued the group's earlier

ideas (e.g., *spelling, mistake, word*), and the eventual descent into a long discussion that was classified as off-task (e.g., *muffin, icing, cherry, cupcake*) in reference to drawings being made on the writeable wall by a different group.

Figure 9 represents the part of the discourse in Group 2 just before the collaboration breaks down. The students have just begun discussing an idea related to a detailed element of the game. However, they are drawing at the same time, and so the discourse is stilted. Figure 10 shows the beginning of the negative social interactions, with negative comments about *spelling mistakes*, and name calling (*smarty pants*). Figure 11 shows one student's comments about a drawing. At this point there has been a failure in the technology, and most of the discussion is about action to fix the problem (with few nouns). Figures 12 and 13 show the breakdown of the focus of the group, as they are distracted from the task and have an off-task conversation (e.g., *muffin, icing, cherry, cupcake*) in reference to drawings they were making on the writeable wall.
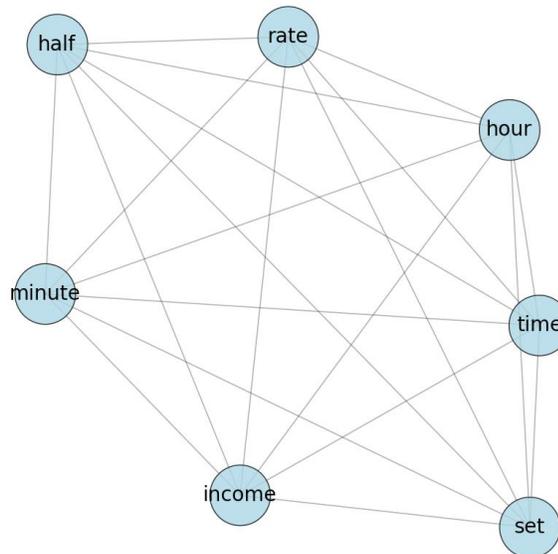

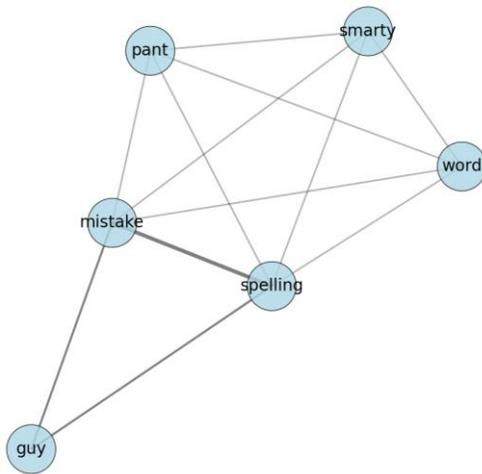**Figure 9. Representation of group 2 collaboration, utterances 300–349**

Figure 10. Representation of group 2 collaboration, utterances 325–374

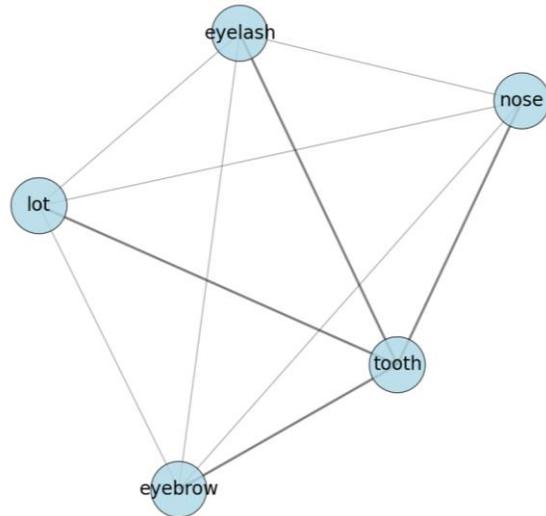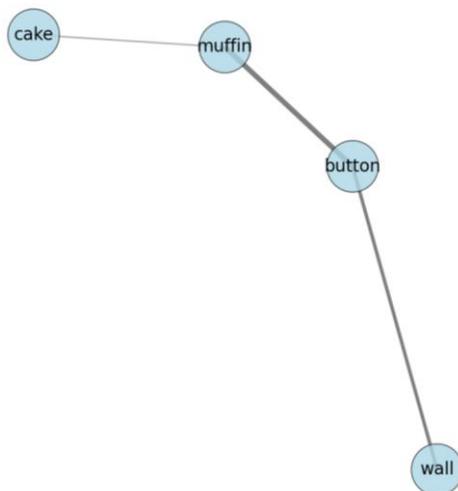**Figure 11. Representation of group 2 collaboration, utterances 350–399**

Figure 12. Representation of group 2 collaboration, utterances 375–424
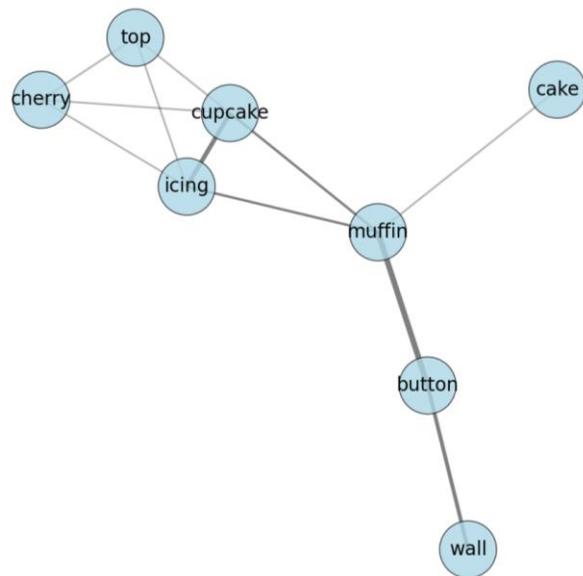

Figure 13. Representation of group 2 collaboration, utterances 400–449

In both groups, phases in the process of idea generation could be identified by the patterns of key concepts and the nature of the connections between them. Few key concepts with strong connections indicated a clear idea; however, the nature of the representation did not show whether it was one person making their case (as in Group 1, Figure 4) or an occurrence of shared meaning making (as in Group 1, Figure 8). Many key concepts with limited strong connections indicated a period close to brainstorming, with many participants suggesting ideas, most unrelated to each other (as in Group 1,

Figure 7). Few key concepts with few connections indicated action of some kind, whether that was the recording of ideas (as in Group 1, Figure 6), or troubleshooting (as in Group 2, Figure 11). Finally, key concepts unrelated to the task or topic indicated off-task discourse (as in Group 2, Figure 12) and an increase in links between key (off-task) concepts indicated an extended period of off-task work (as in Group 2, Figure 13). In each of these cases, understanding what preceded the moments that each graph represents helps to understand the process that each group is undertaking, and in fact, in most cases cause for intervention would be the continuation of a group in any of the above phases of their collaborative design work.

4.4   Evaluation and Reformulation

As described in the framework, the tool requires evaluation of how the actual behaviours of the structure perform against its expected behaviours. However, only some of the actual behaviours have been tested at this point due to limitations of time and resources. This section describes the process of evaluation and reformulation required to advance the design process further.

Most critically, evaluation is required for the behaviour of how useful the tool is to instructors. This would ideally be done as an in-situ experiment, with a number of instructors that currently orchestrate online group activities using the tool for LA and being surveyed about their perceptions of the utility of the tool: Did it reveal anything about the status of the groups? Were the concepts indicated by the tool indicators of key concepts used by the group? Was the tool reliable and/or useful? Could it be improved and if so, how? By asking these questions of multiple instructors, an understanding of how well the tool satisfies this behaviour could be developed.

This understanding would most likely lead to reformulation of one or another of the three types. For example, the tool may prove to be entirely unhelpful to instructors, at which point the very function of the tool may be questioned and reformulated. Or perhaps the tool may prove useful but a behaviour is identified during the process of evaluation that could further improve the tool, leading to reformulation of behaviours, which in turn leads to changes in structure. Or some tweaks to the structure might be identified to improve performance in the behaviours already established.

5   DISCUSSION AND CONCLUSIONS

This paper has contributed an overview of different ways to develop novel tools for use in learning analytics and has focused upon design from first-principles as a way of promoting innovation in the design of tools for ADA. In Section 3 a framework for how theory fits into design of new tools was posited, and in Section 4 an example was presented that resulted in the creation of a new tool to aid instructors in orchestrating online groups, a tool that has potential significance (following future testing and validation) in its own right. The example shows how theory-led design occurs; yet even in the example it is apparent that the notion of design being theory-led lies in a continuum rather than a dichotomy. On this continuum the design of tools may be increasingly informed by theory. This is not

opposed to design for meeting the needs of users but rather a complement. In the framework it was stressed that use of theory is most critical in establishing first principles, where theory allows for the epistemological foundations for the tool and the perspectives upon learning adopted to be made explicit.

The example developed in Section 4 makes explicit a commitment to group cognition and language analysis, as well as an understanding of the role of word repetition in turn-taking during conversation. These principles informed the development of the novel tool — the selection of data, the method of analysis and of representation. The tool itself was demonstrated in Section 4.3 using real-world data from natural language chat between participants in a two groups engaged in a design task. Whilst the results show the proof of concept of the tool, much work is required to demonstrate its utility within the cannon of LA. In particular, the claim that it is useful for instructors in orchestrating online collaborative work needs be tested, ideally with real-world instructors of online classrooms in real-time, testing both for demonstration of the tool's accuracy in helping instructors and for instructors' perceptions of its usefulness.

The technique developed provides a visual representation (for the purposes of orchestration) of automatically identified topics raised in the discourse using sliding windows (to show change over time). Other research discussed (Thompson, Ashe, Wardak, et al., 2013) showed that the development of design ideas, which can be identified using this technique, was an effective indicator of a group's progress through this part of the task, and also aligned with other areas of activity, such as collaborative processes. With training, we propose that this technique could be used to provide instructors with visualizations that could indicate a group that needs help to progress in their task. We do not suggest that this would be the only measure, indeed other parts of speech can be used to indicate successful collaboration (Thompson, Kennedy-Clark, Kelly, & Wheeler, 2013). In the other research on this dataset, we suggested that it is the social activity of the learners that needed to be supported by the facilitator, that the learners were very capable of generating ideas, but that unproductive pauses, such as negative social interactions, or an inability to move past the negotiation of roles and rules in the group, prevented the groups from engaging in this idea generation. Understanding how the development of successful collaborative activity can be supported by instructors could add to our understanding of orchestration. As stated earlier, group cognition (Stahl, 2006) assumes that knowledge emerges from the interaction of social organization, tool use, and epistemic factors (Goodyear & Carvalho, 2014), which are beyond that of the influence of any particular individual. Using custom-built LA tools, such as the one suggested in this paper, could give us insight into the underlying mechanisms that support this emergence.

In the introduction, we claimed that theory-led design has the potential to yield innovation in the development of LA tools, and that the development of LA tools, and their application, may then contribute to learning theory. Whilst there are many available off-the-shelf technologies and representations, the argument is that much can be gained by designing domain-specific instruments,

where the resources and skills to do this are available. By considering stakeholders, objectives, and first-principles and having these informed by theory, existing instruments can be adapted and novel instruments developed. Whilst clearly such innovation has been occurring and will continue to occur, the paper serves to draw attention to the importance of theory-led design. The mindful application of LA has the potential to provide us with insights into the activity of learners. By connecting the questions we ask of learning theories, we provide a context for the data extracted and analyzed, and potentially contribute further to our understanding of that theory, and learning. In this paper, we show that this same consideration can be applied to the *design of learning analytics tools* themselves, and we expand the contribution that LA can make, to include our understanding of how learning activity unfolds, and how this can be shaped by instructors.

ACKNOWLEDGEMENTS

REFERENCES

Abras, C., Maloney-Krichmar, D., & Preece, J. (2004). User-centered design. In W. Bainbridge (Ed.), *Encyclopedia of Human–Computer Interaction* (pp. 445–456)*.* Thousand Oaks, CA: Sage Publications.

Arnold, K. E., & Pistilli, M. D. (2012). Course signals at Purdue: Using learning analytics to increase student success. *Proceedings of the 2nd International Conference on Learning Analytics & Knowledge (LAK 2012),* 267–270. http://dx.doi.org/10.1145/2330601.2330666

Bakhtin, M. M. (1981/2010). *The dialogic imagination: Four essays*. Austin, TX: University of Texas Press.

Bird, S., Klein, E., & Loper, E. (2009). *Natural language processing with Python*. Sebastopol, CA: O'Reilly Media, Incorporated.

Blei, D. M., Carin, L., & Dunson, D. (2010). Probabilistic topic models. *Signal Processing Magazine, IEEE, 27*(6), 55–65. http://dx.doi.org/10.1109/MSP.2010.938079

Blei, D. M., Ng, A. Y., & Jordan, M. I. (2003). Latent dirichlet allocation. *The Journal of Machine Learning Research, 3*, 993–1022. Retrieved from http://dl.acm.org/citation.cfm?id=944937

Bonacich, P. (1972). Factoring and weighting approaches to status scores and clique identification. *Journal of Mathematical Sociology, 2*(1), 113–120. http://dx.doi.org/10.1080/0022250X.1972.9989806

Bonk, C. J., & Graham, C. R. (2012). *The handbook of blended learning: Global perspectives, local designs*. San Francisco, CA: Pfeiffer.

36

Buckingham Shum, S., & Ferguson, R. (2012). Social learning analytics. *Educational Technology & Society, 15*(3), 3–26. Retrieved from http://www.editlib.org/p/74970

Campbell, J. P., DeBlois, P. B., & Oblinger, D. G. (2007). Academic analytics: A new tool for a new era. *Educause Review, 42*(4), 40.

Chiu, M. M. (2008). Flowing toward correct contributions during group problem solving: A statistical discourse analysis. *Journal of the Learning Sciences, 17*(3), 415–463. http://dx.doi.org/10.1080/10508400802224830

Chiu, M. M. (2013). Statistical discourse analysis of an online discussion: Cognition and social metacognition. In D. D. Suthers, K. Lund, C. P. Rosé, C. Teplovs, N. Law (Eds.), *Productive multivocality in the analysis of group interactions* (pp. 417–433). New York: Springer.

Cui, W., Wu, Y., Liu, S., Wei, F., Zhou, M. X., & Qu, H. (2010). Context preserving dynamic word cloud visualization. *Pacific Visualization Symposium (PacificVis), 2010 IEEE*, 121–128. http://dx.doi.org/10.1109/PACIFICVIS.2010.5429600

De Liddo, A., Buckingham Shum, S., Quinto, I., Bachler, M., & Cannavacciuolo, L. (2011). Discourse-centric learning analytics. *Proceedings of the 1st International Conference on Learning Analytics and Knowledge (LAK '11),* 23–33. http://dx.doi.org/10.1145/2090116.2090120

Dillenbourg, P., & Jermann, P. (2010). Technology for classroom orchestration. In M. S. Khine & I. M. Saleh (Eds.), *New science of learning* (pp. 525–552). New York: Springer. http://dx.doi.org/10.1007/978-1-4419-5716-0_26

Dillenbourg, P., Nussbaum, M., Dimitriadis, Y., & Roschelle, J. (2012). Design for classroom orchestration. *Computers & Education*, *69,* 485-492. http://dx.doi.org/10.1016/j.compedu.2013.04.013

Dorst, K., & Vermaas, P. E. (2005). John Gero's function-behaviour-structure model of designing: A critical analysis. *Research in Engineering Design, 16*, 17–26. http://dx.doi.org/10.1007/s00163-005-0058-z

Garrison, D. R., & Kanuka, H. (2004). Blended learning: Uncovering its transformative potential in higher education. *The Internet and Higher Education, 7*(2), 95–105. http://dx.doi.org/10.1016/j.iheduc.2004.02.001

Gee, J. P., & Green, J. L. (1998). Discourse analysis, learning, and social practice: A methodological study. *Review of research in education, 23,* 119–169. http://dx.doi.org/10.3102/0091732X023001119

Gero, J. S. (1990). Design prototypes: A knowledge representation schema for design. *AI Magazine, 11*(4), 26. http://dx.doi.org/10.1609/aimag.v11i4.854

Gero, J. S. (2000). Computational models of innovative and creative design processes. *Technological Forecasting and Social Change, 64*(2), 183–196. http://dx.doi.org/10.1016/S0040-1625(99)00105-5

Gero, J. S., & Kannengiesser, U. (2004). The situated function–behaviour–structure framework. *Design Studies, 25*(4), 373–391. http://dx.doi.org/10.1016/j.destud.2003.10.010

Goodyear, P., & Carvalho, L. (2014). Introduction: Networked learning and learning networks. In L. Carvalho & P. Goodyear (Eds.), *The architecture of productive learning networks* (pp. 3–22). New York: Routledge.

Goodyear, P., Jones, C., & Thompson, K. (2014). Computer-supported collaborative learning: Instructional approaches, group processes and educational designs. In M. D. Merrill, J. Elen, & J. M. Spector (Eds.), *Handbook of Research on Educational Communications and Technology* (pp. 439–451). New York: Springer.

Greller, W., & Drachsler, H. (2012). Translating learning into numbers: A generic framework for learning analytics. *Educational Technology & Society, 15*(3), 42–57. Retrieved from http://hdl.handle.net/1820/4506

Jones, D., Beer, C., & Clark, D. (2013). The IRAC framework: Locating the performance zone for learning analytics. In H. Carter, M. Gosper & J. Hedberg (Eds.), *Proceedings of the 30th Australasian Society for Computers in Learning in Tertiary Education Conference (ASCILITE 2013). (pp.446-450).* Sydney: Macquarie University. Retrieved from http://eprints.usq.edu.au/24352/

Kennedy-Clark, S., & Thompson, K. (2013a). Collaborative process analysis coding scheme (CPACS): Examining the macro-and micro-level of students' discourse in a virtual world. *International Journal of Virtual and Personal Learning Environments (IJVPLE), 4*(2), 19–49. http://dx.doi.org/10.4018/jvple.2013040102

Kennedy-Clark, S., & Thompson, K. (2013b). Using multimodal discourse analysis to identify patterns of problem solving processes in a computer-supported collaborative environment. In H. W. Lim & F. Sudweeks (Eds.), Innovative methods and technologies for electronic discourse analysis (pp. 94–118). Hershey, PA: IGI Global. http://dx.doi.org/10.4018/978-1-4666-4426-7.ch005

Kop, R. (2011). The challenges to connectivist learning on open online networks: Learning experiences during a massive open online course. *The International Review of Research in Open and Distance Learning, 12*(3), 19–38. Retrieved from http://www.irrodl.org/index.php/irrodl/article/view/882

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, UK: Cambridge University Press.

Lockyer, L., & Dawson, S. (2011). Learning designs and learning analytics. *Proceedings of the 1st International Conference on Learning Analytics and Knowledge (LAK '11),* 153–156. http://dx.doi.org/0.1145/2090116.2090140

Lockyer, L., Heathcote, E., & Dawson, S. (2013). Informing pedagogical action: Aligning learning analytics with learning design. *American Behavioral Scientist*, *57*(10). http://dx.doi.org/10.1177/0002764213479367

Lund, K., & Suthers, D. D. (2013). Methodological dimensions. In D. D. Suthers, K. Lund, C. P. Rosé, C. Teplovs, N. Law (Eds.), *Productive multivocality in the analysis of group interactions* (pp. 21–35). New York: Springer.

Macfadyen, L. P., & Dawson, S. (2010). Mining LMS data to develop an "early warning system" for educators: A proof of concept. *Computers & Education, 54*(2), 588–599. http://dx.doi.org/10.1016/j.compedu.2009.09.008

Macfadyen, L. P., & Dawson, S. (2012). Numbers are not enough: Why e-learning analytics failed to inform an institutional strategic plan. *Educational Technology & Society, 15*(3), 149–163. Retrieved from http://www.ifets.info/journals/15_3/11.pdf

Manning, C. D., & Schütze, H. (1999). *Foundations of statistical natural language processing* (Vol. 999). Cambridge, MA: MIT Press.

Martinez-Maldonado, R., Clayphan, A., Yacef, K., & Kay, J. (2015). MTFeedback: Providing notifications to enhance teacher awareness of small group work in the classroom. *IEEE Transactions on Learning Technologies, 8*(2), 187–200. http://dx.doi.org/10.1109/TLT.2014.2365027

Matsuzawa, Y., Oshima, J., Oshima, R., Niihara, Y., & Sakai, S. (2011). KBDeX: A platform for exploring discourse in collaborative learning. *Procedia-Social and Behavioral Sciences, 26*, 198–207. http://dx.doi.org/10.1016/j.sbspro.2011.10.576

Mazur, J. M., & Lio, C. H. (2004). Learner articulation in an immersive visualization environment. *Extended Abstracts on Human Factors in Computing Systems (CHI EA '04),* 1355–1358. http://dx.doi.org/10.1145/985921.986063

Mazzolini, M., & Maddison, S. (2003). Sage, guide or ghost? The effect of instructor intervention on student participation in online discussion forums. *Computers & Education, 40*(3), 237–253. http://dx.doi.org/10.1016/S0360-1315(02)00129-X

Mercer, N. (2007). Sociocultural discourse analysis: Analysing classroom talk as a social mode of thinking. *Journal of Applied Linguistics and Professional Practice, 1*(2), 137–168**.** http://dx.doi.org/10.1558/japl.v1.i2.137

Mu, J., Stegmann, K., Mayfield, E., Rosé, C., & Fischer, F. (2012). The ACODEA framework: Developing segmentation and classification schemes for fully automatic analysis of online discussions. *International Journal of Computer-Supported Collaborative Learning, 7*(2), 285–305. http://dx.doi.org/10.1007/s11412-012-9147-y

Nivre, J., Allwood, J., & Ahlsén, E. (1999). *Interactive communication management: Coding manual V1.0.* Göteborg: Göteborg University, Department of Linguistics. Retrieved from http://www.ling.gu.se/projekt/tal/doc/ICM_manual.pdf

Norrick, N. R. (1987). Functions of repetition in conversation. *Text-Interdisciplinary Journal for the Study of Discourse, 7*(3), 245–264. http://dx.doi.org/10.1515/text.1.1987.7.3.245

Oshima, J., Matsuzawa, Y., Oshima, R., & Niihara, Y. (2013). Application of social network analysis to collaborative problem solving discourse: An attempt to capture dynamics of collective knowledge advancement. In D. D. Suthers, K. Lund, C. P. Rosé, C. Teplovs, N. Law (Eds.), *Productive multivocality in the analysis of group interactions* (pp. 225–242). New York: Springer.

Oshima, J., Oshima, R., & Matsuzawa, Y. (2012). Knowledge building discourse explorer: A social network analysis application for knowledge building discourse. *Educational Technology Research and Development, 60*(5), 903–921. http://dx.doi.org/10.1007/s11423-012-9265-2

Page, L., Brin, S., Motwani, R., & Winograd, T. (1999). *The PageRank citation ranking: Bringing order to the web* (Technical report). Retrieved from http://ilpubs.stanford.edu:8090/422/

Rebedea, T., Dascalu, M., Trausan-Matu, S., Armitt, G., & Chiru, C. (2011). Automatic assessment of collaborative chat conversations with PolyCAFe. In C. Delgado Kloos et al. (Eds.), *Towards Ubiquitous Learning: Proceedings of the 6th European Conference of Technology Enhanced Learning (EC-TEL 2011*), (pp. 299–312). New York: Springer. http://dx.doi.org/10.1007/978-3-642-23985-4_24

Reimann, P. (2009). Time is precious: Variable- and event-centred approaches to process analysis in CSCL research. *International Journal of Computer-Supported Collaborative Learning, 4*(3), 239–257. http://dx.doi.org/10.1007/s11412-009-9070-z

Reimann, P., Markauskaite, L., & Bannert, M. (2014). e-Research and learning theory: What do sequence and process mining methods contribute? *British Journal of Educational Technology, 45*(3), 528–540. http://dx.doi.org/10.1111/bjet.12146

Roschelle, J., Dimitriadis, Y., & Hoppe, U. (2013). Classroom orchestration: Synthesis. *Computers & Education, 69*, 523–526. http://dx.doi.org/10.1016/j.compedu.2013.04.010

Rosé, C., Wang, Y.-C., Cui, Y., Arguello, J., Stegmann, K., Weinberger, A., & Fischer, F. (2008). Analyzing collaborative learning processes automatically: Exploiting the advances of computational linguistics in computer-supported collaborative learning. *International Journal of Computer-Supported Collaborative Learning, 3*(3), 237–271. http://dx.doi.org/10.1007%2Fs11412-007-9034-0

Sacks, H. (1972). An Initial investigation of the usability of conversational data for doing sociology. In D. Sudnow (Ed.), *Studies in Social Interaction* (pp. 31–74). New York: Free Press.

Sawyer, K. (2006). Analyzing collaborative discourse. In K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (pp. 187–204). Cambridge, UK: Cambridge University Press.

Sayyadi, H., & Raschid, L. (2013). A graph analytical approach for topic detection. *ACM Transactions on Internet Technology (TOIT), 13*(2), 4. http://dx.doi.org/10.1145/2542214.2542215

Scheffel, M., Niemann, K., Leony, D., Pardo, A., Schmitz, H.-C., Wolpers, M., & Kloos, C. D. (2012). Key action extraction for learning analytics. In A. Ravenscroft et al. (Eds.), *21st Century Learning for 21st Century Skills: Proceedings of the 7th European Conference of Technology Enhanced Learning* (EC-TEL 2012), (pp. 320–333). New York: Springer. doi: 10.1007/978-3-642-33263-0_25

Sherin, B. (2013). A computational study of commonsense science: An exploration in the automated analysis of clinical interview data. *Journal of the Learning Sciences, 22*(4), 600–638. http://dx.doi.org/10.1080/10508406.2013.836654

Siemens, G., & Baker, R. S. J. (2012). Learning analytics and educational data mining: Towards communication and collaboration. *Proceedings of the 2nd International Conference on Learning Analytics and Knowledge* (LAK '12), 252–254. http://dx.doi.org/10.1145/2330601.2330661

Siemens, G., & Long, P. (2011). Penetrating the fog: Analytics in learning and education. *Educause Review, 46*(5), 30–32. Retrieved from http://er.educause.edu/articles/2011/9/penetrating-the-fog-analytics-in-learning-and-education

Soter, A. O., Wilkinson, I. A., Murphy, P. K., Rudge, L., Reninger, K., & Edwards, M. (2008). What the discourse tells us: Talk and indicators of high-level comprehension. *International Journal of Educational Research, 47*(6), 372–391. http://dx.doi.org/10.1016/j.ijer.2009.01.001

Stahl, G. (2006). *Group cognition: Computer support for building collaborative knowledge*. Cambridge, MA: MIT Press.

Stahl, G. (2009). *Studying virtual math teams* (Vol. 11). New York: Springer Science & Business Media.

ISSN 1929-7750 (online). The Journal of Learning Analytics works under a Creative Commons License, Attribution - NonCommercial-NoDerivs 3.0 Unported (CC BY-NC-ND 3.0)

40

Stahl, G. (2012). Theories of cognition in collaborative learning. In C. E. Hmelo-Silver, C. A. Chinn, C. Chan, & A. M. O'Donnell (Eds.), *International handbook of collaborative learning* (pp. 74–90). London: Routledge.

Stahl, G., Koschmann, T., & Suthers, D. (2015). Computer-supported collaborative learning: An historical perspective. In K. Sawyer (Ed.), *Cambridge Handbook of the Learning Sciences* (2nd ed.). Cambridge, UK: Cambridge University Press.

Suthers, D. D., Lund, K., Rosé, C. P., Teplovs, C., & Law, N. (2013). *Productive multivocality in the analysis of group interactions*. New York: Springer.

Tannen, D. (1987). Repetition in conversation: Toward a poetics of talk. *Language, 63*(3), 574–605.

Teplovs, C., & Fujita, N. (2013). Socio-dynamic latent semantic learner models. In D. D. Suthers, K. Lund, C. P. Rosé, C. Teplovs, N. Law (Eds.), *Productive multivocality in the analysis of group interactions* (pp. 383–396). New York: Springer.

Thompson, K., Ashe, D., Carvalho, L., Goodyear, P., Kelly, N., & Parisio, M. (2013). Processing and visualizing data in complex learning environments. *American Behavioral Scientist, 57*(10), 1401–1420. http://dx.doi.org/10.1177/0002764213479368

Thompson, K., Ashe, D., Wardak, D., Yeoman, P., & Parisio, M. (2013). Identification of patterns of tool use and sketching practices in a learning by design task. In N. Rummel et al. (Eds.), *To See the World* and *a Grain of Sand: Learning Across Levels of Space, Time, and Scale: Proceedings of the 10th International Conference on Computer-Supported Collaborative Learning (CSCL 2013)* (pp.478–485). Madison, WI: International Society of the Learning Sciences. Retrieved from http://gerrystahl.net/proceedings/cscl2013/cscl2013proceedings1.pdf

Thompson, K., Ashe, D., Yeoman, P., & Parisio, M. (2013). Phases of design: Following idea development and patterns of collaborative discussion in a learning by design project. In N. Rummel et al. (Eds.), *To See the World* and *a Grain of Sand: Learning Across Levels of Space, Time, and Scale: Proceedings of the 10th International Conference on Computer-Supported Collaborative Learning (CSCL 2013)* (pp. 494–501). Madison, WI: International Society of the Learning Sciences. Retrieved from http://gerrystahl.net/proceedings/cscl2013/cscl2013proceedings1.pdf

Thompson, K., Kennedy-Clark, S., Kelly, N., & Wheeler, P. (2013). Using automated and fine-grained analysis of pronoun use as indicators of progress in an online collaborative project. In N. Rummel et al. (Eds.), *To See the World* and *a Grain of Sand: Learning Across Levels of Space, Time, and Scale: Proceedings of the 10th International Conference on Computer-Supported Collaborative Learning (CSCL 2013)* (pp. 486–493). Madison, WI: International Society of the Learning Sciences. Retrieved from http://gerrystahl.net/proceedings/cscl2013/cscl2013proceedings1.pdf

Trausan-Matu, S. (2013). Collaborative and differential utterances, pivotal moments, and polyphony. In D. D. Suthers, K. Lund, C. P. Rosé, C. Teplovs, N. Law (Eds.), *Productive multivocality in the analysis of group interactions* (pp. 123–139). New York: Springer.

Trausan-Matu, S., Dascalu, M., & Rebedea, T. (2012). A system for the automatic analysis of computer-supported collaborative learning chats. *12th International Conference on Advanced Learning Technologies (ICALT)*, 95–99. http://dx.doi.org/10.1109/icalt.2012.101

Trausan-Matu, S., Dascalu, M., & Rebedea, T. (2014). PolyCAFe—automatic support for the polyphonic analysis of CSCL chats. *International Journal of Computer-Supported Collaborative Learning*, *9*(2), 127–156. http://dx.doi.org/10.1007/s11412-014-9190-y

Trausan-Matu, S., & Rebedea, T. (2010). A polyphonic model and system for inter-animation analysis in chat conversations with multiple participants*.* In A. Gelbukh (Ed.), *Computational linguistics and intelligent text processing (Lecture Notes in Computer Science)* (*Vol. 6008,* pp. 354–363). New York: Springer.

Trausan-Matu, S., Rebedea, T., Dragan, A., & Alexandru, C. (2007, August 15). *Visualisation of learners' contributions in chat conversations*. Paper presented at the Workshop on Blended Learning, Edinburgh, United Kingdom. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.95.4885&rep=rep1&type=pdf

Van Barneveld, A., Arnold, K. E., & Campbell, J. P. (2012). Analytics in higher education: Establishing a common language. *EDUCAUSE learning initiative, 1*, 1–11. Retrieved from http://net.educause.edu/ir/library/pdf/eli3026.pdf

Verbert, K., Duval, E., Klerkx, J., Govaerts, S., & Santos, J. L. (2013). Learning analytics dashboard applications. *American Behavioral Scientist*, *57*(10), 1500–1509. doi:0002764213479363.

Vygotsky, L. S. (1930/1978). *Mind and society: The development of higher mental processes*. Cambridge, MA: Harvard University Press.

Wallach, H. M. (2006). Topic modeling: Beyond bag-of-words. *Proceedings of the 23rd International Conference on Machine Learning (ICML 2006)*, 997-984. http://dx.doi.org/10.1145/1143844.1143967

Wasserman, S., & Galaskiewicz, J. (1994). *Advances in social network analysis: Research in the social and behavioural sciences*. Thousand Oakes, CA: SAGE.

Williams, C. B., Yoon Suk, L., Gero, J. S., & Paretti, M. C. (2012, October). *Examining the effect of design education on the design cognition: Measurements from protocol studies*. Paper presented at the Frontiers in Education Conference (FIE), Seattle, Washington. Retrieved from http://ieeexplore.ieee.org/xpl/mostRecentIssue.jsp?punumber=6454261

Winograd, T., & Flores, F. (1986). *Understanding computers and cognition: A new foundation for design*. Bristol, UK: Intellect Books.

Wise, A., & Paulus, T. M. (In press). Analyzing learning in online discussions. In R. Andrews & H. C. (Eds.), *SAGE Handbook of eLearning* (2nd ed.). Thousand Oakes, CA: SAGE.

Wise, A., Zhao, Y., & Hausknecht, S. (2014). Learning analytics for online discussions: Embedded and extracted approaches. *Journal of Learning Analytics, 1*(2), 48–71. Retrieved from https://epress.lib.uts.edu.au/journals/index.php/JLA/article/view/3532/4157

Witten, I. H., Paynter, G. W., Frank, E., Gutwin, C., & Nevill-Manning, C. G. (1999). *KEA: Practical automatic keyphrase extraction.* Paper presented at the 4th ACM Conference on Digital Libraries, Berkley, California. Retrieved from http://www.nzdl.org/Kea/Nevill-et-al-1999-DL99-poster.pdf