Technology Support for Scalable and Dynamic Collaborative Learning: A Pyramid Flow Pattern Approach

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To my parents
(Mr & Mrs. Manathunga)
&
To my husband
(Kusal)

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Abstract

Collaborative Learning is the pedagogical approach that considers social interactions as key means to trigger rich learning processes. Collaborative Learning Flow Patterns define best practices to orchestrate collaborative learning activity flow mechanisms (i.e., group formation, roles or resources allocation, phase change). Flow patterns have been experimented and evaluated as effective in small scale settings for decades. Directly applying these pedagogical methods to large learning scenarios is challenging due to the burden that scale represents in the orchestration load or the difficulty of keeping a dynamic meaningful progression when flexible changes are required in a large classroom or in a MOOC. Some attempts have shown positive results, but research around scalable collaborative learning approaches, models and technologies for large classes is scattered. This dissertation conducts a systematic literature review of collaborative learning applications on large classes and analyses the social learning potential of diverse technology-supported spaces in massive courses. Then the dissertation focuses the study on how collaborative learning could address key challenges (i.e., scalability and dynamism) identified in large collaborative learning contexts. Consequently, the thesis proposes a Pyramid flow pattern instantiation, composed of a model with a set of algorithmic rules for flow creation, flow control and flow awareness as well as a PyramidApp authoring and enactment system implementing the model. Experimentation across diverse learning contexts shows that, on one hand, the contributions support meaningful scalable and dynamic collaborative learning and on the other hand, learners and educators perceive the experiences as engaging, with learning values and effective from the perspective of orchestration.

Resumen

El aprendizaje colaborativo es el enfoque pedagógico que considera las interacciones sociales como un medio clave para desencadenar procesos de aprendizaje ricos. Los patrones de flujo de aprendizaje colaborativo definen buenas prácticas para orquestar mecanismos de flujo en actividades de aprendizaje colaborativo (es decir, la formación de grupos, la asignación de roles o recursos, los cambios de fase). Los patrones de flujo han sido probados y evaluados como efectivos en entornos de pequeña escala durante décadas. La aplicación de estos métodos pedagógicos en grandes escenarios de aprendizaje supone un reto debido a la carga que representa la escala en la orquestación, así como a la dificultad de mantener una progresión dinámica con sentido pedagógico cuando se requieren cambios flexibles en un aula grande o en un MOOC. Existen algunos intentos interesantes, pero la investigación en torno a enfoques de aprendizaje colaborativo escalables, y modelos y tecnologías para entornos educativos con muchos estudiantes está dispersa. Esta tesis lleva a cabo una revisión sistemática de la literatura sobre aplicaciones de aprendizaje colaborativo con muchos estudiantes y analiza el potencial de aprendizaje social de diversos espacios apoyados por la tecnología en este tipo de contextos. A continuación, la tesis se centra en el estudio de cómo el aprendizaje colaborativo podría abordar desafíos clave identificados en contextos de aprendizaje colaborativo con un gran número de estudiantes (es decir, la escalabilidad y el dinamismo). En consecuencia, la tesis propone una instanciación del patrón de flujo Pirámide, compuesto de un modelo con un conjunto de reglas algorítmicas para la creación, el control y la conciencia del flujo de aprendizaje, así como un sistema de creación e implementación del modelo. La experimentación realizada en distintos contextos de aprendizaje demuestra que, por un lado, las contribuciones apoyan un aprendizaje colaborativo escalable y dinámico, y que, por otro lado, los estudiantes y los educadores perciben las experiencias como amenas, con valor para el aprendizaje y efectivas desde la perspectiva de la orquestación.

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Chapter 1

Introduction

This chapter discloses the general research context of the dissertation, the goal, derived partial objectives, the research methodology followed, the main evaluation studies carried out and a summary of the results obtained. The general context of the research is framed along scalable collaborative learning approaches and collaborative learning flow patterns' applicability in large class scenarios. Particularly, this work proposes conceptual models and a Pyramid pattern inspired technological solution to implement collaborative learning in scalable and dynamic learning contexts. A Design Based Research methodology was followed with iterative processes at different stages during the thesis life-cycle. Apart from the thesis contributions, the chapter also explains the limitations of the work, main conclusions and future research lines that can be devised from this work. The chapter concludes with a structure of the thesis.

1.1 Introduction

Mutual interactions positively reinforce the way humans learn (Bandura, 1971) and since early years concepts like social constructivism, activity theory, conversational learning have been causing educational approaches to emphasize on collaborative rather than individual learning (Naismith et al., 2004; Scardamalia & Bereiter, 2006; Stahl, Koschmann, & Suthers, 2006). In education, collaboration is a coordinated process by which individuals construct and maintain shared conceptions where knowledge is co-constructed socially (Roschelle & Teasley, 1995). In collaborative learning, situations are created in which particular forms of interactions among learners are expected to occur and that would trigger learning mechanisms (Dillenbourg, 1999). Computer-Supported Collaborative Learning (CSCL) is the field of study which contributes with mechanisms and technologies supporting creation of such collaborative learning situations (Dillenbourg, Sanna, & Fischer, 2009; Roschelle & Teasley, 1995; Stahl, Koschmann, & Suthers, 2006). Hence, CSCL environments should be carefully designed and implemented incorporating interaction generation and regulation mechanisms.

Free collaboration does not necessarily result in fruitful learning outcomes (Dillenbourg et al., 2009; Hernández-Leo, 2007). Therefore strategies are required in the design process to scaffold productive interactions and/or to facilitate activities by monitoring and intervening when required (Dillenbourg, 1999). In CSCL, shaping up the way that collaborations are desired to happen with technology-mediation is known as "CSCL scripting" (Dillenbourg, 2002; Hernández-Leo, 2007). More precisely, scripting is aimed to trigger specific types of interactions beneficial for learner cognition while achieving educational objectives. Scripts structure the collaborative process by defining the activity sequence, creating roles in groups and constraining interactions among peers in social and cognitive activities that would otherwise occur rarely or not at all (Dillenbourg & Tchounikine, 2007; Kobbe et al., 2007). In this notion, scripting is possible with an emphasis on individual learner's activities with finer granularity and scaffolding, known as "micro-scripts" whereas "macro-scripts" are defining desired interactions in coarse-grained activity flows (Dillenbourg & Tchounikine, 2007; Kobbe et al., 2007). This dissertation work falls under macro-scripting in CSCL.

Flow orchestration refers to the real-time management of CSCL scripts (Dillenbourg, 2013; Dillenbourg & Jermann, 2010), regulating multiple activities, actions and processes in the CSCL scenarios. Dynamic or flexible orchestration is the combination of design and real-time adaptation of the script with a freedom to modifications (Dillenbourg & Jermann, 2010). Collaborative Learning Flow Patterns (CLFPs) are examples of macro-scripts that reflect best practices to orchestrate collaborative learning that are broadly accepted and repetitively utilized by practitioners (Hernández-Leo, 2007). Examples of such patterns are Jigsaw, Pyramid or Snowball, Think-Pair-Share (TPS) and Thinking Aloud Pair Problem Solving (TAPPS). Each pattern is driven by its own pedagogical rationale and constraints (see Table1.1) imposed by the governing pedagogy that should not be modified during the learning design. On the contrary, a pattern implementation and the collaborations can be enriched further by introducing additional parameters such as group formation characteristics or role allocation requirements. These additional factors are flexible to be satisfied since those do not violate the underlying pedagogy of the pattern. Consequently, effective and meaningful CSCL script design requires effort, understanding the pattern definitions and types of constraints (Dillenbourg & Tchounikine, 2007; Hernández-Leo et al., 2006). Previous work in the field had demonstrated extensive knowledge in designing pattern based collaborative activities effectively (Hernández-Leo, 2007; Pérez-Sanagustín, Burgos, Hernández-Leo, & Blat, 2011; Rodríguez-Triana, 2014), yet applicable mostly either at small-scale or co-located learning settings. Script modifiability is also non-trivial, due to unexpected situations like learners not being present or leaving the classroom in the middle of an activity, spoiling on-going collaborations. Considering above aspects, script designing and managing orchestration manually require lot of effort and time (Dillenbourg & Tchounikine, 2007; Hernández-Leo, 2007; Sharples, 2013). Therefore, technology mediated or semi-automated orchestration services are beneficial in managing group formation, phase changing, role allocation and rotation, resource distribution, mediate communication and coordination like flow controlling and group awareness. An ideal CLFP orchestration service (either automated or semi-automated) needs to incorporate mechanisms to design meaningful, flexible scripts while facilitating dynamic changes to pre-created script designs and re-implement.

Table 1.1 Jigsaw and Pyramid pattern descriptions

Jigsaw pattern	***Pyramid pattern***
Relates to a situation where several small groups of students (‘Jigsaw’ groups), each trying to solve a complex problem that can be divided into sub-problems. Each group participant studies one sub-problem individually. Then participants from different Jigsaw groups who studied similar sub problems, meet in temporary ‘Expert’ groups to exchange ideas about their common sub-problems. Finally, participants return back to their Jigsaw groups to share knowledge and solve the global problem. This pattern fosters individual accountability and personal responsibility.	Starts individually or forming initial small groups (usually pairs) to study a common problem and propose initial solutions. Then, students are grouped into small groups to compare and discuss their proposals and, finally, propose a new shared solution from the group. Students are guided so that the groups join with new groups to form larger groups in order to generate new agreed proposals. Likewise this will iterate till the whole group reaches upon a global consensus. This pattern fosters positive interdependence and individual accountability.

Script design and orchestration of CSCL activities are required in different scales varying from small face-to-face classroom settings to massive online learning communities. Predicting potential dynamic conditions or (re)designing scripts on-the-fly in a large face-to-face classroom and managing the orchestration load by the practitioner is not practical (Sharples, 2013). Moreover, how large virtual learner communities or Massive Open Online Courses (MOOCs) communities engage in collaborative learning activities is gaining research attention more, attributing to the rapid growth and popularity of MOOCs (Saadatdoost, Sim, Jafarkarimi, & Mei Hee, 2015; Tsai & Kyle, 2013). Most large learner communities are not static unlike traditional classrooms, dynamic learner behaviours are inherent and diversified culturally, socially and even geographically, that large multidisciplinary efforts in practices are required. Strategies that work well in a conventional classroom cannot extrapolate to such learning contexts directly. Pre-defined or rigid scripts will not be able to apply upon diversified large learner communities to derive meaningful interactions. Therefore, collaborative learning models need to be redesigned not only to be effective under a range of settings, but to be packaged and used everywhere (Stahl, 2015).

Though, social and collaborative learning with peers in forums have been fruitful (Dragon et al., 2013), in large learning contexts such threaded discussions become mass and difficult to follow (Scardamalia & Bereiter, 2006). Hence, novel scalable pedagogies capable of offering collaboration opportunities are required (Ferguson & Sharples, 2014; Saadatdoost et al., 2015; Siemens, Gasevic, & Dawson, 2015). Some attempts have shown interesting results by enabling collaborations in MOOCs via social media tools (Alario-Hoyos, Perez-Sanagustin, Delgado-Kloos, Parada G., & Munoz-Organero, 2014; Knox, 2014). Yet, such scenarios neither harness benefits that structured CSCL opportunities have to offer, nor address issues related with dynamic conditions like inconsistent student participation (drop outs or late joiners). Attempts like audience response systems (clickers) (Herreid, 2006), shared displays (Infante, Hidalgo, Nussbaum, & Alarcón, 2009) have shown positive collaboration results in synchronous large class contexts. But these examples are more contextualized, not easily applicable in distance learning contexts and do not adopt sound macro-scripts to structure collaborations.

Considering aforementioned themes and circumstances, the main motivation recognized in this research is enabling structured CSCL orchestration in large learner contexts where scalability and dynamism are essential concerns. Within the context of this dissertation “***scalability***” is defined as the means of elastically accommodating growing numbers of learners while being pedagogically effective, and “***dynamism***” is defined as the means of keeping activity progression while maintaining enthusiasm and versatility. Thus, the challenges of the dissertation are framed across CLFPs, meaningful orchestration support, large classes (both face-to-face and distance) with active participation, dynamism and scalability. More precisely, study the literature and pattern definitions to extract a potential pattern with scalability essence and further study its compliance and technological viability to be suitable for large learning scenarios.

Remaining sections of this chapter are arranged as following. Section 1.2 explains the main research goal and the partial objectives of the thesis, section 1.3 describes the research methodology and section 1.4 summarizes the main contributions. Section 1.5 provides the limitations of this work, section 1.6 explains the conclusions and section 1.7 describes future research directions derived from this thesis followed by a final subsection describing the structure of the dissertation.

1.2 Dissertation goals

Considering above research context and challenges existing in the domain, the global aim of this dissertation is formulated as, "*how collaborative learning flow patterns can be instantiated and technologically supported to implement scalable and dynamic CSCL scenarios?*". Figure 1.1 illustrates the research context, the goal of the dissertation along with the contributions and the evaluations conducted. As depicted in Figure 1.1, above global aim is sub-divided into partial objectives which were addressed along the line of the dissertation.

[OBJ_1] To identify how CSCL scenarios have been designed to support large scale learning contexts in the literature

The current CSCL body of knowledge is mostly known for its contributions in small learner groups (Stahl, 2015). How this visible body of knowledge has been applied in large learning contexts, which collaborative learning methodologies have been experimented upon which educational settings are some interesting factors to further investigate. Also understanding different technological approaches implementing CSCL in large classes and the level of orchestration support provided is critically important to propose novel CSCL technologies. A synthetization of the extent that current CSCL practices are involved in the design and enactment of collaborative learning in large learning communities is essential to this dissertation context.

[OBJ_2] To model flexible conditions in CLFPs to implement scripts effectively

Generating effective scripts with desired interactions can be time consuming and require prior experience (Dillenbourg, 2002; Hernández-Leo, Asensio-Pérez, Dimitriadis, & Villasclaras-Fernández, 2010). Differentiating between intrinsic and extrinsic constraints in macro-scripts is vital in the learning design since that defines the flexibility of the macro-script (Dillenbourg & Tchounikine, 2007; Pérez-Sanagustín et al., 2011; Rodríguez-Triana, 2014). Diverse learning contexts and their parameters introduce new constraints to be considered to fine-tune orchestration aspects (e.g. group formation, role or resource allocation). Articulation of such additional elements and the level of flexibility in CLFPs without spoiling the pedagogical rationale is the key to design effective scripts. Hence, modelling these multiple constraints in a CLFP constraint framework along with parameters is equally important for the implementation of orchestration services to be adapted by practitioners easily.

[OBJ_3] To model types of social and collaborative learning spaces for MOOCs.

Forum discussions being prevalent and straightforward in implementing are widely available in MOOCs. Thus, such learning platforms lack in offering a wide range of social or collaborative learning opportunities (Rosé et al., 2014; Siemens et al., 2015). As MOOCs are diversified, less-predictable, dynamic learning contexts with massive amounts of participants with varied motivations, traditional CSCL scripts are not easily applicable. Therefore, it is crucial to study what are conceivable social learning opportunities existing or potential to implement in future. In that context, formulation of a social learning space grid modelling types of social and collaborative learning spaces followed by a relevant case study applying such spaces can direct to address this objective favourably.

[OBJ_4] To propose an instance of CLFP addressing scalability and dynamism challenges.

CSCL activities can be structured for desired interactions to occur in large classes also, if those are designed considering scalability and dynamism elements. A synthesis of flow pattern definitions and their scalability aspects can lead to identification of potential scalable CLFPs. Pyramid (a.k.a. Snowball) flow pattern (Hernández-Leo et al., 2006) can be characterized as potentially scalable; thus a Pyramid instantiation along with required algorithm mechanisms to address scalability and dynamism can guide to tackle this objective.

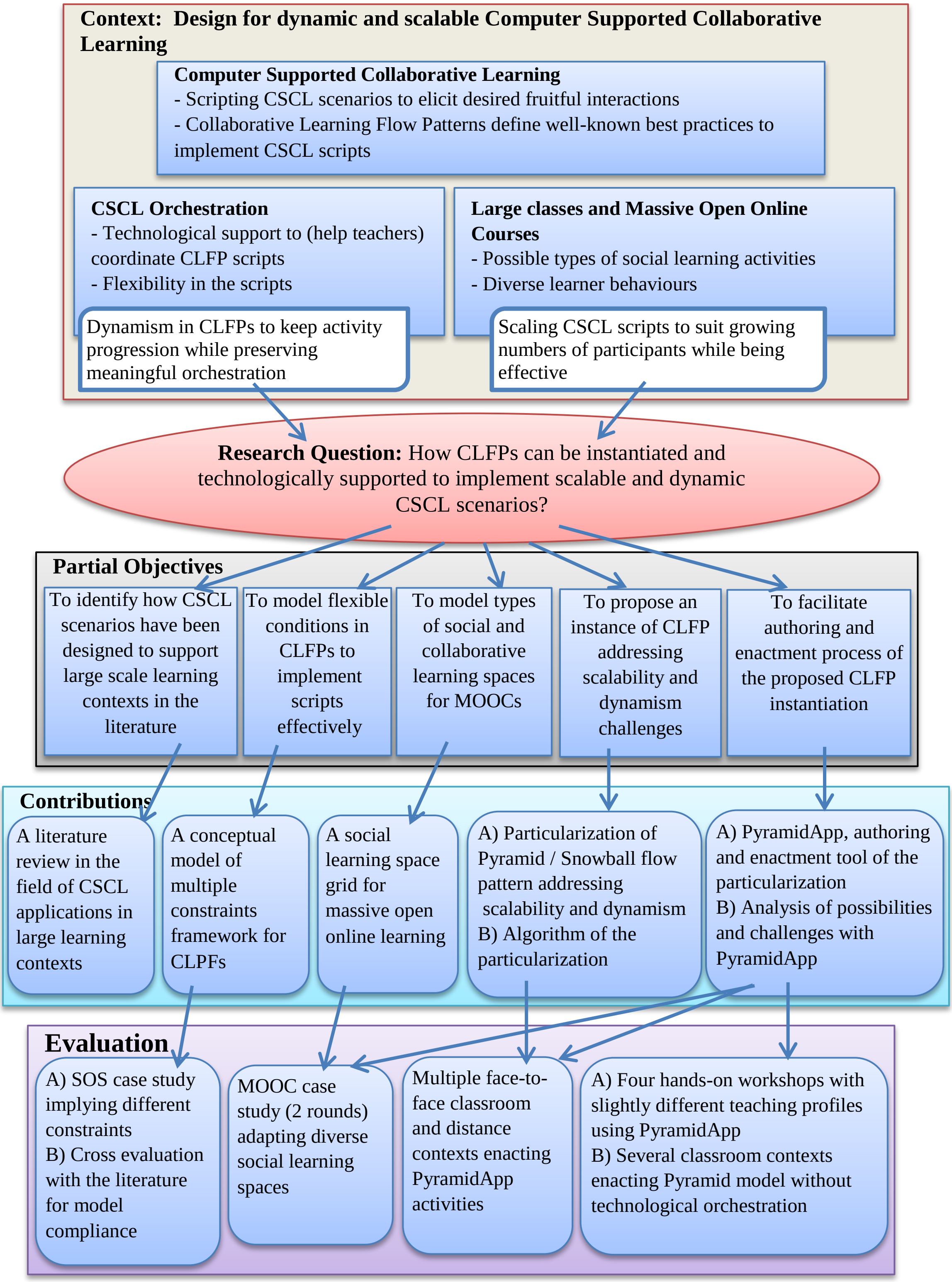
[OBJ_5] To facilitate authoring and enactment process of the proposed CLFP instantiation.

To address this objective and to provide technological orchestration support for the identified Pyramid particularization, a novel implementation is required. This novel implementation (PyramidApp) would be composed of two aspects as flow enactment, to deploy Pyramid inspired activity designs and flow authoring for the learning design process of such activities. Evaluation studies across different learning settings of PyramidApp are useful to learn the feasibility and the appropriateness of the novel authoring and enactment technology.

It should be noted that due to the nature of the research methodology followed, Design Based Research (DBR) (Amiel & Reeves, 2008) in this dissertation, above partial objectives emerged and evolved throughout the process during different iterations. Further information about the research methodology adaptation is discussed in section 1.3.

1.3 Research Methodology

The main research question and the partial objectives addressed in this dissertation are framed in a CSCL multidisciplinary problem domain (Stahl, Koschmann, & Suthers, 2006). Rather than following traditional experimental design where parameters and influencing factors are known in advance and controlled, this thesis work demands a hybrid approach of exploring and understanding ways on how design variables make sense in real learning settings. The process demands iterations where stakeholders (learners, educators and researchers) are engaged, throughout, not purely data driven and the theoretical background is evolving and facilitated by informal observations. As a result, Design Based Research methodology (Amiel & Reeves, 2008) is adopted for this work inculcating repetitive iterations and refinements of the solutions as a systematic process in which stakeholders are inclusive.



Context: Design for dynamic and scalable Computer Supported Collaborative Learning

Computer Supported Collaborative Learning
- Scripting CSCL scenarios to elicit desired fruitful interactions
- Collaborative Learning Flow Patterns define well-known best practices to implement CSCL scripts

CSCL Orchestration
- Technological support to (help teachers) coordinate CLFP scripts
- Flexibility in the scripts

Dynamism in CLFPs to keep activity progression while preserving meaningful orchestration

Large classes and Massive Open Online Courses
- Possible types of social learning activities
- Diverse learner behaviours

Scaling CSCL scripts to suit growing numbers of participants while being effective

Research Question: How CLFPs can be instantiated and technologically supported to implement scalable and dynamic CSCL scenarios?

Partial Objectives

To identify how CSCL scenarios have been designed to support large scale learning contexts in the literature

To model flexible conditions in CLFPs to implement scripts effectively

To model types of social and collaborative learning spaces for MOOCs

To propose an instance of CLFP addressing scalability and dynamism challenges

To facilitate authoring and enactment process of the proposed CLFP instantiation

Contributions

A literature review in the field of CSCL applications in large learning contexts

A conceptual model of multiple constraints framework for CLPFs

A social learning space grid for massive open online learning

A) Particularization of Pyramid / Snowball flow pattern addressing scalability and dynamism
B) Algorithm of the particularization

A) PyramidApp, authoring and enactment tool of the particularization
B) Analysis of possibilities and challenges with PyramidApp

Evaluation

A) SOS case study implying different constraints
B) Cross evaluation with the literature for model compliance

MOOC case study (2 rounds) adapting diverse social learning spaces

Multiple face-to-face classroom and distance contexts enacting PyramidApp activities

A) Four hands-on workshops with slightly different teaching profiles using PyramidApp
B) Several classroom contexts enacting Pyramid model without technological orchestration

Figure 1.1: Schema of the research context, global research question, specific research objectives, contributions and evaluation studies of the dissertation

Design Based Research defines a cycle of reflective and long-term foundation between practitioners and researchers systematically (see Figure 1.2). It begins with identifying and negotiating research goals with researchers and proposing novel designs (i.e. new strategies or derived from existing principles) to the learning environment which will undergo several iterations of verification across authentic settings and refinements. Such rigorous re-examinations lead to development of solid theoretical and practical perspectives enriched with proper descriptions (Amiel & Reeves, 2008; Design-Based Research Collective, 2003).

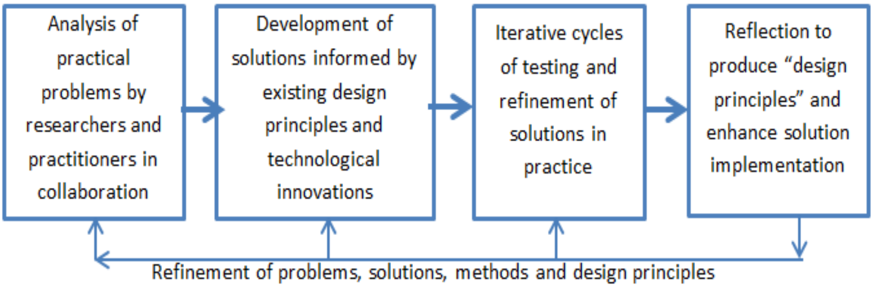


Figure 1.2: DBR model (Amiel & Reeves, 2008)

For the simplicity of understanding and explanation, we categorised the whole thesis process into four iterative cycles, within each, Design Based Research methodology was incorporated. Figure 1.3 shows these cycles, individual research questions that were set for each stage, which solutions were introduced or built-up to address the gaps identified, iterations of testing and refinements along with some timeline information and resulting reflections on the practices. How the Design Based Research methodology and the iterative process were embraced within the dissertation is explained in detail for each cycle in this section. The main research question and the partial objectives mentioned in section 1.2 are listed as a series of research questions in Table 1.2 that are used within each cycle. The sequence of cycles was not completely linear in time since some of the evaluation rounds had to consider temporal requirements of planned studies. Therefore, some cycles overlapped where the evaluations of the previous cycle were on-going, yet we had to initiate a new cycle. But within the cycles, DBR iterations were sequenced in way where a new iteration was instantiated only when the previous iteration was finalized with sufficient results and reflections.

- *Cycle 1:* At the outset of my work, scalable active pedagogies targeting large learner communities was spotlight due to the impact of Massive Open Online Courses and other open learning spaces (Ferguson & Sharples, 2014; Kay, Reimann, Diebold, & Kummerfeld, 2013). This shed the light to investigate how and to which extent existing research had addressed massiveness in potentially large learning scenarios ([RQ1] in Table 1.1). After discussing with an expert researcher, it was decided to conduct a systematic literature review (Kitchenham, 2004) to learn existing insights and research gaps. More concretely, to understand the types of activities and experimental settings supported by collaborative learning technologies in large learning scenarios, as well as the types of mechanisms and technological facets considered to support collaboration. After defining the search criteria to filter research articles, the most relevant article batch was gathered in multiple iterations, to analyse. These articles were coded using a qualitative data analysis tool and clustered in different directions like the quotient of sample, CSCL techniques used, educational context of the research, technological approach and types of collaborative activities experimented. The coding style was refined several times to fine-tune diverse analysis factors during the analysis process. Ultimately the study exposed contemporary under-explored avenues to apply collaborative learning in large learner communities. Further details and the analysis results of this literature study are available in Chapter 2.

Table 1.2: Research questions addressed in the context of this dissertation

Main research question
How collaborative learning flow patterns can be instantiated and technologically supported to implement scalable and dynamic CSCL scenarios?
Specific research questions
[RQ1] How CSCL scenarios have been designed to support large scale learning contexts in the literature? (related to [OBJ_1] in section 1.2)
[RQ2] How to identify flexible conditions in CLFPs in order to design CSCL scripts effectively? (related to [OBJ_2] in section 1.2)
[RQ3] Which are potential social and collaborative learning spaces suitable for massive open online learning? (related to [OBJ_3] in section 1.2)
[RQ4] How Pyramid (a.k.a. Snowball) pattern can be instantiated to address scalability and dynamism challenges? (related to [OBJ_4] in section 1.2)
[RQ5] What possible effects from such pattern instantiation can have when it is introduced as a novel technological approach? (related to [OBJ_5] in section 1.2)

- *Cycle 2:* During this cycle, we focused on [RQ2]. Next challenge in the dissertation was to study how CSCL scripts can be designed effectively; essentially how patterns can be scripted realizing the extent of flexibility. After studying CSCL script design based on constraints, a generic framework of CLFP constraints is proposed. Constraints defined by the pedagogy (or CLFP definition) (Dillenbourg, 2002; Hernández-Leo et al., 2006) are presented as the "conceptual model for CLFP hard constraints" whereas adjustable extrinsic factors that are preferred to be satisfied are presented as "generic model for soft constraints". The models were tested and refined in two iterations: 1) conceptualized constraints were applied on a Jigsaw pattern (Hernández-Leo et al., 2006) inspired technological representation called "Signal Orchestration System" (Hernández-Leo et al., 2012) and experimented in a classroom setting, 2) examined similar studies considering constraints in collaborative learning contexts and validated against the proposed models to evaluate the model compliance and to recognize any absent factor. Proposed conceptual framework and other related research work in this cycle are further explained in Chapter 3 including derived reflections upon the design principles.

- *Cycle 3:* After recognizing existing research gaps in the domain of CSCL in large learning scenarios and further studying how pattern constraints can be applied while achieving flexibility to effectively design scripts, the next stage was to propose a scalable, pattern inspired algorithm [RQ4]. Commonly used CLFPs like Jigsaw, Pyramid, Think-Pair-Share, TAPPS (Hernández-Leo et al., 2010) were extensively studied to understand the scalability aspects that each pattern has (see Appendix A), which then was discussed with an expert researcher for additional insights. Pyramid CLFP was seen intuitively scalable while being pedagogically meaningful with accumulated interactions. Pyramid flow pattern is structured in a way that individuals attend a given task and suggest an initial solution. Then they are assigned with small groups to discuss on initial suggestions and agree upon a common suggestion from the group which will be propagated to the next level where much larger groups are formulated enriching collaborations and consensus reaching. At the global level, all participants agree upon one or few selected suggestions that are reflected or debriefed with the whole class. Pyramid pattern promotes individual accountability and positive interdependence among peers. While preserving the essence of the pattern definition, an algorithm, feasible of scaling and preserving dynamism, was proposed (see Appendix B). The algorithm creates multiple pyramids following similar configurations (such as number of levels, group size at level 2, timing values, etc.) to accommodate large numbers of learners. Addressing [RQ5], a novel technological representation of the Pyramid instantiation, named PyramidApp was implemented based on existing CSCL principles. This instantiation implements a rating feature as the integrated consensus reaching mechanism and an integrated discussion space for collaborations. PyramidApp has been evaluated and refined iteratively in diverse perspectives from application features to algorithm scalability and dynamism. Hence, this process had numerous minor iterations of application testing and refinements though Figure 1.3 summarizes it into two main iterations only. During the second iteration, PyramidApp was integrated in the Integrated Learning Design Environment (ILDE) (Hernández-Leo, Asensio-Pérez, Derntl, Prieto, & Chacón, 2014) allowing sharing and reusing once created pyramid designs. Moreover, an authoring functionality was implemented considering Pyramid design requirements and tested with real practitioners in several CSCL workshops. An expert researcher shared PyramidApp experiences in those workshops that shed light to participants on applicability within real practice as specified in DBR methodology. Chapter 5 and 6 give comprehensive report about this stage and the synthesised reflections.

- *Cycle 4:* MOOCs are essentially known to be massive learning scenarios and MOOC researchers highlight the absence of enhanced collaboration opportunities (Rosé et al., 2014; Siemens et al., 2015). To address [RQ3] from Table 1.1, within this thesis, existing social learning instruments were studied considering major MOOC platforms like edX, Coursera, FutureLearn. Furthermore, a three months research stay at the Institute of Educational Technology, Open University, England with Professor Mike Sharples provided an extensive knowledge and experience sharing space as the Academic Lead of FutureLearn platform. As a result of this collaboration, a conceptual model, "Social Learning Space Grid" for MOOCs is proposed. Using PyramidApp with other social learning spaces like conversational flows and study groups in FutureLearn, one MOOC case was designed and enacted. Reflections from this exploratory study were reported to be incorporated in subsequent MOOC runs, emphasising on impacts for actual practices. Chapter 4 expresses details about the work carried-out during this cycle.

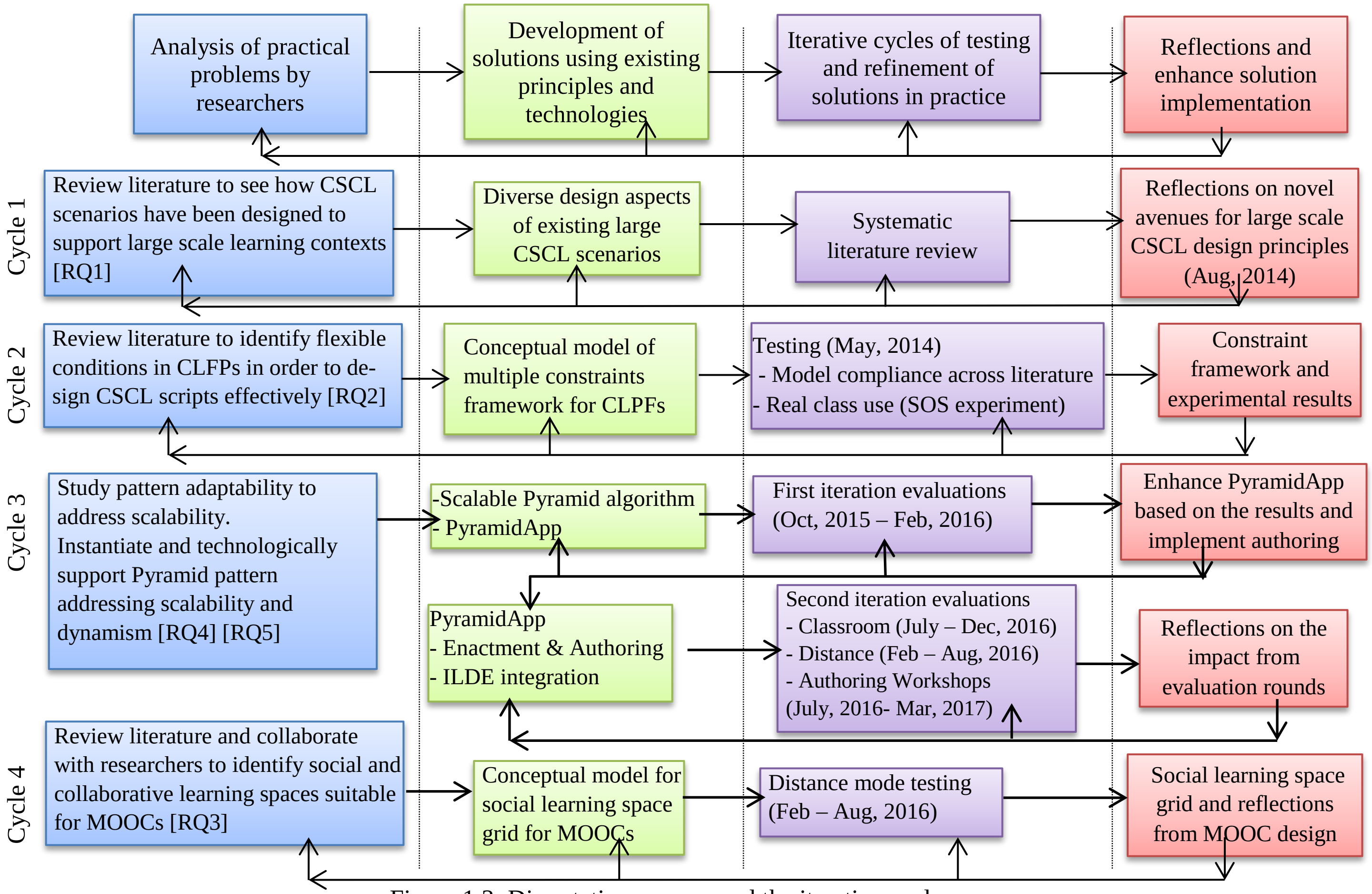


Figure 1.3: Dissertation process and the iterative cycles

In *cycle 1,* we employed more qualitative analysis approach as the evaluation methodology. Two researchers filtered out around 100 journal articles systematically to study current state-of-the-art. A coding structure was defined in order to be able to categorise filtered article contents for gaining better insights. The coding structure was refined iteratively considering research questions addressed in the cycle. One researcher (author of this thesis) utilized a qualitative data analysis tool (Atlas.ti[1]) mainly to code the articles and to extract other qualitative attributes belonging to those articles. We do recognize that using more coders would increase the credibility of the research. However, we consider a single-coder is sufficient, given the interpretive nature of the study as we do not aim to quantify or obtain any statistical significant results among variables in the analysis and we follow a deductive approach (a predetermined and agreed coding structure with an expert) (Muñoz, 2015). Our aim is to learn which research aspects and to what extent these aspects have been addressed in the literature. Chapter 2 in the thesis reveals further information about *cycle 1* systematic process, the coding structure employed and a report of derived analysis from the study that laid foundation for the complete thesis work.

During the processes of c*ycle 2, 3* and *4*, the dissertation was deviated towards a mixed mode of evaluations due to the nature of data gathered in extensive rounds of experiments carried-out considering diverse learning scenarios, target groups and types of learning activities with related to different subjects. For the evaluation stages in these cycles, a mixed method design (Creswell, 2012) was introduced since experiments included both qualitative and quantitative data sources. As Creswell (2012) states, mixed method research design is a procedure for collecting, analysing and mixing both qualitative and quantitative methods in series of studies to gain better understanding of the research question(s). Hence, in the this work, heterogeneous data gathering techniques, data sources and evaluation methods (i.e., pilot studies, application feature analysis and evaluation studies) were employed during different iterations of DBR appropriately enriching the analysis aspects of the dissertation (see Table 1.3). Both pilot studies and evaluation studies were conducted upon non-probabilistic convenience samples (Fraenkel & Wallen, 1993) because of the less-constrained accessibility and availability. A comprehensive analysis conducted on *cycle 3* experimental cases and the derived results contributing to the main research question directly, are reported in Appendix C with further details.

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[1] http://atlasti.com/ (Last accessed April, 2017)

Table 1.3: Heterogeneous data sources and data gathering techniques

Technique	***Description***	***Purpose***
User generated artefacts (Practitioners)	Collection of pyramid designs created using PyramidApp authoring during the workshops and other experimental settings by practitioners including values for design parameters and temporal details about their designs	Workshops were mainly aimed to train available possibilities of CSCL and to highlight PyramidApp as one such instance. Hands-on experiments with practitioners provide insights of CSCL authoring requirements. Also, workshops allowed to evaluate compatibility of PyramidApp features across user requirements
Activity logs (Learners)	Learner actions using PyramidApp (e.g., user session details, submitted options, rating values and details, timing records, group structures and pyramid structures) are available for both pilot experiments and evaluation studies	To measure application performance factors affecting scalability, dynamism and for fault tolerance. Also to measure timing conditions leading to feasibility of PyramidApp in different learning contexts
Questionnaires[2] (Practitioners and learners)	Likert scale based questionnaires were designed iteratively during the process, composing of 5 point scale (1- I don't like at all to 5- I like very much) and few open-ended items	To learn about learner opinions on diverse range of aspects (e.g. usability, efficiency, reliability, etc.) of PyramidApp. Also, to gather opinions from practitioners about activity authoring aspects
Observations (Practitioners and learners)	Semi-structured naturalistic observations by one or more researchers depending on the situation. Collected data are observation notes, audio and video recordings, pictures during experiments	To provide further insights to data collected by the learning activity sequence occurred during evaluations including reactions and comments by practitioners and learners

1.4 Main Contributions

In this section a summary of important contributions of the dissertation including evaluation results is provided. Later in the section it also mentions different publications up to the date of thesis submission and the research projects within which this work is framed.

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[2] Generic questionnaire templates are available in Appendix C

1.4.1 Contributions

As depicted in Figure 1.2, there are several contributions culminated from this work aligned to partial objectives mentioned in section 1.2.

- **A literature review in the field of CSCL applications in large learning contexts**
  A collection of journal articles[3] during the period of 2000 to 2013, were filtered out systematically and coded by using Atlas.ti, a qualitative analysis tool in order to analyse diverse research aspects addressed such as technological approaches, experimental settings, collaborative learning methods and orchestration support. Among the main results obtained from this analysis, the level of massiveness considered in top scientific journal papers on collaborative learning technologies was low and the scenarios studied were predominantly contextualized in co-located higher education settings using Learning Management Systems mainly. The most common activities considered were open and structured discussions and the most broadly used orchestration mechanism was group formation following diverse policies. A detailed report on the systematic literature review and results are provided in Chapter 2.

- **A conceptual model of multiple constraints framework for CLFPs**
  A CSCL scenario can be affected by constraints imposed by the pedagogy, namely intrinsic constraints, and external factors named as extrinsic constraints (Dillenbourg & Tchounikine, 2007; Hernández-Leo et al., 2006; Pérez-Sanagustín et al., 2011). Scripting effective collaborative activities realizing the dichotomy of intrinsic and extrinsic notions is challenging. Hence, a comprehensive generic framework expressing identification of intrinsic and extrinsic conditions related to CLFPs is critical for learning designers, educators and tool developers. As a contribution from this dissertation, we proposed 1) Pattern-independent conceptual model for CLFP hard constraints 2) Context-independent generic soft constraint model and validated these models across the attempts in the literature to evaluate the model compatibility. Furthermore a naturalistic experiment gave more insights to real application of

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[3] List of articles is publicly available here: https://goo.gl/Q6n5yM

constraint based CLFP implementation. The framework and experimental details are further explained in Chapter 3.

- **A social learning space grid for massive open online learning**
  Forum discussions are predominantly widely exercised social and collaborative learning space within MOOCs. We sought out potential social learning spaces that exist or possible to introduce in these platforms where learners of diverse nature and behaviours are expected. Social learning space grid situates possible social learning opportunities along three dimensions as time constrained, task constrained and time or task unconstrained. These dimensions and further details about the model along with an exploratory study are explained in Chapter 4.

- **Pyramid / Snowball particularization and algorithm mechanisms addressing scalability and dynamism**
  After learning potential scalable and flexible aspects resides in a Pyramid / Snowball flow (see Appendix A), an algorithm was designed to address scalability and dynamism. Key rationale behind the algorithm includes three main mechanisms (i.e., flow creation, flow control and flow awareness rules) introduced to tackle scalability and dynamisms. The algorithm incorporates parameters related to these three dimensions (see Appendix B). Flow creation rules like number of pyramid levels, students per pyramid, group size are mainly focusing on being scalable whereas flow control rules like timer values focus on the dynamism of the approach. Flow awareness rules like current pyramid level, popular options contribute to the usability aspects. Rating options are used as the process to select more popular options to be promoted to upper levels of the Pyramid. Inspired by the discussion bus metaphor (Ferguson & Sharples, 2014), where participants can be added or removed to on-going Pyramids, the algorithm adds learners to once formulated Pyramids. When it reaches maximum allocation, multiple pyramids are formulated on demand. Moreover, a discussion space allows learners to share their ideas and collaborate to seek most interesting option as the group solution. The algorithm and the proposed mechanisms are discussed further in Chapter 5 and Chapter 6. Also more information about algorithm mechanisms is available in Appendix B.

- **PyramidApp authoring and enactment systems and the analysis of evaluation studies**
  Above algorithm and the three mechanisms (flow creation, control and awareness rules) are the underlying logic for web-based PyramidApp application, implemented mainly using technologies like JavaScript to serve the front-end, PHP and MySQL at the back-end. PyramidApp is integrated in Integrated Learning Design Environment (ILDE) (Hernández-Leo et al., 2014) which supports cooperation within learning design communities where members share and co-create multiple types of learning design solutions covering the complete lifecycle from conceptualizing to authoring and implementation. Since PyramidApp is composed of both authoring and implementation systems, it was seen very relevant to be integrated in ILDE that provided more additional features to the application like easy sharing, publishing and duplication of Pyramid designs in communities. Practitioners can create and enact Pyramid inspired CSCL activities within ILDE for free. Activity participants can access such activities using the given public URL. PyramidApp incorporates "flow authoring" system to design and monitor activities and "flow enactment" system to enact Pyramids. Flow authoring system implements flow creation and controlling rules mostly where educators are required to provide appropriate values for Pyramid design parameters. Parameter tooltips and default values in the fields can guide educators in the design process. PyramidApp flow enactment system uses peer rating as the consensus reaching mechanism in the activity, in which rating is accompanied by peer discussions supported via an integrated text-chat within PyramidApp. More details about the application, cross-case analysis of pilot and evaluation studies are available in Chapter 5 and 6. An extended case-by-case analysis is available in Appendix C.

1.4.2 Main evaluation studies

This dissertation comprises of a number of pilot and evaluation studies executed in different cycles and iterations following DBR methodology. Figure 1.3 depicts these cycles.

- In *cycle 2,* a naturalistic high school Art classroom was used to evaluate the validity of a Jigsaw pattern based system inspired by the CLFP constraint framework imposing both intrinsic (following Jigsaw rules) and extrinsic constraints (constraining homogenous group formation for the type of the device used). Students enjoyed the activity, preferred to repeat such collaborative activities again. Orchestration devices like lamps and wearable devices (Hernández-Leo et al., 2012) were used well and students preferred integration of such devices with the Jigsaw activity. Chapter 3 provides further information about the experiment.

- Several small iterations improved PyramidApp up to the latest version during *cycle 3*. Initial prototypical PyramidApp and small group (10 – 20 students from a first year undergraduate course) pilot studies laid foundation to recognize potential issues related to the key challenges; scalability and dynamism. Based on the pilot studies and the results, the algorithm was enhanced and changes or new features were incorporated to the system prior to next round of pilot studies. Moreover these pilot studies assisted in identifying default parameter values for flow creation and control rules in the algorithm. Three different experimental settings (undergraduate students from an engineering school, secondary school students and students from a vocational training centre) were employed in the initial round of evaluation studies. The aim was to evaluate whether the rules and mechanisms of PyramidApp offer scalability (being able to accommodate increasing numbers of participants) and preserve dynamism (being able to keep activity progression) in face-to-face classrooms while maintaining pedagogical, practical effectiveness and preserving enthusiasm and usability. A cross-analysis of these settings contributes with better prospects of scalability and dynamism in classrooms within fair time durations (between 5 to 16 minutes) complying to the desired time requirements of the teacher involved, with multiple pyramids running. Utility of the discussion feature is a contextualized factor, so as the pedagogical value of the discussions occurred. System features such as viewing winning options, rating peers and levelling up denoting Pyramid progression offered gaming effects that were perceived with higher satisfaction across all experimental settings. Further descriptions of pilot and evaluation studies along with respective analysis are provided in Chapter 5. Data sets from two of these evaluation studies (secondary school and vocational training settings) are openly available for any interested party as PyramidApp configurations and participants behaviour dataset (Manathunga & Hernández-Leo, 2016b).

- Next milestones to be evaluated were enhanced PyramidApp flow enactment and flow authoring systems during the second major iteration of thesis *cycle 3*. A series of evaluation studies was conducted across diverse educational settings (first, second and third year engineering undergraduate students and Masters' students) either in face-to-face classrooms or in distance mode with different epistemic tasks like question formulation after group presentations, problem solving activity, case study analysis or open-ended opinion seeking using PyramidApp. Moreover, some activity rounds emulated Pyramid pattern, structuring the activity by the educator rather using PyramidApp. Such emulations helped to understand the feasibility of the proposed model and to understand practicalities or challenges existing with or without PyramidApp. A cross-analysis of three experimental settings (first and second year students and the Masters' level) revealed that higher the education level, higher the perception of activity enjoyment while realizing the usefulness of novel technological applications in the class. Once PyramidApp is familiarized after enacting several rounds, passing the novelty effect, learners enjoyed more the activity. It is very important to consider such repeated attempts of novel tools when evaluating for more potential successful activities rather considering only the initial attempt. Enhanced PyramidApp flow enactment evaluations are reported in detail, analysing case by case in Appendix C whereas a cross-case analysis from diverse perspectives is provided in Chapter 6.

- PyramidApp flow authoring system was evaluated in four teacher training workshops, addressing CSCL and examples of collaborative learning activities. Practitioners from primary to higher education levels participated and created Pyramid designs using ILDE. Once an activity is designed, it is crucial to publish that design to make it public. Hence, it is important to evaluate authoring and publishing aspects. Also, number of attempts to design equally matters to result in potentially successful activity designs. Practitioners enjoyed designing pyramid activities. Majority of the workshop participants were enthusiastic about its implications and usage. Some of managed to enact Pyramid activities successfully after the workshops (see Appendix C). Many interesting suggestions emerged, like introducing evaluation mechanisms to PyramidApp or enabling blended mode with different timing values. Chapter 6 includes the analysis of flow authoring workshops.

- During thesis *cycle 4,* evaluation studies were acted-out in dynamic distance large learner environments like MOOCs using the enhanced PyramidApp flow enactment. An exploratory MOOC case study (3D Graphics for Web Developers MOOC) was conducted in FutureLearn platform comprising of two runs which included several PyramidApp rounds in the course design. Yet, PyramidApp was integrated as an externally linked application that MOOC participants had to access using a separate login due to the MOOC platform policies. Some key results obtained were PyramidApp was capable of accommodating learners in the collaborative activity irrespective of the instance they join with the course, discussion content was very relevant, leading to further discussions though it was not heavily utilized. Some preferred rating similar to up-voting in Stack Exchange (Posnett, Warburg, Devanbu, & Filkov, 2012) whereas some did not like the concept of filtering-out their individual submissions. Pyramid progression email notifications helped participants to return to on-going activities, but some learners did not pay attention for these. Within MOOC context, it was learnt that more structured pyramid activities should be designed and embedded within the main course outline to expect higher engagement. Chapter 4 reveals more information about this MOOC exploratory study.

1.4.3 Publications

This dissertation is organized and presented as a compendium of research articles published and submitted for review as given below.

[Pub1] – Manathunga, K. & Hernández-Leo, D. (2015). Has Research on Collaborative Learning Technologies Addressed Massiveness? A Literature Review. *Journal of Educational Technology & Society*, 18 (4), 357–370.

[Pub2] – Manathunga, K., & Hernández-Leo, D. (2016). A Multiple Constraints Framework for Collaborative Learning Flow Orchestration. In Chiu D., Marenzi I., Nanni U., Spaniol M., Temperini M. (Eds.), *Advances in Web-Based Learning: Proceedings of 15th International Conference on Web-based Learning, ICWL 2016* (pp. 225-235). Rome, Italy: Springer LNCS (volume 10013).

[Pub3] – Manathunga, K., & Hernández-Leo, D. (2016). PyramidApp: Scalable Method Enabling Collaboration in the Classroom. In K. Verbert, M. Sharples, & T. Klobučar (Eds.), *Adaptive and Adaptable Learning: 11th European Conference on Technology Enhanced Learning, EC-TEL 2016* (pp. 422-427). Lyon, France: Springer LNCS (volume 9891).

[Pub4] – Manathunga, K., Hernández-Leo, D., & Sharples, M. (2017). A Social Learning Space Grid for MOOCs: Exploring a FutureLearn Case. Accepted to be presented at *5th European Stakeholder Summit, EMOOCS 2017*. Madrid, Spain: Springer LNCS (to appear).

[Pub5] - Manathunga, K., & Hernández-Leo, D., Authoring and Enactment of Mobile Pyramid-based Collaborative Learning Activities. Submitted to journal [Under review]

[Pub6] – Manathunga, K., & Hernández-Leo, D., (2017). Towards Scalable Collaborative Learning Flow Pattern Orchestration Technologies. Accepted to be presented at *9th International Conference on Education and New Learning Technologies, EDULEARN 2017*. Barcelona, Spain: IATED (to appear).

1.4.4 Projects

Part of this dissertation work contributes to certain objectives of several projects and some workshops mentioned in the above section 1.4.2 were conducted for the fulfilment of partial objective of these projects.

1. EEE (Educational Reflected Spaces) and RESET[4] (REformulating Scalable Educational ecosysTems). Date: 2012 – 2017. Funding entity: Spanish Ministry of Science and Innovation (TIN2011-28308-C03-03 and TIN2014-53199-C3-3-R). Participant entities:

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[4] http://reset.gast.it.uc3m.es/

UC3M, UVA, UPF. Principal Investigators (UPF): Josep Blat and Davinia Hernández-Leo.

2. MDM (Maria De Maeztu) – Educational Data Science (EDS)[5]. Date: 2016 – 2019. Funding entity: Spanish Ministry of Science and Innovation (MDM-2015-0502). Participant entity: GTI-Learning group at Universitat Pompeu Fabra. Principal Investigator of EDS sub project: Davinia Hernández-Leo.

3. CoT (Communities of Teaching as a data-informed design science and contextualized practice). Date: 2016 – 2019. Funding entity: RecerCaixa, Catalonia. Participant entity: Universitat Pompeu Fabra. Principal Investigator: Davinia Hernández-Leo.

1.5 Limitations

In this dissertation we proposed a generic framework to model CLFP constraints and a social learning space grid for MOOCs as theoretical frameworks which we assume will open up innovative research avenues for other interested researchers. Throughout this work we conducted number of evaluation studies (see section 1.4.2) using the Pyramid instantiation and its technological implementation. By sharing information on such studies and our experiences we hope any other interested party could benefit when conducting similar studies and evaluations. Moreover the collection of publications mentioned in section 1.4.3 can be considered as first indicators of the relevance and originality of our proposals. Here we note down the limitations and challenges we encountered that can guide for potential future research work as explained in the subsequent sections.

- **Application usability limitations**

The existing monitoring view of PyramidApp is informative, yet primitive in terms of user-friendliness; thus further improvements in the monitoring view are required. As with any piece of novel technology, initial introduction round of PyramidApp did not provide the best results. But after students are familiarised with the application, they enjoyed the activities (see Appendix C). In some case studies, students were neither taking the activity seriously nor being actively engaged in discussions due to the nature of the task being too general like, “propose a question about the curricu-

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[5] https://www.upf.edu/web/mdm-dtic/projects

lum of the school" or "propose an outdoor activity that you would like to do". In multiple cases, PyramidApp discussion section was not utilized extensively, instead casual greetings and getting-to-know messages were ample. On the contrary, many rich discussions occurred within some face-to-face classrooms outside the application. The reasons may be that the natural instinct of easy conversing with your neighbour/friend rather than chatting through a discussion board or may be due to the time limitations or nature of the task or the learning setting. Hence, some mechanisms are required to be incorporated to improve the usability of the discussion space of PyramidApp.

With several cases it was also noted that the notifications (timer or email notifications) were not given attention properly, thus learners could not complete the intended task for those levels. In the distance mode, some had valued these email notifications whereas others have expressed it as a burden to access email to view the notification. Thus improving the notification system for better awareness in the application is required. PyramidApp activity enactment system is already employed with visualizations of pyramid progression, levelling and group awareness. Yet, it was seen that further improvements in these aspects could enhance user-friendliness and ease of understanding. In the two rounds of the MOOC case study, the level of participation was not relatively high due to the presentation manner of PyramidApp (as an external link within the course page) or activity being mentioned as "optional". At the initial MOOC round Pyramid activity, we noticed that some options of some groups did not receive any rating and there was no option to be selected as highly rated due to lack of participation. Also in both classroom settings and distance mode of the application, some had commented that the allocated waiting times were too long and that they were bored after sometime. Within internal iteration of the thesis cycles, some of these limitations were addressed with new proposals as explained in the following section.

- **Pedagogical limitations**

Currently PyramidApp only supports for sharing text-based options or links to some creative artefacts and we evaluated these aspects for different types of activities (see Appendix C). PyramidApp algorithm and the implementation aspects could be extended to support more types of epistemic tasks to suit diverse subject ranges. While practitioners appreciated PyramidApp flow authoring features and capabilities during the workshops, they suggested additional possibilities too. Suggestions include incorporating assessment techniques, improving monitoring view and embedding different types of learning tasks at different levels of the Pyramid. Some asked to enable blended mode of PyramidApp where one type of task is done at home in distance mode and another task is enacted in the face-to-face class in the same activity.

- **Interoperability limitations**

PyramidApp is a web based application, integrated in ILDE (Hernández-Leo et al., 2014) currently. This version of the application is not designed anticipating compliance with standards like IMS-LTI[6]. Interoperability among collaborative learning tools is critical for better prospects like easy exchange of data (Harrer, Pinkwart, McLaren, & Scheuer, 2008). PyramidApp also has the potential capabilities to make it compatible with LTI specification, so that it's interoperable across any LTI complaint tool providers such as Learning Managements systems, and other learning platforms.

- **Methodological limitations**

As mentioned in section 1.4.2 and in Appendix C, PyramidApp evaluations were conducted across diverse experimental settings. Yet, there are some methodological limitations in this research work such as lack of repetitive studies, motioning students for a longer time period using novel technology, evaluating learning gains and student performance before and after introducing novel collaboration approach. How successful the collaborations were could not be derived with the current series of experiments due to either those experiments were intended for evaluating other aspects or due to varied practical reasons like time restrictions and difficulties in reaching out for naturalistic learning settings to be experimented throughout longer time periods.

1.6 Conclusions

As mentioned in the section 1.2, the goal of the dissertation was to address "*how collaborative learning flow patterns can be instantiated and technologically supported to implement scalable and dynamic CSCL scenarios*". In order to reach our intended goal, we defined several partial objectives deduced from the main goal asserting diverse challenges in the domain.

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[6] https://www.imsglobal.org/activity/learning-tools-interoperability

[OBJ_1] To identify how CSCL scenarios have been designed to support large scale learning contexts in the literature.

To tackle this objective we conducted a systematic review of the relevant corpus of research publications from the literature of CSCL and large learning contexts. Findings from the analytical study reveals that 55% of articles considered a portion of less than 100 students as the sample size of the study and most studies are predominantly contextualized into higher education using mainstream technologies like Learning Management Systems or Web 2.0 tools. Most widely used collaborative activities were open or structured discussions, but comprehensive orchestration support for CSCL design and enactment was not addressed frequently. Research findings are reported and published in a JCR-indexed journal as mentioned in section 1.4.3. This knowledge acquired is very relevant and useful to propose novel CSCL technologies to large class contexts.

[OBJ_2] To model flexible conditions in CLFPs to implement scripts effectively.

We proposed a generic conceptual framework of CLFP constraints composing of two sub models as Conceptual Model for CLFP Hard Constraints and Generic Model for Soft Constraints. The models were cross-analysed with similar attempts from the literature which provided insights to what extent hard or soft constraints had been considered and how previous approaches are compatible and expressed within our proposed framework. Jigsaw based classroom experiment inspired by the framework using SOS and orchestration devices (Hernández-Leo et al., 2012) illustrates constraint extraction and automatic orchestration support ensuring feasibility of the framework while preserving activity enjoyment. The proposed framework is beneficial for educational technologists when designing pattern-based CSCL technologies.

[OBJ_3] To model types of social and collaborative learning spaces for MOOCs.

In order to address this objective we proposed a Social Learning Space Grid introducing potential social and collaborative learning spaces after considering current approaches available in major MOOC platforms. By referring to the grid, practitioners can know about possible collaboration spaces considering three dimensions as time constrained, task constrained or time and task unconstrained to choose the most appropriate space as preferred. Also novel technologies, inspired by the grid, can be proposed enabling enhanced collaboration opportunities in MOOCs. From the grid, three collaboration spaces (PyramidApp, study groups and conversational flows) were offered in two rounds of a MOOC by UPF presented in FutureLearn platform. The exploratory study provided insights on how diverse social learning spaces can be offered in a MOOC and suggests including more structured and engaging activities to improve the learning design and learner engagement of MOOCs.

[OBJ_4] To propose an instance of CLFP addressing scalability and dynamism challenges.

To tackle this partial objective, commonly used CLFPs and their definitions (Hernández-Leo, 2007; Hernández-Leo et al., 2010) were further scrutinized in order to devise scalable pattern instantiation. Pyramid CLFP devised showed potentially scalable prospects, which then further studied to realize an algorithm and related mechanisms to overcome practical challenges (i.e. scalability and dynamisms) when implementing for large contexts. Flow creation, control and awareness mechanisms were seen critical to address these challenges; thus such mechanisms were incorporated to the Pyramid flow pattern definition to accommodate large leaner communities while preserving a pedagogically meaningful flow. For each mechanism, set of design parameters with default values, either proposed by the developers or derived from the pilot studies were identified. Number of initial experimentations led to refine the proposal several times finally contributing to a full-fledged application called, PyramidApp.

[OBJ_5] To facilitate authoring and enactment process of the proposed CLFP instantiation.

PyramidApp, the technological solution of the proposed Pyramid instantiation, is contributing directly to the core research question that this dissertation was attempting to solve. By incorporating both Pyramid flow authoring and flow enacting systems, we managed to launch PyramidApp as a full-fledge educational application supported by both web and mobile platforms. Diverse evaluation studies revealed how learners and practitioners perceived PyramidApp. Cross analysis of PyramidApp flow enactment evaluations showed activity enjoyment in most of the cases but the efficacy in terms of perceived usability and perceived impact of learning relied upon many other factors such as type of task, education level and the mode being distance or face-to-face classroom. Results from practitioner workshops about the authoring system were very positive in terms of perceived relevance and usefulness. Some workshop participants created and enacted PyramidApp activities in their classrooms, after the workshop and many stated that they prefer using such applications within their teaching. These contributions lead to conclude that PyramidApp proposes a pattern-based, scalable CSCL mechanism enduring growing numbers of learners while preserving dynamism of the flow meaningfully.

The global aim of the dissertation was subdivided into aforementioned partial objectives. We addressed each derived objective and accomplished affirming that this dissertation managed to achieve its global aim. The models proposed, the algorithm for the Pyramid instantiation along with the mechanisms introduced during the process have correctly guided the formulation of PyramidApp as a full-fledged system capable of authoring and enactment of CSCL activities. Supporting open science movement, we have already made some evaluation study data openly available (Manathunga & Hernández-Leo, 2016) and also PyramidApp code is available in a Git repository shared as free software, possible to download, modify or use under GNU Affero General Public License. Yet, there are number of challenges faced and lessons learned during this process, as expressed in section 1.5 which lead to further research directions, to some of which we already have proposed solutions as mentioned in the following section.

1.7 Future Work

Section 1.5 categorises and describes the limitations of the thesis that lead to interesting future lines of work as discussed below.

- **LTI compliant pluggable constraint-based CSCL services**

We proposed two models for hard and soft constraints representation which can lead to design flexible orchestration services more meaningfully. The social learning space grid expresses many different combinations of collaboration mechanisms that can be implemented within MOOCs. CSCL services can be developed considering both flexibility and scalability considering different constraints that can enrich learning. If such CSCL services are made available as pluggable independent services, educational designers of large learner communities can adopt such services depending on individual course requirements, learning contexts and the level of orchestration load that can be managed by the educators. Especially in collaborative learning, tool interoperability and data exchange between tools are crucial (Harrer et al., 2008). Thus, PyramidApp needs to be modified to be an interoperable independent service complying with standardizations such as LTI specification.

- **Study other possible instances of Pyramid and other possible CLFPs at scale**

Detailed analysis of CLFPs for their scalability (see Appendix A) provides insights to more scalable approaches. Among other use cases proposed in Appendix A, we implemented one particularization as PyramidApp. It would be interesting to instantiate other possibilities as proposed in the use cases. Moreover, other patterns like Thinking Aloud Pair Problem Solving (TAPPS) (Hernández-Leo et al., 2010) with potential scalable aspects can be further considered to be implemented in large learner communities.

- **Improve usage of discussion feature**

To mitigate the discussion reluctance that was observed with some evaluation cases, we introduced sentence opening cues (Weinberger, 2003) like "I propose" or "these aspects are not clear to me" to the chat feature. It would be worthwhile to evaluate the value of these cues which we could not assess during this thesis time limit. Also it is possible to modify the algorithm and implementation aspects to enforce discussions by blocking the rating feature till a particular student discusses within the group.

- **Improve engagement in the distance mode**

With the MOOC evaluation studies carried out in the thesis cycle 4, we learnt that some Pyramid groups did not receive any participation or rating values. To overcome such issues, we modified PyramidApp logic to select one random option from such groups to be selected in the distance mode. Also, when formulating groups for the next level, the algorithm is modified to apply a condition of grouping inactive groups with active groups based on the participation received in the current level. Furthermore, PyramidApp would be extended with additional features such as providing artificial intelligent student models to take over the roles of actual students, if they are not active or struggling in the activity.

- **Lessen the issue of long waiting times**

Some initial evaluation studies revealed that students were waiting between Pyramid levels for too long that led to boredom. After recognizing this problem, we incorporated options from the other peer groups to be visible in the waiting screen, so that students can acquire an idea about their peer group status while waiting. Further, the application can be modified to enable discussions or to engage in another learning activity while they are in the waiting state, till the other group members or the peer group finishes.

- **Improvements for visual and pedagogical appealing**

PyramidApp authoring system incorporates activity monitoring view for practitioners and currently this functionality is average. Further modifications to this would increase the usefulness of the functionality. Also, it would be beneficial for students, to allow proposing completely new options after collaborating and reaching upon consensus if they don’t agree on the already proposed options. By following suggestions gathered through practitioner workshops, PyramidApp algorithm and the implementation can be extended to include assessment components and different types of activities. Moreover, enabling blended mode Pyramid activities that function with different timer values for different levels in the same Pyramid flow would also be interesting. PyramidApp authoring can be enriched by integrating recommendation services for practitioners to guide then in the design process. When a practitioner provides basic details about his preferred learning scenario, the system can provide suggestions acquired from similar successful collaborative learning contexts, thus providing easy adaptation for practitioners.

- **Methodological improvements**

It would also be interesting to measure the quality of interactions occurred and the success rate of collaborations happened in this type of pattern-based collaborative activities. If repeated evaluations can be conducted and further analysed for above factors, perceived efficacy of learning and improved performance using PyramidApp can be ensured.

1.8 Structure of the dissertation

This section is devoted to express the dissertation structure in the subsequent chapters. Each chapter is composed of a publication or a submission for review as mentioned in above section 1.4.3, as this thesis is presented as a compilation of five articles: One JCR-indexed peer-reviewed journal article and another is submitted for reviewing in another JCR-indexed peer-reviewed journal. Moreover the dissertation is composed of two full papers, a short paper from Springer LNCS and another paper from IATED international conference proceedings. When expressing each publication, we have provided a synopsis of the chapter at the beginning and illustrated the relationship of the paper with the thesis process and contributions following the format suggested, as in (Muñoz, 2015).

- Chapter 2 – This chapter includes initial foundation for this work, i.e., an extensive literature review on how massiveness has been addressed in the CSCL community and the results of the analysis. The chapter contents are from the [Pub1] mentioned in section 1.4.3.
- Chapter 3 – This chapter presents the proposed conceptual framework for CLFPs, a cross-analysis of the framework with the literature and a Jigsaw based case explored in a naturalistic classroom setting. Chapter contents are from the [Pub2] in section 1.4.3.
- Chapter 4 – A social learning space grid for massive open online contexts is proposed within this chapter. Further, an exploratory case study applying social and collaborative learning spaces intertwined in a MOOC, offered in the FutureLearn platform provides more insights of grid application. This work is the [Pub4] from section 1.4.3.
- Chapter 5 – This chapter explains about the scalable particularization of Pyramid flow pattern proposed in this dissertation. Primitive critical algorithm mechanisms, first iteration of PyramidApp enactment system and the first iteration of evaluation studies followed by the results are explained here. The chapter contents are from the [Pub3] in section 1.4.3.
- Chapter 6 – Here more comprehensive, matured iteration of PyramidApp (both authoring and enactment systems) and an aggregated analysis of diverse evaluation studies are presented. The chapter contents are from the [Pub5] from section 1.4.3.
- Appendix A – Analysis of the potential scalability of the CLFPs. This section reveals detailed analysis of widely used patterns and illustrates set of potential use cases to be inspired as pattern-based scalable orchestration services. This section complements to the contents in Chapter 5 and 6. The chapter contents are from the [Pub 6] from section 1.4.3.
- Appendix B – PyramidApp design and algorithm mechanisms. This section explains the Pyramid particularization algorithm

mechanisms (flow creation, control and awareness rules) introduced and the underlying rationale of the mechanisms followed by the PyramidApp design. This section is useful for further understanding contents of both Chapters 5 and 6.

- Appendix C – Analysis of PyramidApp evaluation studies. This sections reports different experimental settings and related information, a case-by-case explanatory analysis, evaluations from two MOOC rounds and finally general templates of the questionnaires used. Contents of this section are complementing mainly with Chapter 6, but some aspects are related to Chapter 4 also.
- Appendix D – Additional related publications resulted from this dissertation work is provided in this section.

Chapter 2

Has Research on Collaborative Learning Addressed Massiveness? A Literature Review

This chapter describes the research work carried out during the first cycle of the thesis process (Figure 2.1). Following research question [RQ1] in Chapter 1 (section 1.3), the main intention of this literature analysis was to gather knowledge about the CSCL literature addressing large learning contexts. The key contribution of studying and analysing a corpus of research articles is a detailed analysis report on how CSCL has been applied upon such educational settings (Figure 2.1) and the related publication is expressed in this chapter. We followed a systematic approach (Kitchenham, 2004; Webster & Watson, 2002) consisting of stages as (1) identify research objectives (2) search articles (3) filtration and evaluation of data set (4) coding and analysis (5) interpretation of results obtained. Article corpus was coded using a qualitative data analysis tool (Atlas.ti) to categorize based on a coding structure defined. We considered five key classifications as quotient of learners, educational setting, collaborative learning activity, collaboration mechanism and technological facets considered. The analysis served to identify number of challenges like preserving activity enjoyment and enthusiasm while maximizing social interactions, technological, cultural and lingual barriers, minimize the complexity of technologies in large learning communities. Some key findings are 55% of top journal articles had considered sample sizes less than 100 students, predominantly contextualized to co-located higher educational settings and practicing either discussions or peer-reviewing.

The content of this chapter was published in a journal article as follows:

Manathunga, K. & Hernández-Leo, D. (2015). Has Research on Collaborative Learning Technologies Addressed Massiveness? A Literature Review. Journal of Educational Technology & Society, Volume 18, Issue No 4, October 2015, Pages 357–370, ISSN: 1436-4522 (online) and 1176-3647 (print). (http://www.ifets.info/journals/18_4/27.pdf)

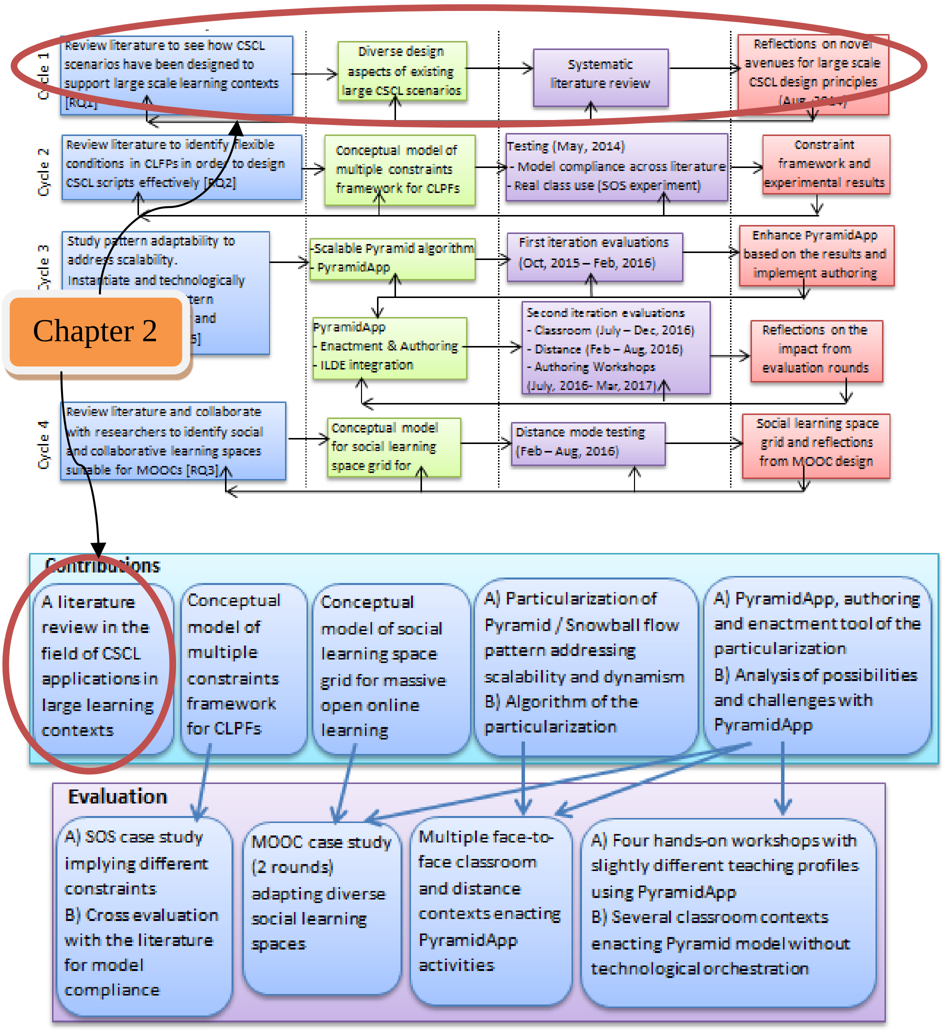

Figure 2.1: Part of the research process and contributions covered by Chapter 2

Has Research on Collaborative Learning Technologies Addressed Massiveness? A Literature Review

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ABSTRACT

There is a growing interest in understanding to what extent innovative educational technologies can be used to support massive courses. Collaboration is one of the main desired elements in massive learning actions involving large communities of participants. Accumulated research in collaborative learning technologies has proposed and evaluated multiple models and implementation tools that engage learners in knowledge-intensive social interactions fostering fruitful learning. However, it is unclear to what extent these technologies have been designed to support large-scale learning scenarios involving arguably massive participation. This paper contributes with a literature review that aims at providing an answer to this question as well as offering insights about the context of use, characteristics of the technologies, and the types of activities and collaboration mechanisms supported. The main results point out that till 2013 the level of massiveness considered in top scientific journal papers on collaborative learning technologies was low, the scenarios studied were predominantly contextualized in co-located higher education settings using Learning Management Systems, the most common activities considered were open and structured discussion, followed by peer assessment and collaborative writing, and the most broadly used mechanism to foster fruitful collaboration was group formation following diverse policies.

Keywords

Literature review, Educational technologies, Collaborative learning, Large classes, Massive courses

Introduction

The interest in educational technologies for massive numbers of learners has recently increased because of the impact that Massive Open Online Courses (MOOCs) are having in the Media and the Society (Sonwalkar, Wilson, Ng, & Sloep, 2013). This impact is shaping a turning point in educational technologies research as it offers an excellent opportunity for the adoption of previous research achievements while creating new scalability research challenges for massive teaching, learning and assessment models (Kay, Reimann, Diebold, & Kummerfeld, 2013). Aligned with existing research evidences, MOOC initiatives recognize the importance of social interaction among learners. Many of them incorporate activities based on discussions and peer-review assessments (Tsai & Wong, 2013). The potential for different pedagogies and collaborative learning methodologies in massive class teaching is prospective and highly concerned. Yet, we envision that this potential is still in its infancy though undoubtedly relevant open discussions and peer-assessments are the main two examples of collaborative learning techniques with current practice in massive courses (Kay et al., 2013; Sonwalkar et al., 2013; Tsai & Wong 2013).

Collaborative learning techniques support the construction of joint knowledge and sharing of meanings by means of fostering potentially effective social interactions (Dillenbourg, 1999). Accumulated research in Computer-Supported Collaborative Learning (CSCL) has proposed and evaluated multiple models and implementation tools that engage learners in knowledge-intensive social interactions (debate, conflict resolution, artefact co-design, mutual explanation, etc.) with identified significant learning outcomes (Dillenbourg, 1999; Stahl, Koschmann & Suthers, 2006). These models involve the application of collaboration-triggering mechanisms such as group formation according to specific policies, role allocation and rotation, distribution of knowledge, etc. and the use of diverse collaboration spaces (shared boards, wikis, etc.) and implementing communication and coordination mechanisms (flow control, group awareness, etc.). However, the standout body of CSCL research is mostly known for its contributions focused on supporting small groups of learners (Stahl, Law, & Hesse, 2013). And the research around scalable collaborative learning approaches, technologies and issues for large classrooms or large learning communities is scattered across scientific publications without explicitly embracing a comprehensive visible body of knowledge.

This paper contributes with a systematic literature review (Kitchenham, 2004; Webster & Watson, 2002) synthesizing a framework that explains existing insights and gaps in the context of applying collaborative learning aimed at massive or large groups. This framework will serve as a foundation for advancing knowledge and uncovered areas (Webster & Watson, 2002) where further research in above aspects could be conducted accordingly. Hence, the rationale for the paper is not to identify CSCL as a branch of MOOCs providing collaboration aspects, but to understand to what extent previous research in CSCL has involved in the design or/and use of technologies suitable to support massive or large-scale participation. The ultimate aim is to characterize which technologies and approaches could be potentially used in MOOCs (or, more generally, in massive learning actions) to support collaboration - because its use with relatively large learner communities has been proved and studied. As a secondary aim, the paper also discusses challenges and promising avenues emerging from the literature review.

Therefore, a first aim of the analysis is identifying the context types for research works that have considered arguably (or potentially) massive / large quantities of learners in the concerned technology-supported collaborative learning scenarios. Then, the concrete focus is on understanding the types of tasks or activities supported by collaborative learning technologies in those scenarios, as well as the types of mechanisms and technological facets considered by these technologies to support collaboration. A systematic approach is followed consisting of stages as (1) identify research objectives (2) search articles (3) filtration and evaluation of data set (4) coding and analysis (5) interpretation of results obtained. The coding of the data is done using a qualitative data analysis tool (Atlas.ti), whose features facilitate researchers a systematic management and coding of text instances in articles. As the research objectives, following specific research questions were formulated:

In research involving arguably or potentially massive technology-supported collaborative learning environments,
RQ1: to what extent the scenarios considered are massive?
RQ2: what are the types of educational sectors and settings considered?
RQ3: what types of activities are proposed?
RQ4: what collaboration mechanisms are implemented?
RQ5: which are their technological facets?

Educational sectors or levels (from primary to adult education and informal learning) and the types of settings (co-located, remote, in physical or virtual spaces) characterize the context of the learning scenarios in which research on collaborative learning technologies have been framed. The literature review will provide insights about in which contexts these technologies have been applied with many learners. As mentioned above, collaboration environments have been proposed for a number of diverse activities (from debates to product co-development), the review will provide light about to what extent these environments have been used in massive situations. Group formation following specific policies and distribution of roles and knowledge are design techniques used in pedagogical methods and technologies (such as collaboration scripts) seeking potentially fruitful social interactions (Dillenbourg, 2002; Hernández-Leo et al., 2006; Dillenbourg, Järvelä, & Fischer, 2009). A potential research question is whether these approaches have been designed for massive scales also.

A realistic educational scenario could have multiple educational tools and technologies involved, including Learning Management Systems (LMS), generic tools, devoted tools, pervasive and ubiquitous devices (Harrer, Pinkwart, McLaren, & Scheuer, 2008; Suo, Miyata, Morikawa, Ishida, & Shi, 2009; Calvo, O'Rourke, Jones, Yacef, & Reimann, 2011). Therefore, inquiring about the technological platforms considered, the interactions between tools and to what extent they are seamlessly connected also has a scientific interest corresponding to massive learning situations. Also from the technological facets perspective, seamless learning implies certain type of interoperability between tools or an enabling technology that acts as a mediator to allow learners to feasibly switch and flow between diverse physical and virtual spaces (Chan et. al, 2006; Pérez-Sanagustín et al., 2012).

The remainder of the paper is structured as follows. Next section details the methodology followed, including the procedure applied to identify possible similar reviews, the search criteria for the literature considered and the method of analysis. Then, a results section is organized as subsections, based on the structure of the research questions. This is followed by a discussion section, which explains requiring concerns on the research aspects with prevailing challenges. The paper concludes with a conclusion of the main findings.

Methodology

Originality of the literature review

A first phase was devoted to identify if a similar literature review attempt was already available. A search clause was formulated including set of keywords denoting the focus of the targeted research topic (Webster & Watson, 2002). The search clause comprised of "review" or "state of the art" or "bibliography" or "survey" (as the nature of the targeted contribution) covering key aspects like “learning” or “education” in “collaborative” or “cooperative” “computer” or “technologically” supported environment targeting “large” or “massive” classes or even “communities” or “MOOCs.”

The resulting search clause with the complete criterion for title search was: (review OR state of the art OR bibliography OR survey) AND (education* OR learning) AND (collaborat* OR cooperat*) AND (large OR massive OR MOOC OR communit*) AND (comput* OR technolog*).

Databases including IEEE Xplore, Web of Science, ACM, Scopus, SpringerLink, ScienceDirect and GoogleScholar were considered for the search since they cover a significant wide range of Computer Science, Education and interdisciplinary scientific publications. The comprehensive search query returned 0 results indicating that this specific topic had not been studied so far. There were no journal articles (either peer reviewed or not), no conference publications neither any text available for that specific topic at the time of writing this article as search query did not present any specific time period.

Literature selection

The next iteration of the search process was to seek the relevant literature to consider in the review (Webster & Watson, 2002). Based on the above formed research questions, a series of keywords were recognized and search was extended up to title, abstract and keywords. Subset of keywords were (education* OR learning) AND (collaborat* OR cooperat*) AND (large OR massive OR MOOC OR communit*) AND (comput* AND technolog*).

For this literature selection Scopus was selected as the database source, given its wide scope that includes the relevant Educational Technology publications (Falagas, Pitsouni, Malietzis, & Pappas, 2008; Chou, 2012), such as those ranked in the “top peer reviewed journals with high impact factors” by Google Scholar (under “Engineering and Computer Science” or “Social Sciences” sub-field “Educational Technology”). Also Scopus gives the facility of maintaining lists of selected papers and provides a graphical view of publications over time. To select the most appropriate and accurate work, few limitations/criteria were implied; such as sources being either peer reviewed journal articles or conference proceedings, published date fallen between 2000 up to December, 2013 and concerned fields are being physical sciences and social sciences while eliminating life and health sciences as they are not related directly with technology enhanced learning. We decided to include aforementioned timespan (starting in 2010) since research on technology supporting collaborative learning was emerging at that time (Dillenbourg, 1999; Stahl, Koschmann, & Suthers, 2006).

Initial screening in Scopus resulted of 6514 papers containing above key terms in topics, abstracts or keywords in only peer-reviewed journal articles and conference proceedings. 3118 articles of them were journal papers. The temporal distribution of the publications is shown in Figure 1. Years from 2007 to 2011 experienced the highest rates of increase in terms of numbers of publications in the topics, reaching certain equilibrium as of 2011. Out of the articles potentially relevant it was required a solid logical filtration for the final selection. Two researchers participated in the final selection phase. As for the first stage, top ranked educational technology journals according to an intersection of the rankings in ISI Journal Citation Report (ISI, 2013) and Google Scholar were concerned and this criterion narrowed down the count to 243 journal articles. During the next stage of article filtration, 100 articles (out of the 243) were chosen as relevant and appropriate by considering the topic, abstract and keywords of each article. The topics of those not considered relevant were diverse: e.g., misplaced topic, not addressing collaboration among learners but among teachers or other stakeholders, unclear role of technology supporting learning activities, etc. A summary of the selected papers (by journal) is presented in Table 1.

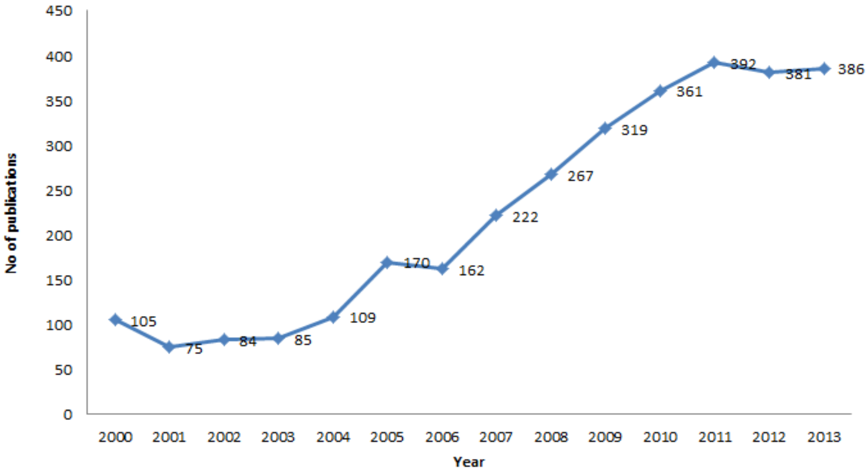


Figure 1. Temporal distribution of retrieved potentially relevant publications

Table 1. Journal papers selected (by journal)

No of selected papers	Journal (alphabetical order)
5	Australasian Journal of Educational Technology
9	British Journal of Educational Technology
39	Computers & Education
10	Educational Technology and Society
2	Educational Technology Research and Development
5	IEEE Transactions on Learning Technologies
2	Interactive Learning Environments
5	International Journal of Computer-Supported Collaborative Learning
6	International Review of Research in Open and Distance Learning
8	Internet and Higher Education
5	Journal of Computer Assisted Learning
4	Language Learning and Technology
100	Total Papers (Complete list of papers available at the online-appendix at https://goo.gl/Q6n5yM)

Analysis method

Selected articles were coded using Atlas.ti, a qualitative data analysis tool (see http://www.atlasti.com/index.html) that helped the categorization process and also the exploration and annotation of articles while providing convenient navigation among the article collection. Most articles were experimental studies from which the two researchers could capture code instances by reading through the methodologies, experimental details and their pedagogical approaches. In this qualitative analysis process, thematic categories or code structure was formed considering the research questions and related classifications widely recognized in the educational and the CSCL fields. Besides, since qualitative data analysis involves the identification and interpretation of themes in textual data, additional codes or sub categories emerged during the analysis process (Kitchenham, 2004; Webster & Watson, 2002). Table 2 collects the structure (or tree) of codes used. The root categories relate directly to the research questions and level one to its main characteristics (see for instance the codes for RQ2 or RQ4). The categories in level two add another layer to the analysis. Most subcategories in this level were formulated at the beginning of the research process, in alignment with the research questions and considering existing categorizations. Examples are types of educational sectors or levels (RQ2), collaboration mechanisms (or CL mechanisms) - either designed by practitioners or socially by students - (RQ4) or "CL activity" type being open or structured discussions or peer assessment (RQ3) or the technological facets used (RQ5) (Dillenbourg, 2002; Hernández-Leo et al., 2006; Dillenbourg et al., 2009). Another set of codes emerged during the analysis, in particular, additional types of activities found in some articles like game/role playing or collaborative presentations (RQ3) and the subcategories defined in the quotient of learners derived from the specific sample sizes revealed in articles (RQ1).

Table 2. Categories of analysis

Level two	Level one	Root
Less than 100 Between 100 and 1000 More than 1000		Quotient of learners (RQ1)
Primary Secondary Higher Vocational Adult	Co-located (same setting) Remote locations (across settings)	Educational setting profile (RQ2)
Open Discussions Structured Discussions Peer assessment Game playing Collaborative writing Collaborative presenting		CL activity (RQ3)
Group formation Role distribution Grouping based on previous performance Resource distribution	Designed by teacher Decided by learner	CL mechanism (RQ4)
LMS or LMS-embedded tools Generic tools Completely new tool	Platforms and tools	Technological facets (RQ5)
No seams Seamful Seamless	Addressing seams	

Regarding RQ5, “platforms and tools” is considered as a code and as subcodes the categories considered were “LMS” or “LMS- embedded tools” or any “general tool” such as social media like Facebook or Blogger, communication tools like Skype or NetMeeting, etc. When researchers had suggested a complete new tool, the article was coded as a “complete new tool.” Seamless support is another aspect concerned in RQ5. Hence the articles were also analysed highlighting such ideas as “seamless” and “seamful” (i.e., inflexible switch between learning spaces), if those had looked into being pervasive and the remaining as “no seams” where there is not a need of being seamless.

Results

Level of massiveness and educational setting profiles

The level of massiveness (research question RQ1), in terms of number of learners participating in activities supported by collaborative learning environments, found in the scientific journal papers selected was relatively low if compared to the many learners involved in MOOCs (Kay et al., 2013; Sonwalkar et al., 2013). 55% from the concerned sample have experimented with less than 100 of participants. 37% involved more than 100 students, yet these did not exceed 1000 (Table 3). Only 8% papers found with a quantity of learners larger than 1000 and this could be recognized as a practical issue observed with experiments addressing large class learning as mentioned in most of the papers. On the other hand several researches mentioned that having larger sample sizes of learners involved in the studies would be interesting from a quantitative research perspective (Walta & Nicholas, 2013; Junco, Elavsky, Heiberger, 2013; Williams, Lewis, Boyle, & Brown, 2011; Ferriman, 2013).

Regarding the types of educational sectors (RQ2), 66.4% of the researchers had experimented collaborative learning technological models and tools with students pursuing higher studies like undergraduate courses, post-graduate work or any vocational studies such as training teachers, nurse, etc. 20.7% found addressing attempts implementing computer supported collaborative activities for primary or secondary schools. 7.7% articles were evident as attempts to embrace technology into adult learning context and another. 67.1% of research had been conducted in co-located situations (same location, physical space) rather than across physical and remote / virtual locations. A summary of the educational sectors by type of setting is provided in Figure 2. Majority (> 50%) from the articles that had experimented with more than 100 participants had been implemented upon higher educational set up and very few attempts were observed for primary or secondary education while another few targeting at vocational training.

Table 3. Quotient of learners

Percentage	Number of learners
55	Less than 100
37	Less than 1000, but greater than 100
8	Greater than 1000

Only 5.2% was observed as informal learning contexts; e.g., where learners share knowledge according to their co-interests in a community (Huang, Yang, Huang, & Hsiao, 2010; Li et al., 2011) These attempts had shown the potential in promoting further collaboration in informal contexts as discussed by Li et al. (2011) by providing a sustainable teamwork platform for researchers to aid in content sharing and managing knowledge resources to build up scholarly communities of knowledge. Further they envision on scaling up to larger learner communities using teamwork platform, SWiCLE to support lifelong learning (Li et al., 2011). Also Huang et al. (2010) article enlightens construction of mobile collaborative learning networks on top of an existing web based platform by the provision of intelligent grouping services to recommend users learning partners of the same interests and specialties. These studies inspire innovate opportunities of using personal data derived from social networks or any other informal contexts for new pedagogical approaches when scaling up collaborative learning strategies, for example in the context of MOOCs.

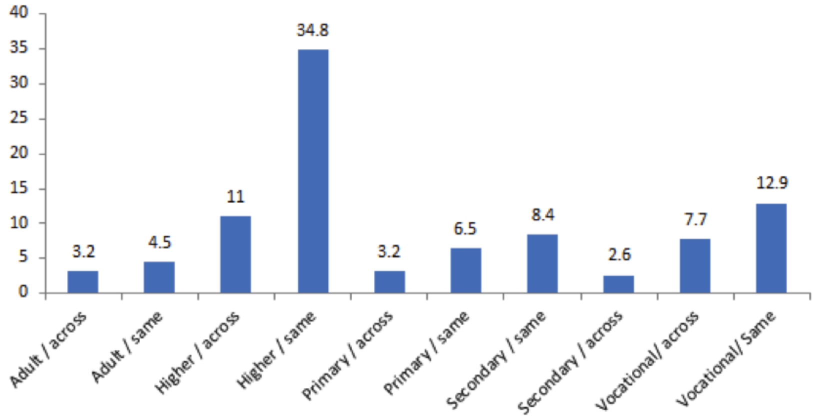


Figure 2. Percentages of educational sectors by settings

Types of collaborative learning activities supported

The third research question RQ3 refers to the type of collaborative activities attempted in the literature aiming fruitful social interactions. The analysis derived six main types of activities considered in "potentially massive" collaborative learning environments as using virtual discussion boards like forums and blogs, peer assessments, games and collaborative writing spaces like Wiki. Figure 3(a) provides a summary as presented in the literature and Figure 3(b) shows the variation of collaborative activities across educational sectors. Discussions could be considered as the most prevalent activity category with highest number of attempts in literature and generally every activity category has higher values for students pursuing higher studies such as undergraduate or postgraduate students.

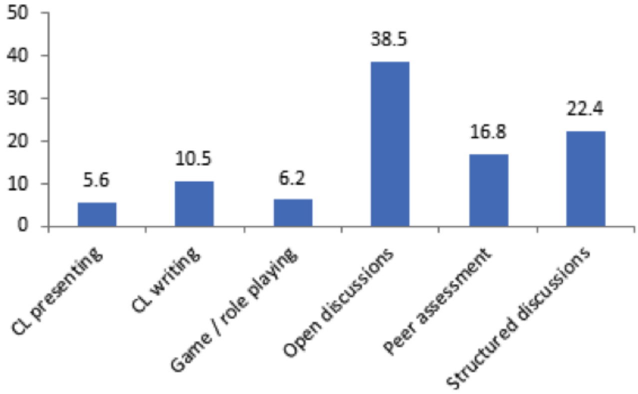


Figure 3(a). Total percentages of main collaborative learning activities supported by technological environments

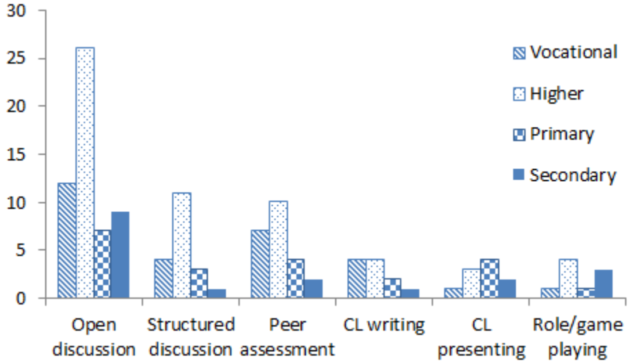


Figure 3(b). Percentages of main collaborative learning activities supported by technological environments by educational sector

60.9% papers have implemented some sort of discussion forums; either structured or open discussions among learners in order to maintain collaboration while another 39.1% have attempted different types of techniques to implement a collaborative learning environment. The highest percentage (38.5%) is inspired by open discussions among learners with no interference of the instructor or a specified structure (Shaw, 2013; Oliveira, Tinoca, & Pereira, 2011; Noroozi, Teasley, Biemans, Weinberger, & Mulder, 2013). 22.4% of articles were promoting structured discussion, through scaffolding by practitioners along the discussion activity or via the implementation of collaborative inquiry models that propose the use of epistemic categories or distribution of roles that condition participation in discussions (Walta & Nicholas, 2013; Ferriman, 2013; So, Seah, & Toh-Heng, 2010; Schellens et al., 2007; Gerosa et al., 2010; Ligorio, Talamo, & Pontecorvo, 2005). Ferriman (2013) had let teachers to provide constructive feedback in the middle of an essay writing activity to guide learners and based on teacher feedback, students post content to the virtual discussion threads ensuring quality content. Walta and Nicholas (2013) use a Community of Inquiry model in which learners participated in structured discussions like designated blogs, journal spaces and small group tutorial discussions along with open discussions via LMS promoting collaboration and reflective learning. Another study uses collaborative inquiry-centred pedagogy (So et al, 2010) providing opening cues like "My theory," "I need to understand" or "A better theory is" with the use of a collaborative knowledge building tool. Schellens et al. (2007) proposed discussion structuring by assigning roles to each participant as "moderator, theoretician, summariser, source searcher" at the beginning of the discussion. Another approach was a forum with seminar leaders initiating the conversation while group members develop the argumentation accordingly and mediators intervene when required (Gerosa et al., 2010). Ligorio et al. (2005) conducted an experiment on collaborative writing of fairy tales by two distant primary schools' kids in which, practitioners monitor pupil interventions during the writing and discussion stages, resolve conflicts in group work, summarize what pupils stated in discussion flows and create space for the pupils with less involvement within activity.

As shown in Oliveira et al. (2011), role of the online teacher/instructor varied, according to the activity phase objectives; for example, during first phase, teacher worked as a facilitator and a critical observer but during the group work stage the responsibility for the discussion leadership was entirely the responsibility of the participants while teacher is a passive observer only. Furthermore, academic moderators had been assigned in certain learning scenarios to lever the learners and also to ensure ethical etiquette and confidentiality in a discussion environment (Walta & Nicholas, 2103). In another article, instructors had introduced few online activities like quick-answer competitions or whole-class ratings as to spark collaborative online learning Zhan, Xu, and Ye (2011) and as in Ferriman (2013) and Ligorio et al. (2005), initial guidance, feedback or topic selection had been done by the teacher in the collaborative activity.

Most of the articles have used technology-mediated discussions such as discussion boards or online chat forums while a few had mentioned only about face-to-face communication. The hybrid of these techniques was also found where learners meet each other face to face as well as they meet in virtual environment (Samarawickrema, Benson, & Brack, 2010; Ladyshewsky, & Gardner, 2008). Another interesting observation is that a significant amount of articles had attempted both synchronous communications like online chat or video conferencing and asynchronous communication techniques like blogs, discussion forums within the experiment to implement collaborative activity (Samarawickrema et al., 2010; Brett, & Nagra, 2005; Wang, 2009; Raymond et al., 2005; Calvo et al., 2011).

Apart from the discussions, the other CL activities observed were peer assessments (Saunders, & Gale, 2011; Freeman, & McKenzie, 2002; Ligorio et al., 2005) with critical evaluation among peers to construct knowledge, collaborative writing spaces such as wikis (Calvo et al., 2011; Brett & Nagra, 2005; Oliveira et al., 2011; Li, Dong, & Huang, 2011) as a medium for socially mediated learning, or either game playing (Susaeta et al., 2010) or role playing (Ioannidou et al., 2010) depending on target activity and collaborative presenting of an end-result of a group collaboration (Tsai, 2010; Raymond et al., 2005).

In the case of the article portion that had participants greater than 100 as the sample size, open discussions surpasses (42.4%) and apart from discussions peer assessment (15.3%), a widely used CL pedagogical technique with larger learner communities, seems prominent too as indicated in Figure 4. More than 50% of the experiments had exercised combination of collaborative learning activities as explained by Oliveira et al. (2011) in the article, after studying and reflecting individually students participated in online discussions, small group work, collaborative writing spaces to share ideas and played games to find the final solution. Hybrids of virtual and physical discussions along with peer assessment are also (Zhan, Xu, & Ye, 2011) seen as fruitful to be implemented upon larger groups. Wang (2009) shows better collaborations using shared spaces with large classes implementing instructional design strategies such as friendship in groups and allowing meaningful tasks to improve individual accountability and positive interdependence along with certain scaffolding like collaborative writing of progress reports and monitoring groups individually.

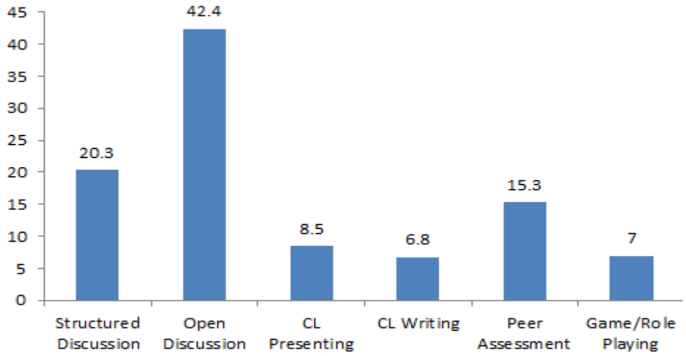
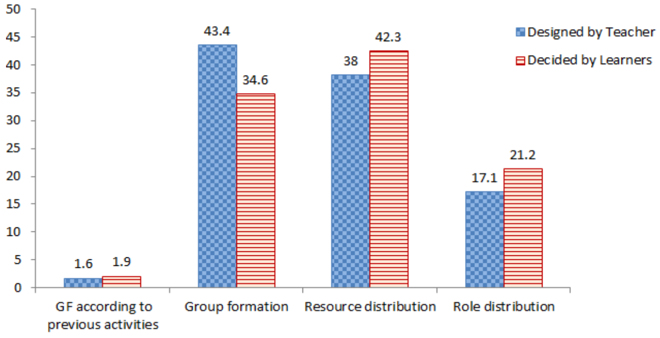


Figure 4. Percentage distribution of collaborative learning activities with experiment samples larger than 100 participants

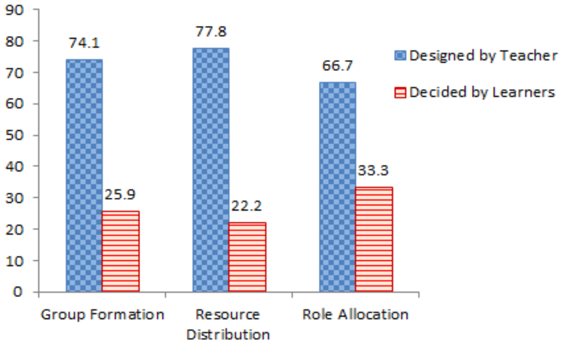
Collaboration mechanisms

RQ4 refers on how to achieve potentially effective collaboration in a collaborative learning technological environment and the corresponding analysis code is “CL Structure” either mediated by the teacher or by learners themselves. Known collaboration mechanisms are group formation according to specific policies, or the progress along a learning flow, the distribution of roles and the distribution of knowledge / resources (Dillenbourg, 2002; Hernández-Leo et al., 2006). These mechanisms orchestrate the elements of a collaborative learning activity with the aim of triggering desired knowledge-intensive social interactions. Group formation is the mechanism presented more in the analysed papers. 40.88% of the papers discuss about a mechanism for group formation either by an external influence or individual willingness. Another 39.23% had mentioned a particular mechanism for distributing learning resources like learning materials or hardware devices within groups or any other component needed for the collaborative learning activity. Only 18.23% performed activity by assigning roles to group members whereas 1.66% had considered previous activities attempted by the student when grouping for collaborative activities.

Only very few instances were found conducting current learning activity by considering learner profile and previous performances (Capuruço & Capretz, 2009; So, Seah & Toh-Heng, 2010). Research in many areas has shown that learning within groups improves students’ learning experience by enabling peers to learn from each other (Ounnas, Davis, & Millard, 2009). Hence, almost all papers had discussed forming groups either by students themselves or by the teacher. Forming groups by teacher or by a particular software program have been considered as designed-by-teacher Group Formation (GF). This mechanism is used in a high quantity of papers (43.4%) as shown in Figure 5. Various practices were observed in literature for forming groups as GF according to geographical location or gender (Samarawickrema et al., 2010; Walta & Nicholas, 2013), using GF algorithms (Sancho-Thomas, Fuentes-Fernández, Fernández-Manjón, 2009), based on the type of activity, experience level or knowledge proficiency (Oliveira et al., 2011; Calvo et al., 2011; Tsai, 2010); but there was a considerable trend for random group formation (Shaw, 2013) and some articles had not expressed their mechanism.



Figrue 5(a)



Figrue 5(b)

Figure 5. Percentage of use of collaboration mechanisms: (a) comparing if the mechanism has been designed by the teacher or decided by the learners, (b) considering larger learner groups (> 100 participants)

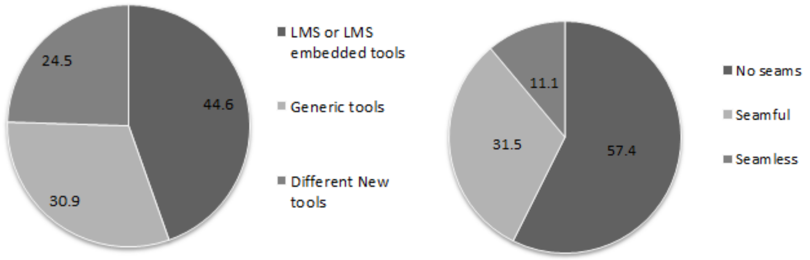
Social resource distribution was encouraged in a collaborative environment when learners exchange resources over teacher mediation. However, in most cases the distribution meant a collective sharing of knowledge. Especially when forums or blogs were used, there was a tendency of exchanging extra learning materials relevant such as additional reading references in web or a link to a video along with the forum or blog post (Schellens, Van Keer, De Wever, & Valcke, 2007). The general trend of resource allocation was sharing learning materials in a LMS or another shared space to be accessible for all. A more truly fostering-collaboration mechanisms based on distribution of knowledge (e.g., to promote positive interdependence and individual accountability within groups) was found in situations of individual resource allocation when teacher allocates resources due to the requirements of the activity or a specific collaboration flow (e.g., Jigsaw activity) (Bochicchio & Longo, 2009; Hernández-Leo et al., 2006; Susaeta et al., 2010) or when students select the content according to their preferences (Wang, 2009).

Only 18.23% papers had discussed about assigning roles in a collaborative activity. The types of techniques for role allocation vary. While in Sancho-Thomas et al. (2009) role distribution was done by using a standard algorithm, in Schellens et al. (2007) the assignment is random. Besides, a negotiated role assignment between learners is also a valued approach since students can select their own roles according to their interests.

As shown by Figure 5(b), teacher/instructor involvement or providing certain scaffolding mechanisms for learner collaboration within the flow design was seen as a common practice even with larger learner communities (>100) rather than letting learners to decide independently. Zhan, Xu, and Ye (2011) had highlighted the significance of different grouping mechanisms and the effects on heterogeneous groups vs homogenous based on learner style in online learning environment as limitations within their experiment with larger learner crowd even though they only had used heterogeneous groups and teacher mediated resources and role allocation. Instructor presence has a heavy influence for the interactions during group work due to the supportive facilitator role as explained by Oliveira et al. (2011) even among massive learner communities.

Technological facets

Following Figure 6 demonstrates usage of different technological facets and tools observed in the concerned literature and how past research had shown interest for seamless aspects. When considering different technologies suggested by the papers (RQ5), it was observed that many researches had used either the existing LMS at their institutions (e.g., Moodle, BlackBoard, WebCT etc.) or a similar platform to a LMS or customized the LMS according to the requirements and embed more tools like discussion boards (Shaw, 2013; Noroozi et al., 2013), conferencing or communication tools (Williams et al., 2011), podcasting tools (Saunders, & Gale, 2011) and reflective journal logs (Ladyshewsky & Gardner, 2008), repositories with required learning materials (Zhan, Xu, & Ye, 2011) or even additional assessment or feedback mechanisms (Saunders & Gale, 2011) to make the final tool more sophisticated. Hence learners are able to experience a comprehensive learning environment with asynchronous or synchronous learning tools (Raymond et al., 2005). As indicated by figure 6(a), total 44.6% from the sample set had used either LMS or LMS-embed tools for their experiments. Another 30.9% had used generic tools such as Wikis, YouTube, Facebook, Blogs, Skype or Presentation tools like Microsoft PowerPoint in order to promote collaborative learning and aid in the learning activity flow. Some of the researches (24.5) had introduced completely new platforms and applications or new hardware devices according to their proposed conceptual model of the research (Ferriman, 2013). It can be derived that a significant number of research work oriented towards relatively high number of participants apply well-known LMSs, generic Web2.0 and communication tools, or LMS integrating specific tools.



(a) (b)

Figure 6. Technological facets: (a) types of platforms / tools, (b) achieving across seams

Ubiquitous and pervasive computing offers new possibilities to work collaboratively mediating social interactions in technology-rich diverse spaces and times and across-technologies seamlessly. Novel experiences for learners including mobile technologies rises new opportunities for collaborative learning (Looi et al., 2010; Suo et al., 2009), also when seamlessly combined with other devices and software tools (Pérez-Sanagustín et al., 2012). Most of the research found in the search had not been able to achieve broad seamless features (Figure 6(b)), even though certain attempts have discussed being seamless within their context. 57.4% of the papers have not considered being seamless across neither technologies nor space or time. 11.1% of the papers had achieved seamless in their solutions, mostly technologically and the other 31.5% discuss that being seamless is advantageous and effective. Also they had convinced productive activity flow is achievable across seams with their solutions.

It was observed that the suggestions for being seamless are augmented by combining several technologies together and offering them as a single solution (Tsai, 2010; Walta & Nicholas, 2013; Saunders, & Gale, 2011). In Calvo et al. (2011) cloud concepts are embedded to continue a collaborative writing activity for a group of learners in diverse contexts or conducting physical lab experiments in a remote virtual environment (Bochicchio & Longo, 2009). Noroozi et al. (2013) propose the use of multiple devices and technologies to conduct an activity involving face-to-face discussions as well as virtual discussion boards and other communication facilities extending the learning experience.

Discussion

The analysed papers identify a number of challenges that arise in technology-supported collaborative learning environments involving a large number of learners. These challenges are related with technological, cultural and lingual barriers (Samarawickrema et al., 2010; Saunders, & Gale, 2011; Ferriman, 2013; Tsai, 2010; So, Seah, & Toh-Heng, 2010), and also with maintaining interest throughout the learning activity in order to promote students' engagement and maximize the social interactions (Walta & Nicholas, 2013; Junco et al., 2013; Ferriman, 2013; Sancho-Thomas et al., 2009) that would lead to fruitful learning. Also as presented in Walta and Nicholas (2013), Wang (2009), Shaw (2013), Yang, Wang, Shen, and Han (2007) and Capuruço and Capretz (2009), minimizing the complexity of technologies and tools and making those flexible ensuring solid flow of learning activities, could be another challenge. Some papers had appreciated having a certain scaffolding structure that could also be mediated by the teacher or instructor (So, Seah, & Toh-Heng, 2010; Wang, 2009). When considering the architectural models proposed, some attempts had reused an existing learning management system either by customizing it according to the needs or embedding new features/tools whereas others had practiced generic tools like Blogger, Skype, NetMeeting or social networking applications like Facebook or Twitter to promote learning. One frequent observation of the literature is that more than one technological approach had been utilized when designing the collaborative architecture as an alternative or complement to traditional LMS approach. Building learning communities by embedding more context-aware approaches such as artificial intelligent agents or contextualized knowledge bases were observed and those are seen as prominent and promising in future approaches (Calvo et al., 2011; Yang et al., 2007; Raymond et al., 2005).

Having homogenous student groups and small sample sizes for experiments had also been reflected as major concerns (Walta & Nicholas, 2013; Junco et al., 2013; Williams et al., 2011; Ferriman, 2013) by most of the researchers and had suggested that the experiments should have been extended to heterogeneous groups with larger sample sizes. This is interesting from a quantitative research perspective, but also important to evaluate the scalability of the technologies. While enabling communication is satisfactorily achieved by the current technologies, managing coordination and maintaining intense collaboration among many students are still challenging. When promoting collaborative activities like group formation, assigning roles or resource distribution teacher intervention had been seen as important by certain researchers. More articles recommended (Huang et al., 2010; Noroozi et al., 2013) forming groups as designed by teachers (manually or with software support), rather than letting students form their own groups according to their preferences since it would lead for subjective groups or free-passers because of friends. Adult guidance or collaboration with more capable peers (Vygotsky, 1978) in problem solving circumstances is encouraged in the learning sciences in order to achieve higher order cognitive levels. Learning being a continuous fluid process, when forming groups or distributing roles for activities, it would be an additional positive factor leading to potentially finest learning groups to be formed if learners’ track record could be considered. But it was revealed that only least effort had been taken in literature with this regard and future research in embedding student profile to orchestrate learning activities will be welcoming.

Conclusion

The literature review presented in this paper has offered an understanding of the research situation (till 2013) around collaborative learning technologies for arguably large numbers of participants. The quotient of learners considered for massive classes or large communities was in 55% of the top scientific journal papers selected under 100 participants, in 37% between 100-1000, and in 8% over 1000. The scenarios studied were predominantly contextualized in higher education settings, followed by primary and secondary education. Scenarios of adult education and informal learning are less common in the reviewed studies. Overall, mainstream software such as general Web2.0 tools and LMS are the main platforms being used in the studies; only a reduced number of cases considered pervasive technologies and specific tools devoted to support collaborative learning. Activities mostly based on communication actions (open or structured discussion) are widespread in massive scenarios as well as peer review tasks devoted to distribute the assessment workload between learners. However, activities requiring higher coordination between learners (e.g., collaborative writing) are rare. Similarly, group formation techniques of diverse type are considered in those activities. Other collaboration mechanisms like allocation of roles or knowledge distribution among group members to structure the collaborative activity are less frequent.

Pedagogical models and platforms for massive courses can benefit from existing research result in technology-supported collaborative learning environments (e.g., application of group formation techniques, considering different types of intervention by instructors). However, there are still important challenges to address in massive collaborative learning. These challenges are of different nature, from cultural to technological, but its core relies on being able foster knowledge-intensive social interactions. Some of the reviewed papers tackle this critical aspect, and there is an additional corpus of research (not considered in the review since it is) deliberately oriented towards small groups of learners, that propose a number of solutions to that purpose. Understanding how these contributions for small groups can be scaled up is an interesting future research line. A related, but different, perspective is the exploration of innovative collaborative learning approaches that may work better at massive scale (Ferguson & Sharples, 2014). An analysis of the different perspectives and building on top of this literature review will allow the formulation of CSCL design aspects for MOOCs. This paper provides a founding framework of conceptual aspects to be considered and a set of discussion pointers that lead to further research directions.

The paper has answered the question of whether research on collaborative learning technologies has addressed massiveness. The question is answered considering top established journal publications in educational technologies. Further literature review is focused on other fora, such as new publication venues centred on MOOCs or recent conference proceedings can also provide a complementary view – to the review presented in this paper – of how research and practice on collaborative learning technologies is now being applied at a massive scale.

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Chapter 3

A Multiple Constraints Framework for Collaborative Learning Flow Orchestration

The chapter reveals about the research work carried out during the cycle 2 of the dissertation (see Figure 3.1). Related to [RQ2] from Chapter 1 (section 1.3), this chapter explains identification of flexible conditions in CLFPs and relevant contributions with the evaluation studies (Fig. 3.1). We modelled the two types of constraints in CLFPs to learn their dichotomy better and to see the flexible aspects in the patterns. "Pattern independent conceptual model for CLFP hard constraints" represents the pedagogical rationale behind the pattern that should not be modified since then the pattern definition is violated. Adversely, soft constraints are preferred to be satisfied, but not compulsory and those are presented as a "context-independent generic soft constraint model". We elaborate constraint applicability with a Jigsaw pattern case study using a technological particularization called SOS (Hernández-Leo et al., 2012) and an Art class in a High school context. With positive results for perceived activity enjoyment and preferences, we concluded that such pattern particularizations can guide practitioners to design pattern based CSCL activities facilitating more meaningful interactions. We also evaluated the framework across similar studies from the literature where collaborations were defined based on some characteristics or constraints. This cross-validation helped us to observe the level of expressiveness of our proposed framework and also to find missing elements during the initial iteration. This chapter consists of a Springer LNCS international conference publication of which the details are as follows:

Manathunga, K., & Hernández-Leo, D. (2016). A Multiple Constraints Framework for Collaborative Learning Flow Orchestration. In Chiu D., Marenzi I., Nanni U., Spaniol M., Temperini M. (Eds.), *Advances in Web-Based Learning: Proceedings of 15th International Conference on Web-based Learning, ICWL 2016* (October), Pages: 225-235, Rome, Italy: Springer LNCS (volume 10013)

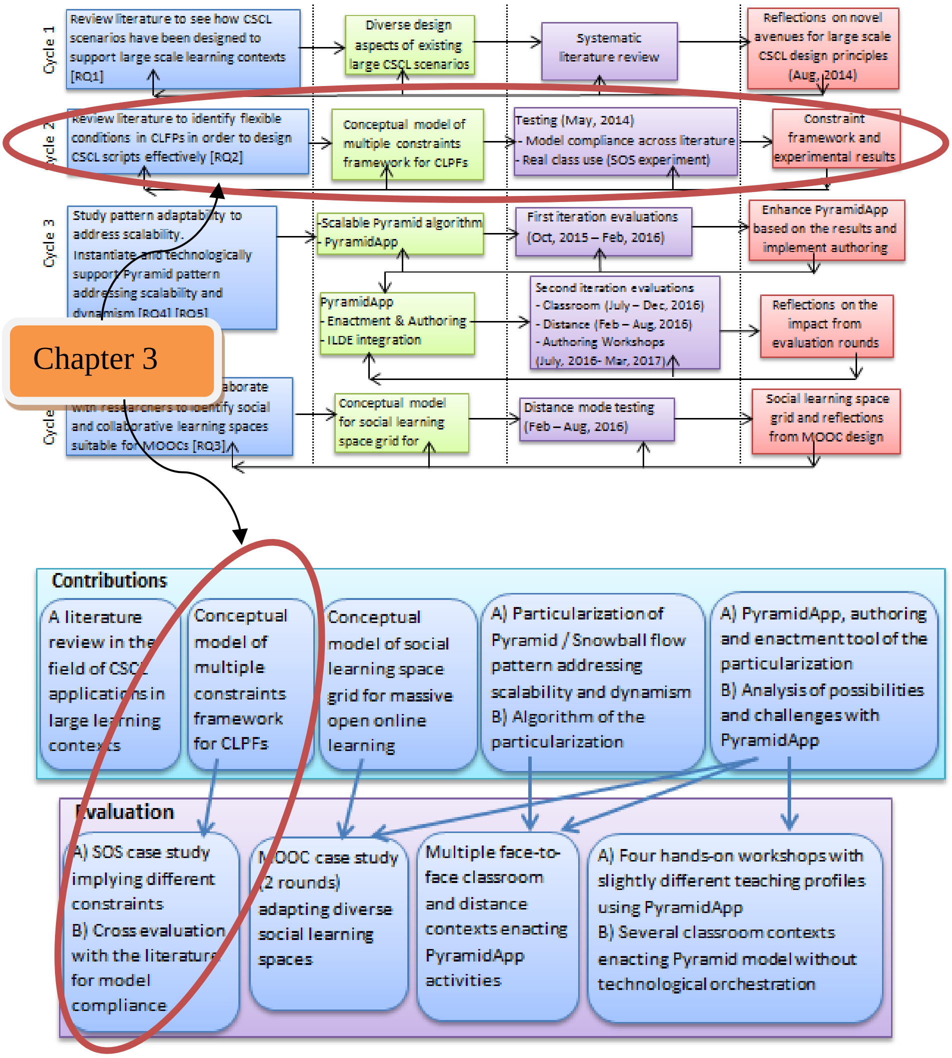

Figure 3.1: Part of the research process, contributions and evaluation study covered by Chapter 3

A Multiple Constraints Framework for Collaborative Learning Flow Orchestration

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Abstract. Collaborative Learning Flow Patterns (e.g., Jigsaw) offer sound pedagogical strategies to foster fruitful social interactions among learners. The *pedagogy behind the patterns involves a set of intrinsic constraints* that need to be considered when orchestrating the learning flow. These constraints relate to the organization of the flow (e.g., Jigsaw pattern - a global problem is divided into sub-problems and a constraint is that there need to be at least one expert group working on each sub-problem) and group formation policies (e.g., groups solving the global problem need to have at least one member coming from a different previous expert group). Besides, characteristics of specific learning situations such as learners' profile and technological tools used provide additional parameters that can be considered as *context-related extrinsic constraints* relevant to the orchestration (e.g., heterogeneous groups depending on experience or interests). This paper proposes a constraint framework that considers different constraints for orchestration services enabling adaptive computation of orchestration aspects. Substantiation of the framework with a case study demonstrated the feasibility, usefulness and the expressiveness of the framework.

Keywords: CSCL, Collaborative Learning Flow Pattern(s), Macro Scripts, Jigsaw, Learning Flow Orchestration

1 Introduction

Collaborative learning supports knowledge construction and sharing by fostering effective social interactions (Dillenbourg, 1999). Computer Supported Collaborative Learning (CSCL) is the field studying the role of technological support to mediate fruitful interactions resulting in effective learning. Research accumulated around CSCL have proposed and evaluated multiple pedagogical models (also called as macro-scripts intended to create quality interactions in collaborative learning (Dillenbourg & Tchounikine, 2007; Hernández-Leo et al., 2006)) and implementation tools that engage learners in knowledge-intensive social interactions (conflict resolution, artefact co-design, mutual explanation, etc.) with identified significant learning outcomes (Dillenbourg, 1999; Stahl et al., 2006).

CSCL macro scripts specify required orchestration aspects such as group formation, role allocation and rotation, distribution of resources, using diverse collaboration spaces (shared boards, wikis, etc.), implementing communication and coordination mechanisms (flow control, group awareness, etc.) (Kobbe et al., 2007). These orchestration aspects of a macro-script introduces set of constraints to shape up desired interactions whilst avoiding the risk of over-scripting (Dillenbourg, 2002). Identification and adaptation of these constraints to design effective scripts are challenging and require proficiency (Dillenbourg, 2002; Hernández-Leo et al., 2010; Spoelstra, van Rosmalen, Houtmans, & Sloep, 2015). Having weak constraints may lead to loose fruitful collaborations. On the contrary, rigid constraints spoil natural peer interaction mechanisms (Dillenbourg & Tchounikine, 2007). Hence, scripts should be flexible with no over-constraining in order to be adaptable in the learning context in operational CSCL. To facilitate flexible script design while avoiding over-scripting, it is important to understand the notions of *intrinsic* and *extrinsic* constraints (Dillenbourg & Tchounikine, 2007). A more detailed explanation of *intrinsic* and *extrinsic* constraints is provided in Section 2.

Collaborative Learning Flow Patterns (CLFPs) like Jigsaw, Pyramid capture the essence of well-known techniques in macro scripts to produce potentially effective collaborations (Hernández-Leo et al., 2006). These patterns introduce set of conditions namely *intrinsic* constraints to be met while shaping up the desired collaborations (Dillenbourg & Tchounikine, 2007). Previous work in the field (Pérez-Sanagustín et al., 2011; Rodríguez-Triana, 2014) had demonstrated extensive knowledge in extracting such constraints, especially in small classroom contexts. Yet more scrutinized insight is required when aggregating CLFP based collaborative learning in large learning contexts (Manathunga & Hernández-Leo, 2015) like Massive Open Online Courses where learner community grows dynamically and constant modifications of pre-created scripts designs are required. Discontinuous participation and varied learner behaviour within such open learning environments require redefining orchestration mechanisms frequently. These concerns raise need to recognize flexible aspects within macro scripts, which types of constraints can be applied and how those can be manipulated. Specifically this contribution proposes a multiple constraint framework to facilitate effective CSCL script design introducing essential parameters. The technological viability of the framework is then evaluated with an automated orchestration service applied upon real-class case study. Signal Orchestration System (SOS) (Hernández-Leo et al., 2012), an implementation of the framework, is a web-based CLFP service provider that facilitates configuring automatic orchestration of collaborative activities across different contexts: physical spaces and course platforms. SOS orchestration services allow adaptive computation of orchestration configurations accommodating dynamic changes like absentees, dropping out students providing dynamic modifications to pre-created CSCL scripts.

Remaining content of the manuscript is spelled out as; section 2 explaining the principles of the framework and its main components presented as two models to accommodate *intrinsic* and *extrinsic* constraints. The section is complemented with a literature analysis across existing proposals. Section 3 illustrates a case study including the framework realization along with experimental details followed by concluding remarks and future research directions.

2 Multiple Constraints Framework

Macro scripts, generally used to structure a collaborative activity to foster intended interactions among learners (Dillenbourg & Tchounikine, 2007). Hence, generating effective scripts for CSCL is time consuming, challenging and require expertise knowledge (Hernández-Leo et al., 2010; Ounnas, Davis, & Millard, 2009; Spoelstra et al., 2015); these concerns become exponential when a large class is considered. Therefore researchers' interest had drawn for CSCL scripting (Dillenbourg, 1999; Hernández-Leo et al., 2006) and computer supported orchestration mechanisms (Sun & Shen, 2014) by identifying and modelling both practitioner and participant constraints. *Intrinsic* constraints are guarded by the pedagogical rationale behind the script and *extrinsic* constraints can be induced from diverse sources such as educational context, technological factors or even from arbitrary decisions (Dillenbourg & Tchounikine, 2007). In CLFP macro-scripts, set of *intrinsic* pedagogical constraints bound to the core of the pattern pedagogy are already defined (Hernández-Leo et al., 2006; Pérez-Sanagustín et al., 2011) to be considered when designing the script (see Table 1). Contrary, characteristics of specific learning situations, such as learners' profiles, their interests and technological tools supporting the activities (course platforms, social media) also provide additional parameters that can be exploited as constraints from a pedagogical perspective (*extrinsic*). Therefore further articulation of the role of context-related *extrinsic* constraints and its operational articulation with *intrinsic* constraints are critical. Automatic or semi-automatic orchestration systems supporting teachers in script design should implement algorithms that require considering both types of constraints. Furthermore in real scenarios constraints need to be considered with priorities for more realistic constraint computations. *Intrinsic* basis is critical since it lays the fundamentals; if these are not satisfied, the underlying pedagogy is violated; hence those should be considered as "hard" constraints. *Extrinsic* or context-related constraints are complementary that are preferred to be implied as those "soft" constraints add beneficial value resulting in meaningful interactions. Articulation of hard and soft constraints needs to be clearly distinguished and applied since it defines the flexibility of the macro-script. These set the rules on the modifiability aspects within the script (Dillenbourg & Tchounikine, 2007). Modelling these multiple constraints in a constraint-framework expressing parameters of hard and soft constraints is equally important for the implementation of orchestration services which can be easily adapted by practitioners when enacting collaborative activities.

2.1 Model of Collaborative Learning Flow Pattern(s) Hard Constraints

Hard constraints are strictly bound with the pedagogical design of the script; hence can be considered as the core of the script design (Dillenbourg & Tchounikine, 2007; Pérez-Sanagustín et al., 2011). In pattern based macro scripting, the pattern definition sets the rationale for the intended orchestration of the collaborative activity (Table 1).

These hard constraints set the boundary of script adaptability in a particular CLFP in order to not to kill the guarding pedagogical rationale. For instance, in Jigsaw pattern, "each group must have at least one expert who had studied each sub task of the activity to collaboratively share knowledge". An analysis of related work (Pérez-Sanagustín et al., 2011; Rodríguez-Triana, 2014) on extraction of *intrinsic* constraints of CLFPs and additional revision of the CLFPs have led to formulate hard constraint conceptual model (Fig. 1). Pattern elements (denoted by white rectangles) and parameters (denoted by ash rectangles) are important to be considered when designing the script. As an example, a Jigsaw activity is defined by three specific phases as "Individual", "Expert" and "Jigsaw" phases (Table 1) with a task (that has number of sub tasks) that include specific number of groups proportionate to the number of sub tasks. Any pattern has a number of phases defined by its definition or derived according to other variables like the number of participants for the activity. These phases have a problem (either one task or set of sub tasks) to be solved and a bunch of groups to solve tasks. If problem > 1, number of problems should be specified. For some CLFPs, problems may be presented with set of roles inherited which is represented with the number of roles as a parameter.

Table 4. Jigsaw and Pyramid patterns hard constraints

Jigsaw pattern	*Pyramid pattern*
Relates to a situation where several small groups of students ('Jigsaw' groups) each trying to solve a complex problem that can be divided into sub-problems. Each group participant studies one sub-problem individually. Participants from different jigsaw groups meet up in temporary 'Expert' groups to exchange ideas about their common sub-problems. Finally, participants return back to their jigsaw groups to share the knowledge and solve the global problem. This pattern fosters individual accountability and personal responsibility.	Starts individually or forming initial small groups to study a common problem and propose initial solutions. Then, students are grouped (usually pairs) to compare and discuss their proposals and, finally, propose a new shared solution. Students are guided so that the groups join with new groups to form larger groups in order to generate new agreed proposals. Likewise this will iterate till the whole group reaches upon a global consensus. This pattern fosters positive interdependence and individual accountability.

Most of the CLFPs have a unique definition for grouping within phases. A group has a size specifying a minimum (and sometimes the maximum) number of participants when composing the group. Generally the number of possible groups is also defined with the pedagogical definition of CLFPs along with different group formation policies. Furthermore roles are defined according to certain policies (Group policy) such as appointing team leader based on previous experiences or highest marks or randomly where every odd number becomes a problem-solver and even number becomes a listener. Therefore different elements (denoted by dashed rectangles in Fig.1) can be attached with group policy parameter like phase dependency when group formation technique depends on the behaviour of the previous phase, completely random or considering practical criteria without pedagogical rationale (e.g., alphabetical order in names). Further context-based elements or soft constraints can be the value for group formation policy which is extensively explored in the next subsection through soft constraint model.

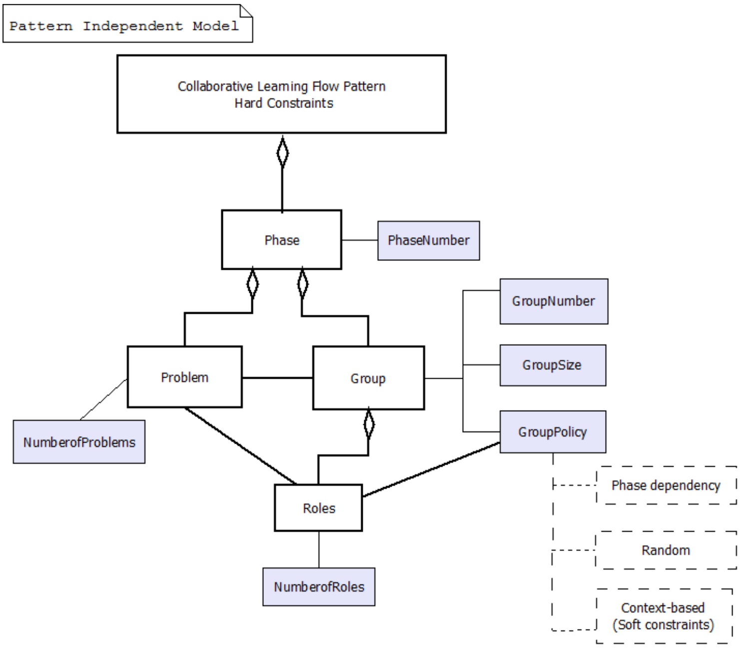

Fig. 2. Conceptual model of CLFP hard constraints

2.2 Generic Model for Soft Constraints

As education contexts generate abundant elements that can be considered when designing collaborative activities causing further fruitful interactions, a soft constraint model is suggested to make the framework more comprehensive. Soft constraints define limitations in a macro-script that are “preferred to be satisfied” (Dillenbourg & Tchounikine, 2007) and do not violate any pedagogical perspective, if not satisfied; hence these are rather flexible in terms of constraint satisfaction. Fig. 2 illustrates a conceptual model that elaborates potential sources to retrieve soft constraints within a given learning scenario. Parameters of learner profile such as personal details (marks, level of education, country of origin) or individual learning style or previous experiences or interests (skills) are used as group formation policies (Spoelstra et al., 2015; Sun & Shen, 2014). With the advent of open APIs exposed by different social media such as Facebook, Twitter, LinkedIn gives an opportunity for educational tool developers to extract public profile details of the learner (Sinha, 2014). Hence, different social media parameters such as number of connections, friendship, preferences, number of likes or tweets, recommendations that had been received can be accepted as soft constraints. Learning setting can be defined in different perspectives such as the infrastructure used like hardware devices or other software tools or the location settings like co-located vs. distant or being in a specific location. Further even individual availability can be vital especially in distance learning contexts (Spoelstra et al., 2015).

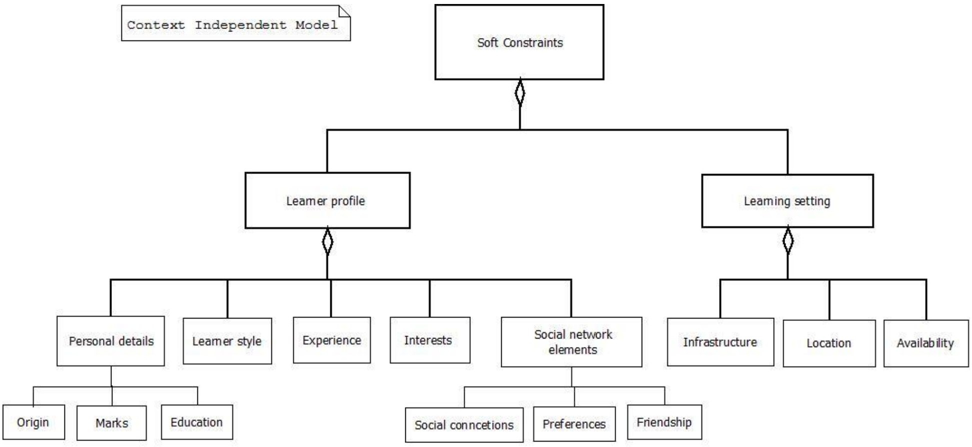

Fig. 3. Generic model for soft constraints

Table 2 demonstrates a literature analysis of various parameters that had been considered in previous work to implement collaborative activities. We studied their approaches and parameters apprehended. The analysis provided insights to what extent hard or soft constraints had been considered and how their approaches are compatible and expressed within our proposed framework (highlighted in bold letters).

Table 5. Constraints based CL studies (analysis & comparison with proposed framework)

Article	Approach / Methodology	Parameters considered
Spoelstra, van Rosmalen, Houtmans & Sloep (Spoelstra et al., 2015)	Based on a survey, learners are allocated in Project-based Learning scenarios. Learner age, gender, Big5 personality test, knowledge and work preferences like language, no of hours, availability are concerned. Formed 3 types of teams: productive, creative and learning teams which were validated by teachers.	Conscientiousness ***(learner style)*** Knowledge ***(experience)*** Demographics ***(origin)*** Preferred time slots ***(availability)***
Sun & Shen (Sun & Shen, 2014)	Using learning styles and genetic algorithm, Jigsaw CLFP is applied. Social features of learners had been considered. An extended service structure with many components (scheduler, inference engine and monitoring service) and also facilitates cloud hosted MOODLE and mobile access.	Jigsaw pattern constraints ***(hard constraints)*** Learning style ***(learner style)*** Comprehensive teamwork skills ***(experience or interests)***

Ounnas, Davis & Millard (Ounnas et al., 2009)	When student name, gender and the learner roles are given as the knowledge to a predicate solver, a group model is generated considering both strong and weak constraints defined by the teacher. Algorithm ensures maximum allocation leaving no orphans.	Learner styles, preferred modules, collaborators, etc. ***(personal details and learner style)*** Past track record of student ***(marks or experience)***
Inaba & Ando (Inaba & Ando, 2014)	Groups are formed based on pre-test results. CL orchestration is provided with "reciprocal schema" script in which learners take turns in different roles (preparer, answerer, grader)	Role assignment ***(hard constraints)*** Same academic level based on marks obtained ***(marks)***
Agrawal, Golshan & Terzi (Agrawal, Golshan, & Terzi, 2014)	Uses clustering algorithm to group criteria being the ability in subject. Algorithm groups students with similar capabilities to maximize team performance, e.g.: highest ability leaders are grouped with highest ability followers	Ability over the subject ***(marks)***
Sinha (Sinha, 2014)	A MOOC has been considered as a social network and applied Social Network Analysis to form groups. Only performed an analysis of an existing Coursera MOOC to construct a social network graph of 3848 edges acquired from discussion forums	Profile information like interests ***(interests)*** Student implicit skills like social positioning within discussions ***(Social connections or Friendship)***

3 Jigsaw pattern based case study

In this section, a case study is explained illustrating feasible implementation of the framework and its usefulness. Jigsaw CLFP (see Table 1) was adhered and the constraints for the collaborative activity were devised following the proposed framework along with technological orchestration support (Table 3). Signal Orchestration System (SOS) (Hernández-Leo et al., 2012), a prototype implementation of the Jigsaw service with signalling mechanism to notify orchestrations aspects (group formation, phase changes and resource allocation) using wearable or smartphones has been used in an authentic educational scenario. The activity was enacted in an Art class of a Catalan High school with 19 students (age: 13-15). Students and the teacher had previous experience of using Moodle. Teacher designed the activity using SOS which allocated students to Expert and Jigsaw phases with respective orchestration signals. List of students was exported to SOS via a Moodle plug-in embedded with SOS and two different personal devices (9 wearable devices and 9 smartphones) were used to retrieve orchestration signals. Five colour lamps were used to identify the group location during phase-switching (Fig. 3). 5 Expert groups were formed to study different art tendencies: Art-deco, Futurism, Modernism, Recycle and Pop-Art and they were allocated into 3 Jigsaw groups representing Industrial, Graphic & Interiors. Jigsaw groups uploaded their final answers to the respective Moodle link. As shown in Table 3, apart from the hard constraints, soft constraints were also applied when forming expert groups (homogenous groups by the device used-wearable or smartphone-in order to observe which device type was easier for them to recognize the signal received). This distribution of devices was only for experimental purposes and there were no pedagogical effects/constraints over the experiment. In the table, "P" denotes the total number of participants and when P is known, the constraint values could be derived accordingly.

When grouping students into Expert and Jigsaw groups, it was compulsorily satisfied that at least one Expert member must be present in each Jigsaw group by the grouping service. Every Jigsaw group included Experts from every sub task and some groups had more than one Expert from the same sub task. In addition to phase constraints, students were allocated to 5 sub tasks, i.e., more than 2 sub tasks but less than half the number of total participants allowing each sub task to have one corresponding Expert group. Fig. 3 shows sample screen devised when enacting Jigsaw phase in SOS and how students were engaged in the activity at Expert and Jigsaw phases. These SOS suggested orchestration arrangements can be modified according to teacher's preference on-the-fly (e.g.: group members, resources, signal colours).

Table 6. Constraints considered in the adaptive orchestration service based on Jigsaw CLFP

Jigsaw Phase	Constraint	Constraints	Description
Phase 1 (Individual) Study given sub-problem individually	Hard	GroupSize_1 >= 1	Each group can consist of an individual or in small-sized groups
		GroupNumber_1 >= 2	There must be at least two groups for collaboration
		2 <= NumberofProblems_1 <= P/2	Should be at least 2 sub-problems but no more than half the number of participants to allow collaboration in expert groups
Phase 2 (Expert) Students with the same sub problem are grouped	Hard	NumberofProblems_2 = NumberofProblems_1	Same sub problems like in the individual phase
		GroupSize_2 >= 2	There must be at least 2 participants in expert group to allow collaboration
		GroupNumber_2 => Number-ofProblems_2	There must be at least one group of experts for each sub-problem
		GroupPolicy_2 = Having same problem as in Phase 1	Experts with same sub-task/problem given in phase 1 should be grouped together

for collaboration	Soft	GroupPolicy_2 = Homogenous (either device1 / device2)	Homogenous groups using the same device are grouped together within context
Phase 3 (Jigsaw) Different experts are grouped to solve the global task.	Hard	GroupSize_3 >= NumberofProblems_1	The group sizes must be large enough to gather experts from all areas
		GroupNumber_3 <= P/GroupSize_3	The number of jigsaw groups must be in accordance with the number of experts of each area
		NumberofProblems_3 = 1	Global task/problem should be solved in Jigsaw phase with experts from all areas
		GroupPolicy_3 = Each jigsaw group having at least one expert	Jigsaw groups must consist of at least one expert representing each sub-problem

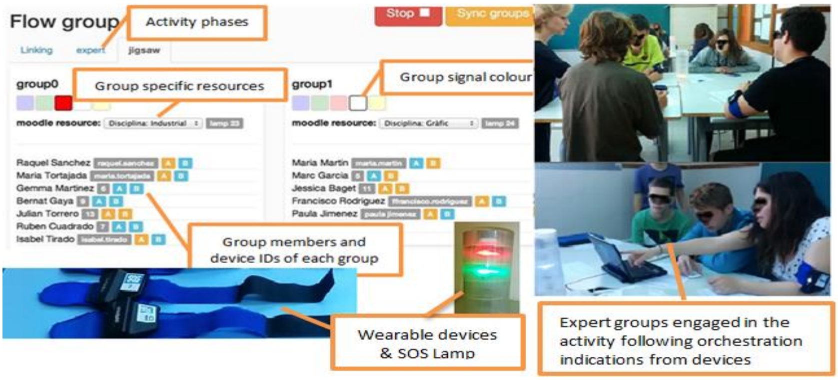

Fig. 4. SOS orchestration configurations, devices and activity enactment at different phases

4 Conclusion

Diverse learning contexts and their parameters introduce different constraints to enrich learner collaborations. These suggestions demand application of further constraints within macro-scripts to fine-tune orchestration aspects (e.g., group formation, resource allocation) based on diverse constraints such as availability, time-zones, etc. Furthermore CSCL scripts need to be flexible within learning context; neither being over-constrained nor killing natural interaction mechanisms. Careful identification of *intrinsic* and *extrinsic* constraints without harming the governing pedagogical rationale is equally important during the design stage. Hence the design of effective scripts requires careful thought-out and expertise knowledge.

This article presents holistic conceptual framework illustrating the derivation of *intrinsic* and *extrinsic* constraints including respective parameters to be considered in a given CLFP that can emerge efficient interactions in a collaborative activity. The substantiation of the previous work also claims that the models comply with the requirements that any automatic or semi-automatic orchestration service should adhere. Jigsaw pattern based case study illustrates constraint extraction and technological application in an authentic class scenario. Further, adherence of diverse constraints guarantees the expressiveness and usability of the proposed framework. Signal Orchestration System, prototype implementation based on the framework enabled automatic orchestration services ensuring feasibility of the framework. Learning technologists can consider the proposed framework when designing more practical technological tools appropriate for collaborative learning.

As future research directions, diverse experimental studies would be carried out in authentic learning contexts including Massive Open Online Courses satisfying different types of requirements and constraints emerging from these contexts. Relevant technological tools required for such experimental settings are being implemented complying with the framework. Such technology mediated orchestration services based on collaborative pedagogical patterns will be then utilized within authentic experimental studies to support practitioners to configure effective CSCL scripts and enact in real class scenarios fostering fruitful knowledge-intensive interactions.

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Chapter 4

A Social Learning Space Grid for MOOCs: Exploring a FutureLearn Case

This chapter discloses the work done during thesis process cycle 4 the contributions deduced from this part of the dissertation along with related evaluation studies (see Figure 4.1). The chapter complements to the research question [RQ3] from Chapter 1 (section 1.3) that seek potential social and collaborative learning spaces suitable for MOOCs. We enabled diverse collaboration spaces in two rounds of a MOOC prepared by UPF (3D Graphics for Web Developers), which launched in the FutureLearn platform. The two MOOC rounds were finished by August, 2016. Main analysis and reporting results were done during a research stay at the Open University, UK in collaboration with Professor Mike Sharples from the Institute of Educational Technology, OU. During the three months research stay, the results from the two MOOC runs were triangulated and analysed to study how learners behaved when different collaboration spaces offered. In Appendix C, in particular in section C.4 more information related to the analysis can be found. We proposed a social learning space grid for MOOCs after studying diverse spaces and leaner behaviours. This work and part of the analysis have been accepted to be presented as a full paper at the European Stakeholder Summit (EMOOCS, 2017).

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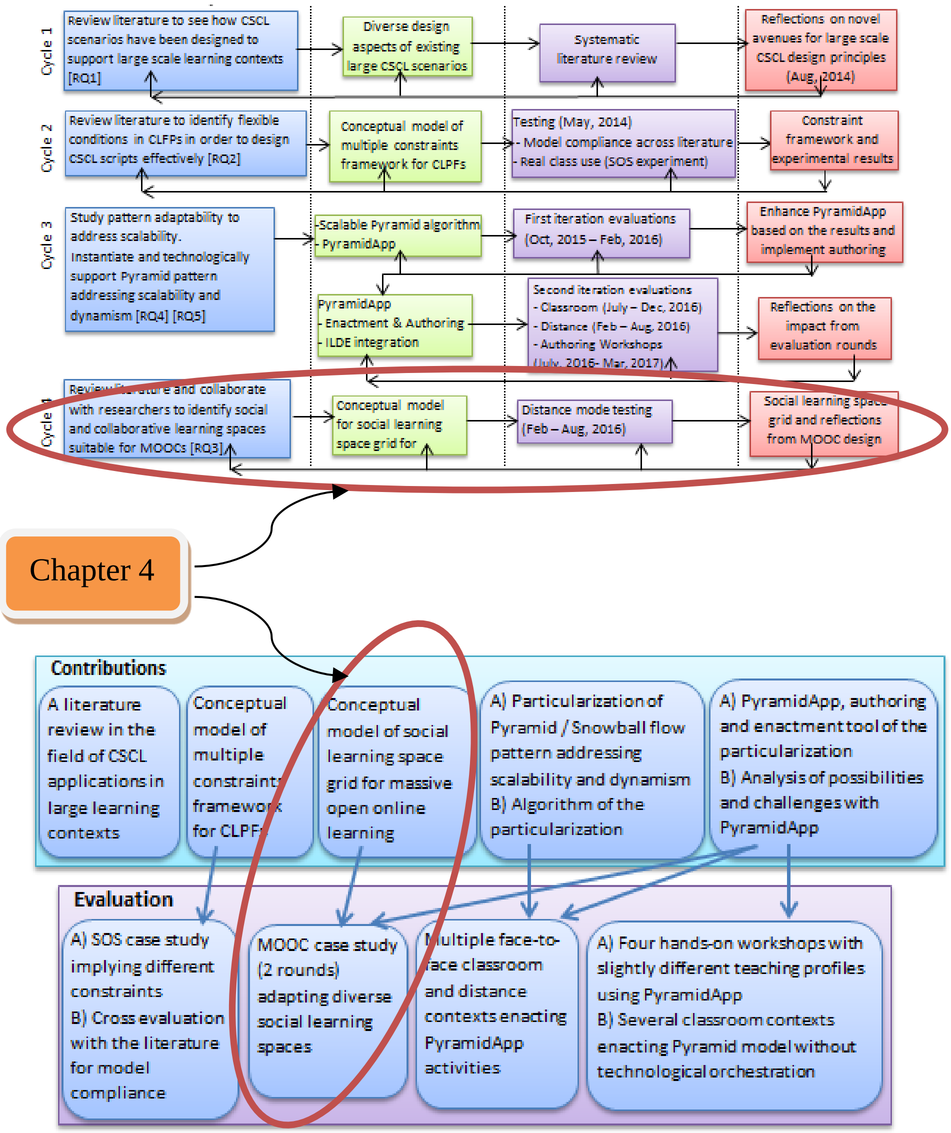

Figure 4.1: Part of the research process, contributions and evaluation studies covered by Chapter 4

A Social Learning Space Grid for MOOCs: Exploring a FutureLearn Case

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Abstract. Collaborative and social engagement promote active learning through knowledge intensive interactions. Massive Open Online Courses (MOOCs) are dynamic and diversified learning spaces with varying factors like flexible time frames, student count, demographics requiring higher engagement and motivation to continue learning and for designers to implement novel pedagogies including collaborative learning activities. This paper looks into available and potential collaborative and social learning spaces within MOOCs and proposes a social learning space grid that can aid MOOC designers to implement such spaces, considering the related requirements. Furthermore, it describes a MOOC case study incorporating three collaborative and social learning spaces and discusses challenges faced. Interesting lessons learned from the case give an insight on which spaces to be implemented and the scenarios and factors to be considered.

Keywords: Collaborative Learning, Social Learning, MOOC

1 Introduction

The fact of putting students into groups does not ensure fruitful learning; rather effective collaborative learning must involve structured activities (Dillenbourg, 2015; Hernández-Leo et al., 2010). Adapting from Social Learning theory, which states that continuous mutual interactions positively influence the way humans learn (Bandura, 1971), many MOOC platforms are moving towards providing social learning opportunities (Dillenbourg, 2015). Yet, forum discussions which are the most widely exercised collaborative or social learning approach in massive learning contexts (Manathunga & Hernández-Leo, 2015), have not seen very effective due to the overwhelming amount of threaded discussions which are difficult to follow (Scardamalia & Bereiter, 2006). Researchers highlight the absence of enhanced collaboration opportunities for MOOC learners (Rosé et al., 2014; Siemens et al., 2015). In this paper, we look into different possibilities of implementing collaborative and social learning aspects in MOOCs along with an exploratory study using three such learning spaces with a MOOC launched on the FutureLearn platform.

Computer Supported Collaborative Learning (CSCL) is the process of knowledge creation by enabling fruitful interactions mediated by technology (Dillenbourg, 2015; Hernández-Leo et al., 2010). Over decades CSCL activities have been applied at small scale in classrooms, but not widely used with large learning contexts, maybe because the scalability factor has not been properly considered in their design (Ferguson & Sharples, 2014; Manathunga & Hernández-Leo, 2015). Social Learning may bring a sense of community, avoiding isolation in online learning and providing possibilities to learn from others (Bandura, 1971). Studies highlight potential benefits of forming sub communities and learner networks with positive encouragement (Alario-Hoyos et al., 2014; Siemens et al., 2015) and understanding emergent social structures in MOOC sub communities (Rosé et al., 2014). Social learning elements, provoking conversational learning and CSCL enforcing rich interactions, are not so easily adaptable or applicable in MOOCs, as they have been in a traditional classroom.

MOOCs have shown the possibility of designing learning at scale and pedagogy that can be driven by discussion and social networking conceptions, where the more people joining, the richer the interactions (Ferguson & Sharples, 2014). Existing fruitful collaboration methods such as tutorial groups, project teams or action learning sets, that work well in small scale settings, are difficult to scale (Ferguson & Sharples, 2014; Siemens et al., 2015). Difficulties are mainly related to diversity in learner's motivations, expectations and differences in cultural expectations (e.g., how individuals should behave in social spaces) and therefore their behaviours when taking the MOOC (Alario-Hoyos et al., 2014; Ferguson et al., 2015). However, some initiatives offering collaborative and social learning opportunities are emerging within MOOCs other than discussion forums, given the concern of implementing novel pedagogies and learning theories (Ferguson & Sharples, 2014; Saadatdoost et al., 2015). 'Study groups' provided by FutureLearn are local, private spaces for around 80 MOOC participants to discuss and share knowledge, 'cohort-specific discussion' by edX allows private group discussions visible only for a specific cohort, 'meet ups at learning hubs' by Coursera enable learners from nearby local to get-together for further discussions or project based learning and 'workspaces' from NovoEd support learning groups and project teams.

Additionally, social networking spaces too provide scalable opportunities by allowing strangers to meet up and enhance connections which can be exploited in the context of education where social elements are complimented with learning (Alario-Hoyos et al., 2014; Knox, 2014). Learner-centred groups introduced within MOOCs harnessing the benefits of social media like Facebook, Twitter, Google+ or Hangout have been seen as fruitful while enhancing learner experience (Alario-Hoyos et al., 2014; Beaven, Hauck, Comas-Quinn, Lewis, & Arcos, 2014; Knox, 2014). Meet-ups, proposed by Coursera, require physical spaces and high levels of facilitation. Cohorts from edX lack novel pedagogical approaches for further interactions. Social media groups such as Facebook Groups are easy to implement, yet very challenging to monitor since interactions are free to emerge and many such groups can exist. Educators require more effort and additional support to structure interactions in such online spaces. Hence, deeper understanding is needed regarding different social and collaborative learning possibilities, to explore challenges and consider options to design suitable learning scenarios. It is equally important to investigate, for massive learner communities, pedagogical methods that have been shown to work well in classrooms, by bridging existing technological challenges.

This paper presents a social learning space grid, organizing diverse social interaction possibilities with underlying rationale, to be used by the MOOC community. We explore the case of a MOOC on 3D Graphics for Web Developers offered on the FutureLearn platform by Pompeu Fabra University, Spain, in which three different collaboration spaces were presented to support collaborative and social learning. We describe these spaces situating them within a proposed framework, identify learning design associated and the motive behind the usage of each space, and discuss examples of use and perceived challenges. Section 2 of the paper describes social learning spaces and presents the social learning space grid followed by diverse particularizations found from literature. In section 3, the MOOC case study is explained along with an analysis of the three collaboration spaces (Study Groups, PyramidApp, Conversational flows) adopted in the MOOC. The final section includes an accumulated discussion of lessons learned and challenges faced followed by concluding remarks and interesting future research directions as contributions from this exploratory study.

2 Social Learning Space Grid

2.1 Social Learning Space Grid: Categories and the Rationale

In order to lay a foundation to address collaborative and social learning aspects with their implications, this study proposes a collaboration space grid (Table 1), a social interaction framework, categorizing existing and prospective scalable collaboration techniques that can be offered within massive online courses. Apart from commonly picked collaboration spaces such as forums with multiple topic threads, dedicated discussion activities or cohort specific discussions in massive learning contexts (Manathunga & Hernández-Leo, 2015), there can be other possibilities of implementing fruitful social interactions. Hence, the social learning space grid (Table 1) will be useful to study the dimensions of possible interactions, respective elements and how these can be used in open online courses. One important dimension is to study how far collaborations can be structured, using which elements. Unconstrained, long-lasting collaborations exist throughout the course lifetime and beyond. Also there exist ephemeral collaborations, constrained to an allocated task or for a given time period. Another dimension of the grid is the size factor affecting interactions. In a MOOC, all the course participants can interact in a common space, or it can be drilled down to small group level collaborations where 15 to 30 participants are grouped into one collaboration space. Moreover, the group sizes can be incrementally growing over the constraints like time or task providing cumulative interactions enriching collaborations.

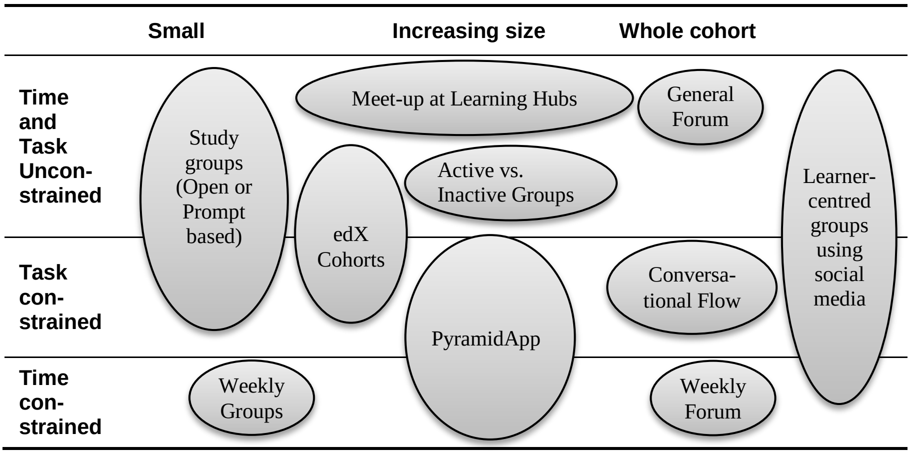
Table 1. Social Learning Space Grid

	Small	**Increasing size**	**Whole cohort**
Time and Task Unconstrained	Groups exist throughout the course. Participants are free to interact at any given moment, for any given task.	Small groups can be joined based on certain criteria or behaviour to interact at any time, for any given task.	An open space for all course participants to interact regarding any topic at any time
Task constrained	Small groups formed to attend a given task	Small groups are combined based on task completion to attend another given task	All course participants attend given task in a common interaction space
Time constrained	Small groups formed to work during a specific time period	Small groups are combined based on time expiration to work together for another specific time period	All course participants attend in a common interaction space during a specific time period

2.2 Particularizations of the Social Learning Space Grid

Table 2 illustrates several examples found in the literature and possible novel interaction mechanisms. Meet-ups at learning hubs by Coursera suggest local physical locations for learners to engage in collaborative learning activities or to clarify content related issues. Such meet-ups can be of varying size depending on the number of learners reaching the particular learning hub. Content-wide and course-wide cohorts on the edX platform, offer different types of interaction environments for MOOC participants where course designers can decide to allow unconstrained cohort experience by opening up cohort specific MOOCs or only certain content are made visible for specific cohorts. Most widely used general forums can attract all participants, leading to massive amounts of threaded discussions if forums are not constrained to tasks or time. In a massive community, small groups can be joined based on certain criteria (e.g., being active or time allocated or task allocated). Time-constrained weekly small groups or weekly forums accessible for all course participants are other possibilities of enabling interaction in MOOCs.

Table 2. Social Learning Space Grid with Examples



The FutureLearn MOOC platform has been developed on a social constructivist pedagogy that promotes effective learning through conversations (Ferguson et al., 2015). FutureLearn MOOCs employ several levels of conversation flows including discussion steps for topic-related learner conversations, a space for comments and replies alongside every activity step for content clarifications and Study Groups to enable small group discussions or more focused group learning opportunities and such groups are consistent throughout the course. Participants are free to leave one group and join the next available, active group. Study groups can be implemented as either open group forums where up to a maximum of 80 MOOC learners are given the opportunity of sharing their learning experiences in a private local space, promoting free interactions that are not constrained by a particular topic, activity or time with no or very little intervention by the educator. Alternatively those can be educator instructions or prompts based, project-based or critique groups that differ from FutureLearn free-flowing discussion steps and focused discussions. Other conversation flows of FutureLearn fall into the task-constrained forums category which provides a wider collaboration space for the whole cohort. Learners are able to comment on and reply to any activity step (task) since each step is associated with a conversation flow dedicated to it. Similarly, dedicated discussion steps available in the platform, are also in the same category since those are connected with tasks. PyramidApp (Manathunga & Hernández-Leo, 2016) is another collaboration space instance that permits growing collaborations based on task and time constraints. PyramidApp is a scalable collaborative pedagogical method inspired by the Pyramid (aka Snowball) collaborative learning flow pattern (Hernández-Leo et al., 2006) facilitating small group activity with cumulative collaborations. A Pyramid flow starts with individual proposals being discussed in small groups which are iteratively joined into larger-groups till a consensus is reached upon at the global level. Such scenarios foster individual participation and accountability (equal opportunity for all, yet with singular contributions) and balanced positive interactions (opinions of all members count). After situating diverse interaction options on the grid, we adopted Study groups, conversation flows and PyramidApp complementing the interaction spaces offered by FutureLearn in the following case study.

3 MOOC Case Study

3.1 Description

“3D Graphics for Web Developers” is a 5-week MOOC, especially for web developers to develop high quality interactive 3D applications to run natively on a browser. It completed two runs in 2016 (First run from February-March and the second run from July-August) on the FutureLearn platform. The MOOC is mainly aimed at web developers, who have existing knowledge of JavaScript, with the theoretical and practical knowledge to start programming 3D graphics applications to run natively in web browsers. There were around 6000 enrolments in the first run of the MOOC and around 4500 enrolments in the second. The MOOC had two lead educators and one mentor to mediate the course. In both runs, the course had more than 10% fully participating learners who had completed at least 50% of all course activity steps. As explained in the social learning space grid (Table 2), this exploratory study used three diverse collaboration spaces: task-constrained educator prompt based study groups (only in the second run of the MOOC); PyramidApp with both task and time constraints, promoting cumulative collaborations for small groups to study together and conversation flows linked to course step for the whole cohort.

As explained in the previous section, FutureLearn platform promotes learning through conversations where each video material or article is facilitated with a discussion thread alongside. Moreover, FutureLearn "Study Groups" were offered to interested learners that were added up to groups of 30 when they clicked on the study group tab available once they access the course content. In this specific course, task-constrained educator prompt-based study groups were offered where learners were expected to become active within the group when the educator sends a prompt and act accordingly. The prompts used were either to discuss a concept or to share artefacts created by learners within groups. To enable cumulative interactions causing collaborative knowledge building (Scardamalia & Bereiter, 2006), PyramidApp (Manathunga & Hernández-Leo, 2016) provided structured collaborations in a way that individuals proposed options (which can be a question, explanation or a 3D artefact) for a given task. Then, they teamed up to compare and discuss their proposals and, finally, propose a new shared 3D artefact or agree upon most relevant options. New larger groups were grown by iteratively combining previous groups in order to generate new agreed options. Provision of rating and discussing in a levelled structure ensured gradual exposure in a collaborative environment. Educators addressed or commented on the most highly rated options and learners are expected to improve knowledge in the critiquing and negotiation process. As pyramids are time and task constrained, once a set of pyramids reach the global level, another set of pyramids are initiated allowing late joiners to participate in the activity and emails are sent notifying about pyramid progression. Educators can easily monitor the activity progression, level by level along with the rated options and discussions happening within groups.

Table 3 shows example learning design of these collaborative and social learning spaces, how those were integrated in the MOOC and the steps along with the step identification to recognize the respective week that a particular learning step was offered (e.g., 1.10 represents week 1, step 10). Initially, there were only task constrained conversational flows for the whole cohort and PyramidApp for small group interactions. With the second run of the MOOC, the study groups feature was available in the platform and ephemeral small group interactions were expected through educator prompt-based study groups since those were dedicated to share course outcomes and created artefacts. More open-ended activities were allocated for conversational flows whereas PyramidApp was assigned for technical aspects discourse, in order to reduce educator's workload by filtering out the most interesting queries to attend to, rather than going through lengthy threads with specific technical issues as the course unveils. Study groups and conversational flows are built-in features of the FutureLearn platform whereas PyramidApp is an external application introduced as an external link within course activity step.

Table 3. Step activity design of the 2nd MOOC run, across three collaboration spaces

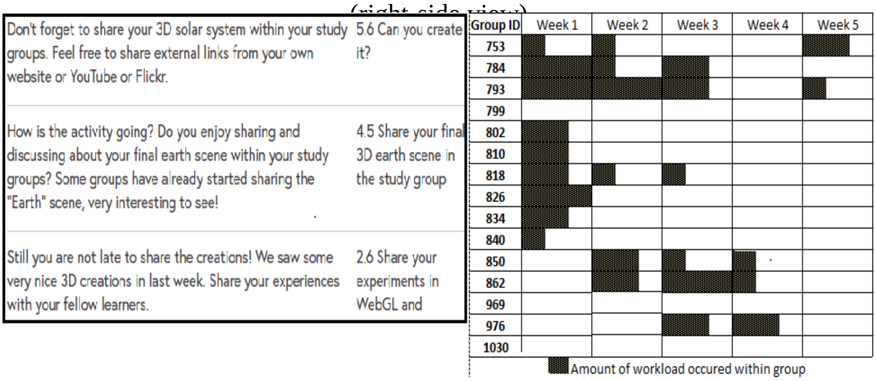
Discussion steps	*Prompt based Study group*	*PyramidApp steps*
1.2 Tell us about yourself!	1.4 Let's share what we know about 3D graphics creation	1.8 Pose questions about WebGLStudio
2.1 What makes a 3D scene look realistic?	2.6 Share your experiments in WebGLStudio	3.5 Pose questions about Three.js API and related utilities
4.7 Share your insights about your realistic earth scene	4.5 Share your final 3D earth scene	5.3 Do you have concerns or questions about advanced 3D concepts?
5.7 Your next steps in 3D graphics programming	5.6 Can you create it? (Share solar system)	

3.2 Results and Observations

Conversation flows were abundantly used in both runs, since every learner is familiar with this due to its presence at every educational step in the platform. Yet discussion steps get flooded easily with hundreds of comments /answers and suggestions, so for an educator or another learner, it can be challenging and time consuming to follow lengthy threads or to filter out relevant comments making knowledge building possibilities limited (Scardamalia & Bereiter, 2006). But the platform provides social networking concepts such as likes, following as filtering mechanisms and it was visible that some learners were using such features in the conversation flows. As the course content was very practical and programming oriented, some learners got lost and frustrated and they were seeking help from peers. Experts were offering help to novices by sharing their suggestions/ideas and experiences to solve technical problems they faced. For example, when *Grant* posted a DOMException error, *Ihor* stated that it was a local server issue, *Sheila* suggested to include images and *Fabien* suggested to try with own webserver to avoid the exception. Also they shared knowledge through programming code samples (e.g., what went wrong when they were trying to integrate the additional library, “Three.js” or which exceptions should be considered when configuring the localhost server) in the discussion steps. For late joiners’ queries and comments, there were fewer interactions or support, maybe because by the time they join most learners had finished the course and left.

In task-driven educator prompt-based study groups, learners posted created artefacts and some learners encouraged others by using social features (likes, comments), positive critiques and suggestions. Study groups are consistent throughout the course and were mostly active upon receiving the educator’s prompts at the beginning of each week (Fig.1). From 16 groups formed, 12 groups had 30 members joined whereas another two had 29 and 4 respectively. Just as in the overall MOOC, a decreasing trend of study group engagement was observed over the course lifetime. Fig. 1 also illustrates the participation patterns in each group (shaded areas represent amount of activity) over the 5 weeks with respective group IDs issued by the platform. The lengths of the shaded boxes are proportionate to the number of days that group members were actively participating (sharing artefacts or commenting). Apart from the three groups that showed no activity in the Study group, other groups showed some interesting clusters of engagement patterns. Most common behaviour (5 out of 12 active groups) was to engage in activities for three weeks from the day the group was formulated.

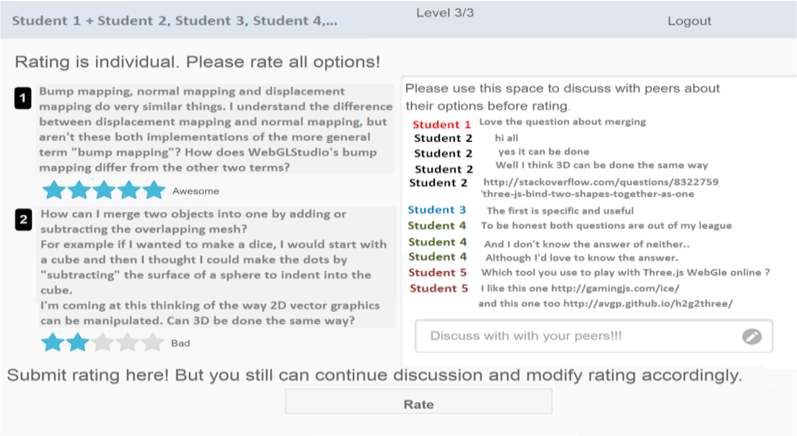
Fig.1. Educator prompts (left-side view) and Study groups behaviour (right-side view)



Don't forget to share your 3D solar system within your study groups. Feel free to share external links from your own website or YouTube or Flickr.	5.6 Can you create it?
How is the activity going? Do you enjoy sharing and discussing about your final earth scene within your study groups? Some groups have already started sharing the "Earth" scene, very interesting to see!	4.5 Share your final 3D earth scene in the study group
Still you are not late to share the creations! We saw some very nice 3D creations in last week. Share your experiences with your fellow learners.	2.6 Share your experiments in WebGL and

PyramidApp was also presented as another social interaction space, via an external link embedded in three different ‘Article’ steps. It allowed learners to submit queries individually and then discuss and negotiate among themselves on more interesting queries for the attention of the educators, leaving behind the ones already addressed or solved at earlier stages or during the discussion process. Fig. 2 shows how learners were curious and rate the questions. Those two questions were selected from the previous level (level 2) and participants in this level (top left hand corner in the screen) can rate then. In the discussion board, some had tried to answer these questions whereas others used it to discuss queries and state their opinions. In this way, the activity can be focused, narrowed down only to specific aspects targeted at specific situations that learners may require additional guidance related to the topic. As a different PyramidApp activity, learner artefacts were shared in groups to rate and critique and it shows that participants appreciated these artefacts and provided suggestions for further improvements like suggesting different materials to be used. PyramidApp used an email notification system to notify learners when subsequent levels were ready, notifying them about the timer values of that level to keep them updated about the activity. Learners who submitted emails received timely notifications. One final notification was sent informing about the selected options and where the answers for winning popular were available at the end of each pyramid.

Fig. 2. Sample PyramidApp scenario with selected options and discussions occurred



Rating is individual. Please rate all options!

1 Bump mapping, normal mapping and displacement mapping do very similar things. I understand the difference between displacement mapping and normal mapping, but aren't these both implementations of the more general term "bump mapping"? How does WebGLStudio's bump mapping differ from the other two terms?

★★★★★ Awesome

2 How can I merge two objects into one by adding or subtracting the overlapping mesh?
For example if I wanted to make a dice, I would start with a cube and then I thought I could make the dots by "subtracting" the surface of a sphere to indent into the cube.
I'm coming at this thinking of the way 2D vector graphics can be manipulated. Can 3D be done the same way?

★★☆☆☆ Bad

Please use this space to discuss with peers about their options before rating.

Student 1 Love the question about merging
Student 2 hi all
Student 2 yes it can be done
Student 2 Well I think 3D can be done the same way
Student 2 http://stackoverflow.com/questions/8322759/three-js-bind-two-shapes-together-as-one
Student 3 The first is specific and useful
Student 4 To be honest both questions are out of my league
Student 4 And I don't know the answer of neither..
Student 4 Although I'd love to know the answer.
Student 5 Which tool you use to play with Three.js WebGle online ?
Student 5 I like this one http://gamingjs.com/ice/
and this one too http://avgp.github.io/h2g2three/

Discuss with with your peers!!!

Submit rating here! But you still can continue discussion and modify rating accordingly.

4 Discussion on challenges faced

It is an interesting viewpoint to understand design and implementation challenges related with three interaction spaces explored in the case study and other aforementioned collaboration spaces (Table 2). In the educator prompt-driven study groups, prompts are required to be carefully designed, more structured and precise. A specific prompt such as, “Does your first 3D scene look “realistic”, “artistic” and “imaginative”? Share links to the work you created using WebGLStudio (or other similar tool), within your study group. Also appreciate others’ creations by liking or commenting on the aspects that you like about those 3D scenes”, would be more meaningful than just asking them to discuss. Course facilitators should constantly monitor groups and interfere if required by sending reminders as mid-week prompts. A better design of activities can be to allocate specific tasks to be done within the study groups and share the resulting conclusions in a related discussion step where the whole cohort can access. Synchronous interaction mechanisms in a MOOC can be futile because not many learners are present at the same time in a platform. Yet, with task and time constraining, to a certain extent, PyramidApp tries to achieve a level of synchronicity, facilitating learners at similar paces to continue their learning experience enriched by social interactions. Activity monitoring is feasible using the PyramidApp monitoring view along with groups and levels information. Existing approaches like meet ups incorporate challenges such as a requirement for physical locations to enact collaborative activities, lack of novel pedagogical approaches and activity structuring to provoke further interactions. Activity monitoring is also demanding in small open groups, since interactions are free to emerge and many such groups can exist, the educator needs more effort to monitor, and require additional support to structure interactions. Though techniques addressing the whole cohort such as forums, conversational flows or large social media groups are easily facilitated, it is difficult to monitor and challenging for knowledge building process (Scardamalia & Bereiter, 2006) due to overwhelming amount of messages. On the contrary, weekly forums can be comparatively easier because of the weekly structure. Hence, a better strategy is to allow small groups to increasingly grow, joined based on certain criteria (e.g., being active or time allocated or task allocated) in a way that reduces the number of groups and with provision of technological facilitation for regrouping and activity monitoring to reduce educator's workload.

5 Conclusion

Implementing scalable pedagogies and novel learning opportunities promoting more learner collaborations in MOOCs is essential and necessary for those to become a disruptive innovation in education. Making MOOCs more social can lead to enjoyable learning experience and the proposed social learning space grid shows potential social interaction methods applicable with examples. The three interaction spaces (conversation flows, study groups and PyramidApp) tested in this case study reveal possible practical challenges such as enabling more structured activities, well-thought out course design and more engaging tasks. Frequently study groups deviated from intended tasks to become help-seeking groups or spaces to get to know each other. Even the conversational flows were not populated equally and late comers were not receiving responses and help as early joiners. Though many learners accessed PyramidApp some were not really engaging in rating and discussing but it was coping with latecomers successfully as new pyramids were created for the same task. Based on these lessons learnt, the activity design for the studied MOOC (e.g., prompts for study groups) has been revised for a third edition of the course. Moreover, future research directions include implementing (quasi-)experimental or experimental designs to study the impact (learning, behaviours, facilitation and monitoring requirements) of different spaces for potentially effective scalable pedagogy considering the social learning spaces and options and combinations of social learning spaces expressed in the grid. The Social Learning Space Grid dimensions provide useful tips for learning technologists to implement social interaction spaces in MOOCs. Based on course requirements suitable social learning spaces can be embedded providing richer interaction opportunities for MOOC learners.

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Chapter 5

PyramidApp: Scalable Method Enabling Collaboration in the Classroom

The chapter explains the research work related to the cycle 3 of the thesis process and relevant contributions made with evaluation studies (see Figure 5.1). Mainly relating to the [RQ4] from section 1.3 in Chapter 1, this work reveals about the rationale for scalable and dynamic Pyramid instantiation with the proposed algorithm mechanisms (flow creation, control and awareness rules). A detailed description about these algorithm mechanisms can be found in Appendix B. Initial iterations of PyramidApp evaluations provide an understanding on feasibility of the proposed approach and to find threshold values to design Pyramids preserving dynamism, allowing progression without freezing. Three experimental studies were carried out in three different educational settings to assess the two main challenges scalability and dynamism when applying CLFPs to large learner contexts. Results and analysis of such studies led us to fine-tune the algorithm and design the authoring system of PyramidApp with proper design parameters. This work was published in EC-TEL 2016 as a short paper article. But in this chapter, we have given the full length article version with more comprehensive details initially submitted for the peer-reviewing process. The publication details of the accepted short paper version are as below:

Manathunga, K., & Hernández-Leo, D. (2016). PyramidApp: Scalable Method Enabling Collaboration in the Classroom. In K. Verbert, M. Sharples, & T. Klobučar (Eds.), *Adaptive and Adaptable Learning: 11th European Conference on Technology Enhanced Learning, EC-TEL 2016* (September) (pp. 422-427). Lyon, France: Springer (LNCS, volume 9891)

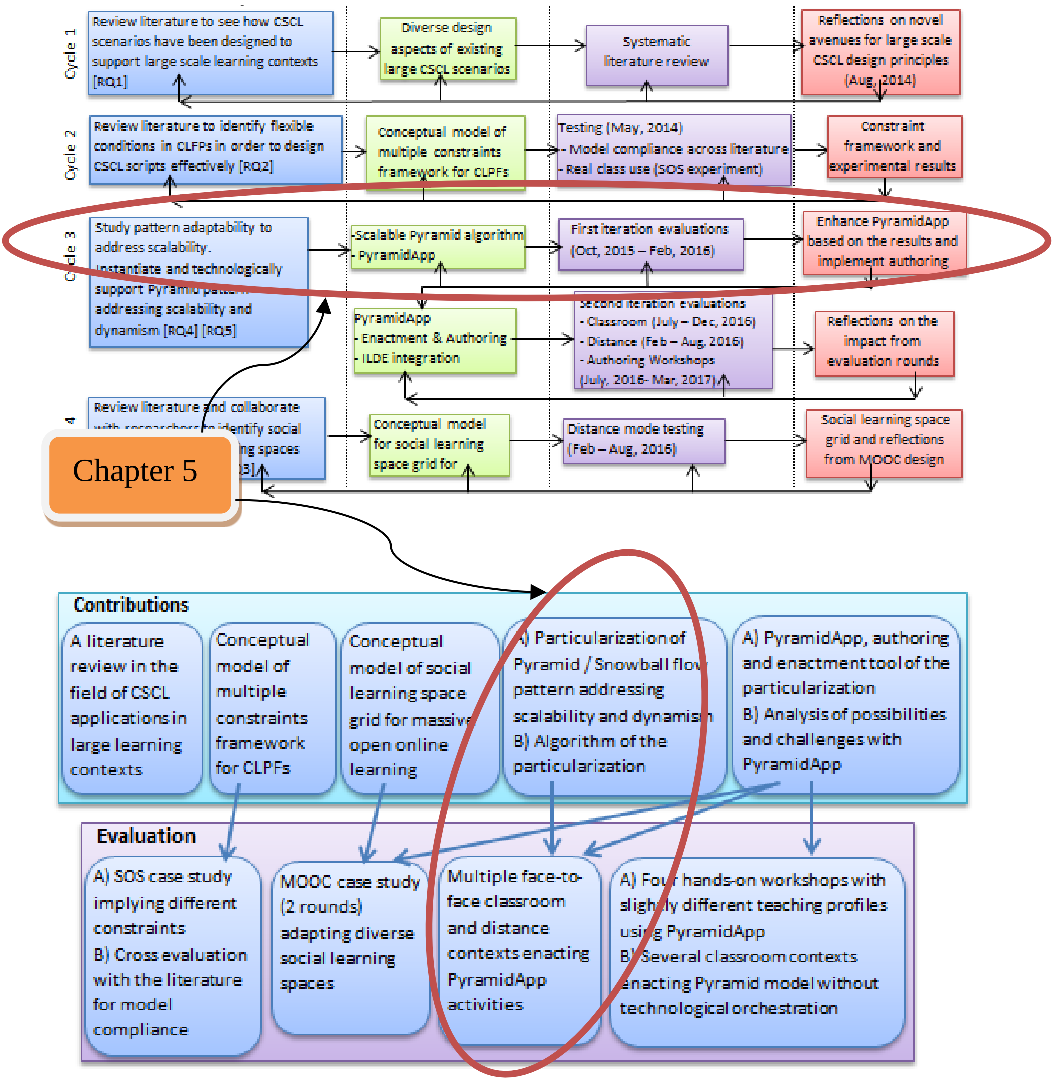

Figure 5.1: Part of the research process, contributions and evaluation studies covered by Chapter 5

PyramidApp: Scalable Method Enabling Collaboration in the Classroom

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Abstract. Computer Supported Collaborative Learning methods support fruitful social interactions using technological mediation and orchestration. However, studies indicate that most existing CSCL methods have not been applied to large classes, meaning that they may not scale well or that it is unclear to what extent or with which technological mechanisms scalability could be feasible. This paper introduces and evaluates PyramidApp, implementing a scalable pedagogical method refining Pyramid (aka Snowball) collaborative learning flow pattern. Refinements include rating and discussing to reach upon global consensus. Three different face-to-face classroom situations were used to evaluate different tasks of pyramid interactions. Experiments led to conclude that pyramids can be meaningful with around 20 participants per pyramid of 3-4 levels, with several pyramids running in parallel depending on classroom total size. Elastic and adaptive creation of multiple pyramids, control timers and flow awareness information facilitated scalability, dynamism and overall user satisfaction with the experience.

Keywords: Computer-Supported Collaborative Learning, Pyramid / Snowball Collaborative Learning Flow Pattern, Large Groups, Classroom

1 Introduction

Multiple findings from educational research highlight the importance of active learning [1]. In particular, sound collaborative learning methods foster rich social interactions between students leading to fruitful learning. Provision of technological means to support collaboration has enabled new or enhanced learning scenarios [2]. Technologies can mediate social interactions; facilitate orchestration regarding coordination requirements (e.g., group distribution); monitor interactions for regulation. Yet, despite the potential of technology, especially effective CSCL methods that favour equal and meaningful interactions between students -sometimes referred as macro-scripts [3, 4]-, have been mostly applied upon small groups of students [5].

Recently, popularity and social impact of open educational settings such as Massive Open Online Courses (MOOCs) have driven more research interest around scalable pedagogies [6,7] and urge to build up pedagogical methods based on active learning approaches [8], including those that foster social interactions [9]. Unstructured discussion through forums and social media helps [10], but its potential effectiveness is limited compared to what can be achieved by more structured CSCL approaches [3] [11]. The need for active learning in large classroom settings has been acknowledged for over three decades [12]. However, actual teaching practice in large classrooms is still broadly based on lecturing with passive participation of students. Only few remarkable initiatives have offered technological solutions to facilitate active learning in large classroom [13, 14, 15]. These solutions are focused on either supporting interactions between students and teachers through collective polls using student response systems (clickers) [13], interactions of multiple students with a single display [14], or self-organized backstage interactions between students while the teacher is lecturing [15]. However, there are no approaches that extrapolate sound macro-scripts methods that structure the collaborative learning flow for effectiveness in terms of fostering individual accountability, positive interdependence and meaningful interactions between students [3, 4].

Direct application of collaborative learning methods that work well in small groups settings is showing to be challenging in both massive virtual learning contexts and large group synchronous classes. This could mean that methods proposed do not scale well or practical aspects of a large classroom hinder a sensible implementation of CSCL methods in this context. Practical aspects include time and teachers' load limitations if learning outcomes of all groups should be measured in a large classroom [16] or implications of flexibility issues with large and varying number of students [17]. The research line addressed in this paper aims at exploring to what extent or with which technological mechanisms, scalability of relevant collaborative learning methods could be feasible. In particular, the paper studies the Pyramid (a.k.a. Snowball) method, which intuitively suggest reasonable scalability potential [18]. Pyramid method has been recognized as a good practice in collaborative learning and formulated as a Collaborative Learning Flow Pattern (Pyramid CLFP) that can be particularized and applied again and again to multiple epistemic tasks and educational levels [4]. Other examples of such CLFPs are Jigsaw or Think-Pair-Share. The collaborative learning flow proposed by Pyramid is structured in a way that students start studying given task or problem individually and proposing an initial solution. Then, individuals team up (usually pairs) to compare and discuss their proposals and, finally, proposes a new shared solution. New larger groups are formed growingly (by iteratively joining previous groups) in order to generate new agreed proposals until a global consensus is achieved. A Pyramid scenario fosters individual participation and accountability (all have the opportunity and need to express a contribution) and balanced positive interactions (opinions of all members count) in a collaborative knowledge-oriented negotiation process. The specific research question that guides this research is, how can the Pyramid flow pattern be technologically-supported to serve as a scalable method for collaboration in the classroom?

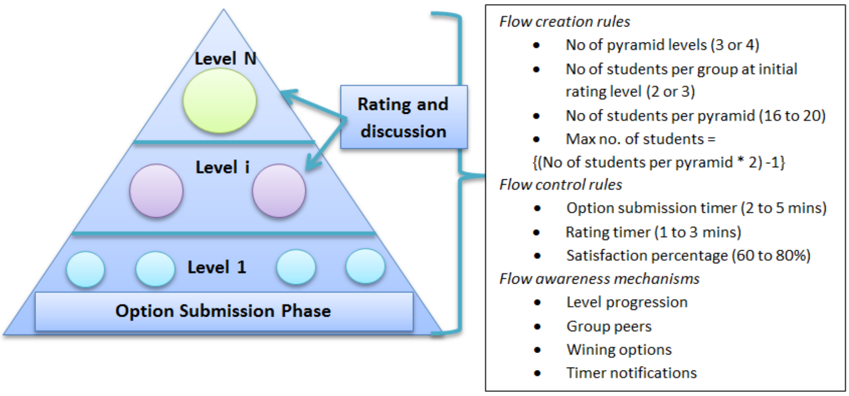
To tackle the question, we have iteratively proposed, prototyped and evaluated refinements of the Pyramid CLFP following a design based research methodology [19]. The initial refinement proposes using peer rating as an integrated consensus reaching feature accompanying discussion support. The refined method is implemented in the "PyramidApp" tool. Main challenges identified at initial iterations referred to *scalability* and *dynamism*. With *scalability* we mean the potential of the method to elastically accommodate an increase in the number of participants while maintaining pedagogical and practical effectiveness. As *dynamism* we mean the method's ability to keep activity progression while preserving enthusiasm and usability. To achieve *scalability* and *dynamism*, iterative refinements of method and prototype incorporate flow creation, flow control and flow awareness mechanisms. A first evaluation of PyramidApp in three contexts offers insights about its scalability prospects and suitability of the proposed flow mechanisms.

Remainder of this paper is structured as follows. Section 2 reveals about the PyramidApp, concepts and features with details of iterations. Section 3 explains diverse experimental settings and pyramid configurations followed by an explanation on data gathering techniques used for evaluation. Section 4 provides analysis of obtained results in these experimental settings compiled with a cross-case analysis and discussion. The paper concludes with a summary including further research directions.

2 PyramidApp

PyramidApp is a technological tool implementing a scalable method that benefits from computational mechanisms to apply Pyramid CLFP principles [18] for the enactment of collaborative learning activities with large groups of students. The main ideas behind the method are implemented as follows. Using the tool, individuals propose their option (i.e. can be a question or an answer for a given task, seeking active comprehension [20] and the application creates small groups from them. These small groups share thoughts and concerns about suggested options to clarify and negotiate before confirming ratings for the options of each member in the small group. Highly rated options are promoted to upper levels and groups grow larger (by joining previous smaller groups) following a pyramid/snowball structure. Rating and discussion propagate till the final level until the complete group of participants reach upon global consensus on the best options proposed. Everyone, including the educator, see the finally selected options to which the educator comments. In large classes, educators do not have sufficient time to comment each individual's option (questions or answers), but can attend for an agreed selection of options more feasibly. At the same time, all students have the chance to express and discuss their ideas and to critically reflect and assess peer's contributions, with potential effects in their negotiation skills and knowledge building process.

Adhering design-based research methodology [19], initial prototypical pyramid implementations were developed and evaluated using small groups (10-20) of students from first-year engineering undergraduate course. Intentions of these pre-experiment rounds were to identify potential *scalability* and *dynamism* issues and iterate options for mechanisms addressing them. After several iterative cycles of refinements and improvements of PyramidApp, Fig.1 demonstrates the current method structure with diverse parameters introduced to preserve *dynamism* while being *scalable*.



Flow creation rules

- No of pyramid levels (3 or 4)
- No of students per group at initial rating level (2 or 3)
- No of students per pyramid (16 to 20)
- Max no. of students = {(No of students per pyramid * 2) -1}

Flow control rules

- Option submission timer (2 to 5 mins)
- Rating timer (1 to 3 mins)
- Satisfaction percentage (60 to 80%)

Flow awareness mechanisms

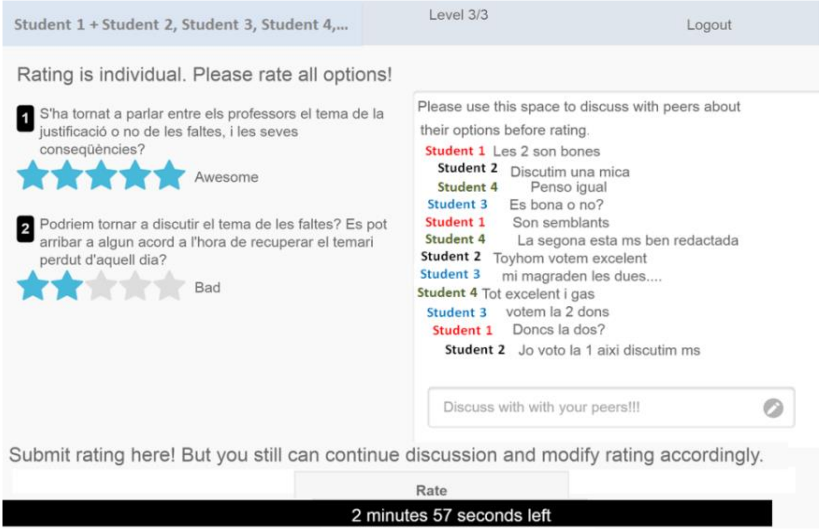
- Level progression
- Group peers
- Wining options
- Timer notifications

Fig. 1. Schema of PyramidApp structure with parameters for flow creation rules, flow control rules and flow awareness mechanisms

Flow creation rules allow *scalability* by automatically adapting the pyramid structure based on the number of joining participants providing an elastic mechanism of multiple pyramid creation. Flow creation rules include defining number of pyramid levels and initial rating level group size, considering a desired size for a pyramid and, when it is exceeded, triggering the creation of another Pyramid flow running in parallel. If there is not enough participants to build a desired-size new pyramid, existing pyramids are increased in size up to a maximum (which is up to an almost double sized of what is desired). *Flow control rules* are proposed to benefit *dynamism*. These rules prevent potential blocking effects in flow progression if participants leave the pyramid activity (for whatever reason: unexpected situation, technological problem, etc.). The rules include a satisfaction percentage stating expected rating completions per group and timers affecting pyramid progression. Once the satisfaction percentage of expected ratings is reached within a group, the rating timer is activated waiting for potential additional ratings during a timeout that, when reached, automatically triggers the start of the next pyramid level. Similarly, during initial option submission, a timer is triggered once the satisfaction percentage is reached per group to accept any more potential option submissions before initiating rating. Parameters in rules are presented in Fig.1 with recommended values that are configurable by the educator if preferred. They were estimated in the aforementioned initial evaluations. For example, it was observed that when number of level increases participants absolve enthusiasm, longer timing values lead to boredom, very high satisfaction percentages may froze pyramid branches or lead higher waiting time when progressing from one level to another.

Moreover, *flow awareness* mechanisms are proposed to elevate learner engagement and usability. These mechanisms are in charge of providing participants with information about progression along the Pyramid flow regarding level, group members, timing notifications and selected options. Fig. 2 illustrates a sample user-interface at a rating stage from PyramidApp student view. Interface consists of group peers indicated on the top left corner, the current pyramid level and total available levels, instructions for rating and discussion space and options to rate with a minimalistic learning curve for students. The timer notification is shown to students who had not finished discussions and rating, indicating available time before next pyramid level and this denotes that the satisfaction percentage has been reached (most group members have already submitted ratings) and a timer is activated.

PyramidApp has evolutionary life cycle adapted from design-based research methodology resulting several iterations of the tool with divergent versions and evaluation cycles. The evaluations presented in this paper use the current version described in this section (we will call it version 2, V2) and a previous intermediate version (that we will call V1). PyramidApp V1 majorly differs from V2, with incorporation of discussion feature facilitating reasoning and negotiation.



Rating is individual. Please rate all options!

1 S'ha tornat a parlar entre els professors el tema de la justificació o no de les faltes, i les seves conseqüències?

2 Podriem tornar a discutir el tema de les faltes? Es pot arribar a algun acord a l'hora de recuperar el temari perdut d'aquell dia?

Please use this space to discuss with peers about their options before rating.

Student 1 Les 2 son bones
Student 2 Discutim una mica
Student 4 Penso igual
Student 3 Es bona o no?
Student 1 Son semblants
Student 4 La segona esta ms ben redactada
Student 2 Toyhom votem excelent
Student 3 mi magraden les dues....
Student 4 Tot excelent i gas
Student 3 votem la 2 dons
Student 1 Doncs la dos?
Student 2 Jo voto la 1 aixi discutim ms

Submit rating here! But you still can continue discussion and modify rating accordingly.

2 minutes 57 seconds left

Fig. 2. PyramidApp student rating view with discussion window (Web tool designed to be used in mobile phones, tablets or personal computers)

3 Evaluation Methodology

Evaluation methodology is planned to study if the proposed method and its technological implementation serve as a scalable method for collaboration in the classroom. We will evaluate whether PyramidApp's rules and mechanisms offer *scalability* potential (ability to accommodate an increase in the number of participants) and preserve *dynamism* (ability to keep activity progression) while maintaining pedagogical and practical effectiveness and preserving enthusiasm and usability. The evaluation also seeks understanding about which configurations of the method (values for parameters in rules, use or not of discussion feature) achieve satisfactory scalability, dynamism and overall impact.

Experiments are conducted in authentic settings, using actual students' classrooms and their teachers being in charge of proposing the epistemic tasks to work along Pyramid flows. This provides ecological validity but contextual factors may affect results. This limitation is considered in a cross-analysis of results between runs of Pyramid flows and contexts. This section explains the characteristics of experimental settings, applied pyramid configuration parameters with values, and data gathering techniques used.

3.1 Experimental settings

Three different experimental settings were used. Within each experimental setting that used PyramidApp V2, we conducted several activity rounds deliberately enabling and disabling chat feature to compare behaviours. Across all experimental settings, 80% satisfaction percentage was maintained. Before starting pyramid activities in every experimental setting, researchers delivered an introduction to PyramidApp and the activity flow.

Experimental setting 1: Higher education - 45 undergraduate students, from two courses, participated in the PyramidApp V1 experiments in which discussion feature was not available. 23 students were from 3rd year course of Distributed Applications Development and their task was to look at a case (software code used in a problem of a previous-year exam) and propose a question that they think was asked during that year exam. 22 students were from a 1st year engineering introductory course in which students have to make oral presentations of small projects. Students acting as audience (two groups, one with 9 students and another one with 13) had to propose and agree on questions for presenters using PyramidApp. Mainly they used smart phones and few of them used laptops too.

Experimental setting 2: Secondary school - The student sample consisted of three classrooms from secondary school students (11-12 years old) taking a course on Information and Communication Technologies. Classroom 1 had 21 students; classroom 2 had 20 students and classroom 3 had only 10 students due to an unexpected reason (some students had to attend another school activity). They had already learnt about “Scratch” and “HTML” concepts and the teacher asked them to propose questions from these two topics in all three different groups of students. Students were using desktop computers in the school computer lab. Two collaborative activity rounds per classroom were enforced using PyramidApp V2 and also the activity rounds varied based on enabling/disabling chat discussions.

Experimental setting 3: Vocational training - This sample had 43 students (age >= 16) from a vocational training centre on agricultural matters. Teachers were interested in three Pyramid flows (rounds) requesting students to contribute with questions and suggestions regarding their overall training; questions about future career opportunities; questions about curriculum, exams or projects; suggestions of outdoor activity or a sport preferred. In the first round of PyramidApp the discussion feature was not presented whereas in the other two rounds it was enabled. Latest PyramidApp version (V2) was used for the experiment and participants used smart phones.

Table 1 shows the pyramid configuration parameters and respective values used across three experimental settings.

Table 1. Pyramid configurations across three experimental settings

Experimental setting		Pyramid configurations	Values	Discussion
Higher education setting	Classroom of 3rd year students (N=23) (1 round)	No of levels	4	Not available
		Students per group in second level	2	
		Question submission timeout	3 mins	
		Rating timeout	2 mins	
	Classroom of 1st year students, two groups (N=22) (8 rounds)	No of levels	3 or 4	Not available
		Students per group in second level	2	
		Question submission timeout	2 mins	
		Rating timeout	1 min	
Secondary school setting	Classroom 1 (N=21) (2 rounds)	No of levels	4	Enabled
		Students per group in second level	2	
		Question submission timeout	3 mins	
		Rating timeout	2 mins	
	Classroom 2 (N=20) (2 rounds)	No of levels	4	Disabled
		Students per group in second level	2	
		Question submission timeout	3 mins	
		Rating timeout	2 mins	
	Classroom 3 (N=10) (2 rounds)	No of levels	3	Round1-enabled Round2-disabled
		Students per group in second level	2	
		Question submission timeout	3 mins	
		Rating timeout	2 mins	
Vocational training setting	N=43 (3 rounds)	No of levels	4	Round1-disabled Round2-enabled Round3-eanbled
		Students per group in second level	3	
		No of pyramids	2	
		Question submission timeout	3 mins	
		Rating timeout	2 mins	

3.2 Data gathering techniques

A mixed mode of data gathering instruments was used to achieve a comprehensive quantitative analysis enriched with qualitative data also. Essentially, quantitative data was collected to test potential *scalability* and *dynamism*. Qualitative data was triangulated with quantitative results to understand if scalability and dynamism is achieved maintaining pedagogical and practical effectiveness while preserving reasonable enthusiasm and usability. Table 2 indicates various data collected for each setting. Log files include activity details such as flow creation values for respective group, pyramid groups formed, options submitted and other related data such as rating timings. Logs were used to calculate complete activity durations, average time taken to perform ratings (discussion enabled/disabled) and to identify more time consuming stages in the Pyramid flow. All experiments were observed by at least one researcher during activity enactment and noted down participants' reactions when interacting with the tool and any emerging issue. Both students and teachers were asked about satisfaction, preferences and opinion about the experience and the tool. The level of details asked from students depended on the time available in each experimental context, using a more condensed approach in some cases (less but holistic questions, e.g., "did you find the interface easy to understand?") and more detailed questions in others (including: preferences for rating peer's questions, chat feature, viewing discussions or finally selected options, pyramid progression and opinions about timer values). In the secondary school setting, it was also possible to have a collective discussion about the experience at the end of the experiment. Teachers were asked about quality of finally selected options and their opinion about overall activity experience.

Table 2. Different data gathering mechanisms in three experimental settings

Data gathering instruments	Higher education	Secondary school	Vocational training
Log files	✓	✓	✓
Observations (no of researchers)	✓ (1)	✓ (1)	✓ (2)
Questionnaire for students	✓ (general/holistic questions)	✓ (general/holistic questions plus a collective discussion in class)	✓ (detailed questions about tool features, experience and outcomes)
Questionnaire for teachers	✓	✓	✓

4 Results

4.1 Higher education setting

Main objectives of this experimental setting and PyramidApp V1 were mostly to recognize appropriate values for flow controls (timers and satisfaction percentage), to understand usability of the proposed student interface and potential utilization of mobile devices to enact pyramid activity in an intermediate iteration. Following the configuration mentioned in Table 1, 3rd year students group consumed 22 minutes to complete the activity since there was a technical fault in the app once the pyramid was initiated. Though they consumed only 5 minutes to finish 2 levels of rating, the whole pyramid consumed more time than expected. More than 90% of the group rated tool interface very user-friendly and one student had commented that it would be better if some communication mechanism is enabled to discuss with peers before rating while another two had mentioned that the application was simple, easy to use and it can be greatly beneficial. The educator stated that students seemed deeply engaged looking at the code to which they should propose questions and finally selected questions were relevant and comprehensive, yet better questions could be possible as some of those had been discarded in the process.

Fig. 3 depicts various timing aspects consumed at each stage in the pyramid activity process by the 1st year student groups (4 rounds of Pyramid flows with each group). On average it took around 3-4 minutes to rate in 3 levels consuming 8-9 minutes in total to do a complete pyramid activity with 10-12 student groups without facilitating discussions. Pyramid flows were not frozen or interrupted thanks to flow control mechanisms (satisfaction percentage and timers, which expired 5 times in total) maintaining *dynamism* and flow creation rules enabling a *scalable* addition of late-comers (there was one late login in one of the rounds) to the pyramid. According to the educator, activity expended bit more time than expected (especially in the round that took over 10 minutes), but functioned well under considerable limits of time. In contrast to other academic years (when only few volunteers posed questions) all students were actively thinking and proposing questions. Resulting questions were relevant, yet sometimes less comprehensively articulated when compared. At some rounds equally important and relevant questions had been eliminated during the process. Some students stated that the activity was easy, fast and funny voting peer's questions. Another had said, "I like the utility and anonymous condition provided to ask a question".

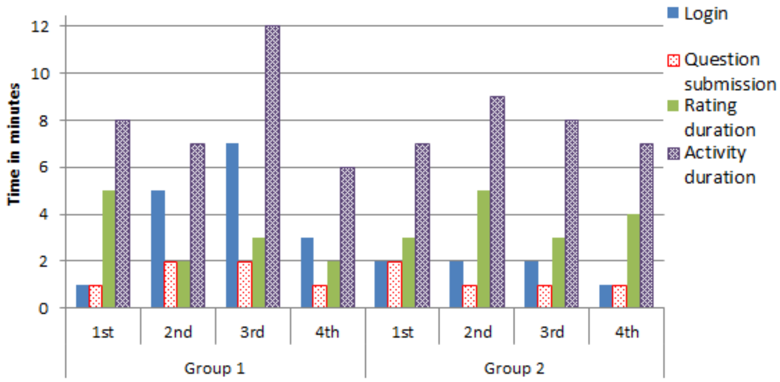


Fig. 3.Time consumptions in pyramid stages in each round with undergraduate first year groups

4.2 Secondary school setting

The second experimental setting used PyramidApp V2 with discussion feature embedded apart from peer-rating. For all cases, students participated very enthusiastically, enjoyed seeing their peers and talking not only using the chat but also making some noisy environment inside the classroom where teacher had to interfere to control the situation. In the pyramid rounds in which discussion chat was enabled, an extensive usage of chat was observed, but mostly with "off-topic" conversations like greetings ("hi","hello") or meaningless words. Flow control mechanisms (timers and satisfaction percentage) allowed smooth Pyramid flows irrespective of multiple timer expirations observed during enactment maintaining *dynamism*. Flow creation rules adhered (see Table 1) were efficiently appropriate accommodating late accessing students permitting *scalability*. Fig. 4 illustrates time consumptions for each pyramid round including variations and total number of participants for vital phases. A significant time difference between enabling or disabling chat within similarly featured samples (classroom 1 & 2) for the same number of pyramid levels is evident. Discussions had occupied students and had delayed rating phase affecting overall activity performance time in classroom 1. When the number of levels is reduced (3 pyramid levels in case of classroom 3, see Table 1), time spent is reduced and chat enabling or disabling does not contribute adversely in terms of complete activity duration. However, a shorter question submission time in classroom 3 and that there were less off-topic utterances in their discussions suggest that contextual aspects observed in classroom 1 (less relaxed atmosphere) could have an effect in dynamism.

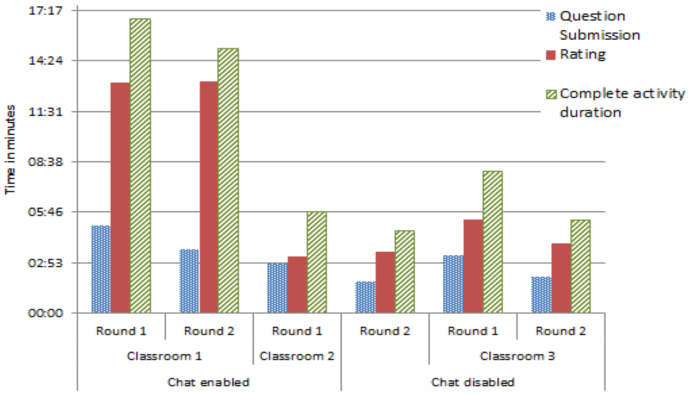


Fig. 4.Time comparisons for pyramid steps among secondary school student classrooms

More than 95% had stated that the application is easily usable whereas none had mentioned it was very difficult. At the end of the experiment, the researcher posted some reflective questions for students like “Did you enjoy the activity?”, “What features they preferred” as collective discussions and some answers were, “It’s good because you get specific answers by teacher”, “You can learn, at the same time voting other peer’s questions”, “You don’t know who posted which question, so rating is not biased”. In classroom 3, students were not happy for disabling discussion in the 2nd round as they said that they prefer chat, so they can talk with peers what to rate. This contrasts with opinions in classroom 1, where few students complained that others were not taking discussion in chat seriously. Though the chat was not presented for classroom 2, most of them had stated that the tool is exciting, funny and they enjoyed. One student had suggested including a responding button, so they can answer peer’s questions and share with the community. Teacher had mentioned that the selected choices were appropriate since those show students’ interests/concerns and also connected to subject concepts. But he was not happy of enabling chat after seeing kids’ behaviour in classroom 1 and proposed to consider its usage depending on audience / classroom atmosphere. Nevertheless, he stated that he finds the tool useful as it allows him to discuss with the students more concrete and relevant questions rose by them.

4.3 Vocational training setting

PyramidApp V2 was used and flow creation rules were enabled to create multiple pyramids if desired size of pyramid exceeds using the formula given in Fig.1. Students were instructed to use smartphones to engage in three pyramid rounds but faced few practical problems such as poor network connections or slow (or no) data connection resulting some students dropping from activity with complaints regarding infrastructure. PyramidApp usability was 86.05% and 83.72% had enjoyed overall experience whereas 14% was neutral in their opinion. 34.88% confirmed that they were satisfied with finally selected options while similar amount was not sure about their opinion and the remaining 30.23% mentioned that they were very dissatisfied. Students' questionnaire results related with tool features are presented in Fig.5.

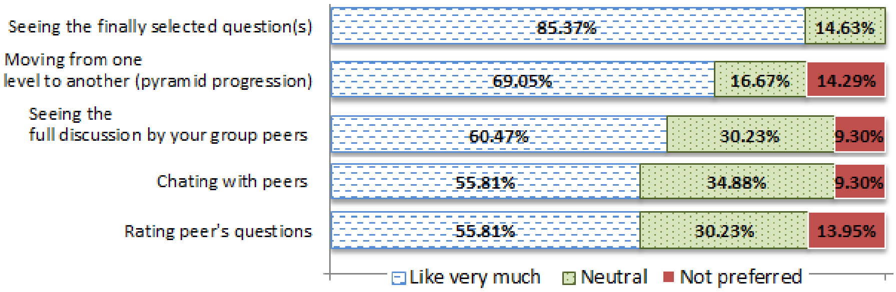


Fig. 5. Acceptance percentages of PyramidApp features

Enabling chat was not highly appreciated, only 55.81% preferred while 34.88% were neutral notably. The second highest voted (69.05%) feature is pyramid progression, moving from one level to another facilitating gaming effect to the activity. Fig. 6 shows time consumptions at diverse activity phases. Though round 2 and 3 had discussions enabled, no significant time difference was noted opposed to round 1.

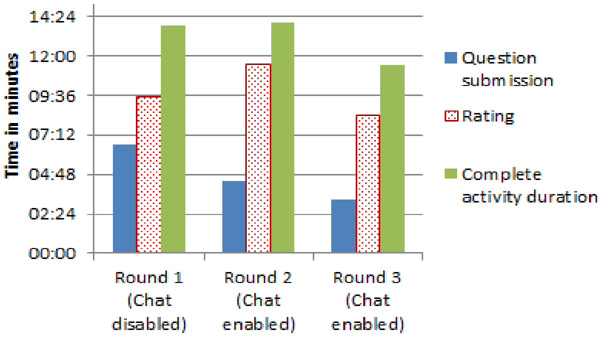


Fig. 6. Time comparisons across pyramid rounds at vocational training centre student groups

When participants were asked whether they had adequate time to discuss and rate, 83.72% stated "yes" and only 13.95% said "not enough". 67.44% participants had agreed that the waiting time between pyramid levels was too long and 32.56% refuted it. This waiting time could be attributed to the fact of having poor network connections too. Having four pyramid levels (three devoted to rating) may have also contributed to this perception. Few had suggested that it would be nice if they could participate in chat even after rating while waiting for the next level. Table 3 shows structural elasticity of the tool ensuring *scalability*, as it is capable to create several Pyramid flows considering flow creation rules (desired size for pyramid) and actual (growing) number of participants managing late comers.

Table 3. Pyramid activity summary of three rounds

Structural aspects (2 pyramids created)	Round 1	Round 2	Round 3
Original pyramid sizes	20 & 16	20 & 16	20 & 16
Final pyramid sizes	20 & 19	20 & 27	20 & 22

Nevertheless of the higher percentage for activity satisfaction, students had indicated that they were not satisfied with every finally selected option from the collective classroom. The type of task proposed (quite open and not related to a particular subject / course) led to some students to not to take the activity seriously and proposed inappropriate options. Several suggested inclusion of a filtering option for teachers/students when inappropriate options are identified. Engagement in discussion rounds was limited. Educators recognized finally selected options were not as relevant as others proposed along the flow and were interested in having the complete log of questions and suggestions by students. However, they appreciated the potential of the method for subject-oriented scenarios in which students are more committed.

4.4 Discussion cross-analysing results

A cross-analysis of results between runs of Pyramid flows and experimental settings offers first evidence regarding to what extent and in which configurations, PyramidApp provides a scalable method for collaboration in the classroom. The proposed refinement of the Pyramid pattern with individual contributions and gradual peer rating, following flow creation and control rules, accommodates well groups of up to 20 students in a single whole pyramid. The proposed method and its implementation offer an arguably interesting scalability prospect. Several pyramids can be created to run parallely in larger classrooms (two pyramids in the vocational training setting) and late comers can be included. Each Pyramid flow results on one single outcome that can be commented by the educator in the collective classroom. A really large classroom of, for example 100 students, will lead to five outcomes, which can be feasibly addressed (commented, answered, assessed) by the teacher. Pyramids of 3 or 4 levels are shown to maintain satisfactory engagement. Flow control rules (timers and satisfaction percentage) facilitated dynamism by preserving activity progression. Depending on the context, a pyramid activity can take between 5 to 16 minutes. The effect of using discussion feature in terms of time required is unclear and its convenient application depends on context. Relevant learning scenarios (e.g., cases analysed in the higher education setting) can be implemented without use of the discussion feature. Overall, as with any pedagogical method, pedagogical effectiveness also depended on context (e.g., classroom atmosphere) and proposed epistemic tasks (e.g., requiring or not active comprehension). Together with the achieved dynamism, flow awareness mechanisms contributed to preserve enthusiasm and usability. Viewing winning options, rating peers and levelling up denoting pyramid progression offered a gaming effect that was perceived with satisfaction across all experimental settings.

5 Conclusion

Diverse educational contexts raise requirements for active pedagogical methods that can be applied with a large number of participants using reasonable time. Time and other practical limitations are important factors that hinder application of active methods, such as collaborative learning, with large groups of students. In the paper we have identified scalability and dynamism as the key requirements to be addressed by those methods and their technology-supported implementations. These requirements call for methods that are able to accommodate an increase in the number of participants and to keep up a flexible activity progression, while maintaining pedagogical meaningfulness, learners' engagement and practical fitness. We have studied the use of a refined implementation of the Pyramid flow pattern. To address scalability and dynamism, the technological solution implemented is PyramidApp tool, which incorporates flow creation rules, flow control rules and flow awareness mechanisms. Results suggest suitability of the mechanisms behind the method and open new perspectives that are worth further exploring with other epistemic tasks, contexts, larger classroom settings and other challenging settings such as massive online courses.

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Chapter 6

Authoring and Enactment of Mobile Pyramid-based Collaborative Learning Activities

As illustrated in Figure 6.1, this chapter work is related to the second major iteration of cycle 3, following Design Based Research methodology (Amiel & Reeves, 2008). With related to [RQ5] from section 1.3 in Chapter 1, this chapter expresses the main contributions and further evaluation studies. ILDE (Hernández-Leo et al., 2014) integrated PyramidApp is explained with more details about both enactment and authoring systems. Three algorithm mechanisms (flow creation rules, flow control rules and flow awareness rules) are explained in the chapter, but a detailed description about these rules can be found in Appendix B. With the insights gained from the first iteration of cycle 3 (see previous chapter), PyramidApp was improved with many major changes. The improved version of PyramidApp enactment system was exhaustively evaluated across diverse settings using different epistemic tasks both in face-to-face classrooms and distance mode. Appendix C shows further information and analysis about these individual experiments. This chapter contains a cross-analysis of the experiments to answer how the perceived enjoyment of the activity across diverse educational levels, epistemic tasks and mode of the application. Moreover, few studies were carried out following the PyramidApp model without the application in classrooms and the results of these are provided in Appendix C. Finally, PyramidApp authoring system has been evaluated for its expectations and efficiency across hands-on workshops with practitioners from different educational settings. Part of this analysis is reported within this chapter and more details can be found in Appendix C. This chapter has been prepared to be submitted for a JCR indexed, peer-reviewed journal which is still under review process at the time of thesis submission.

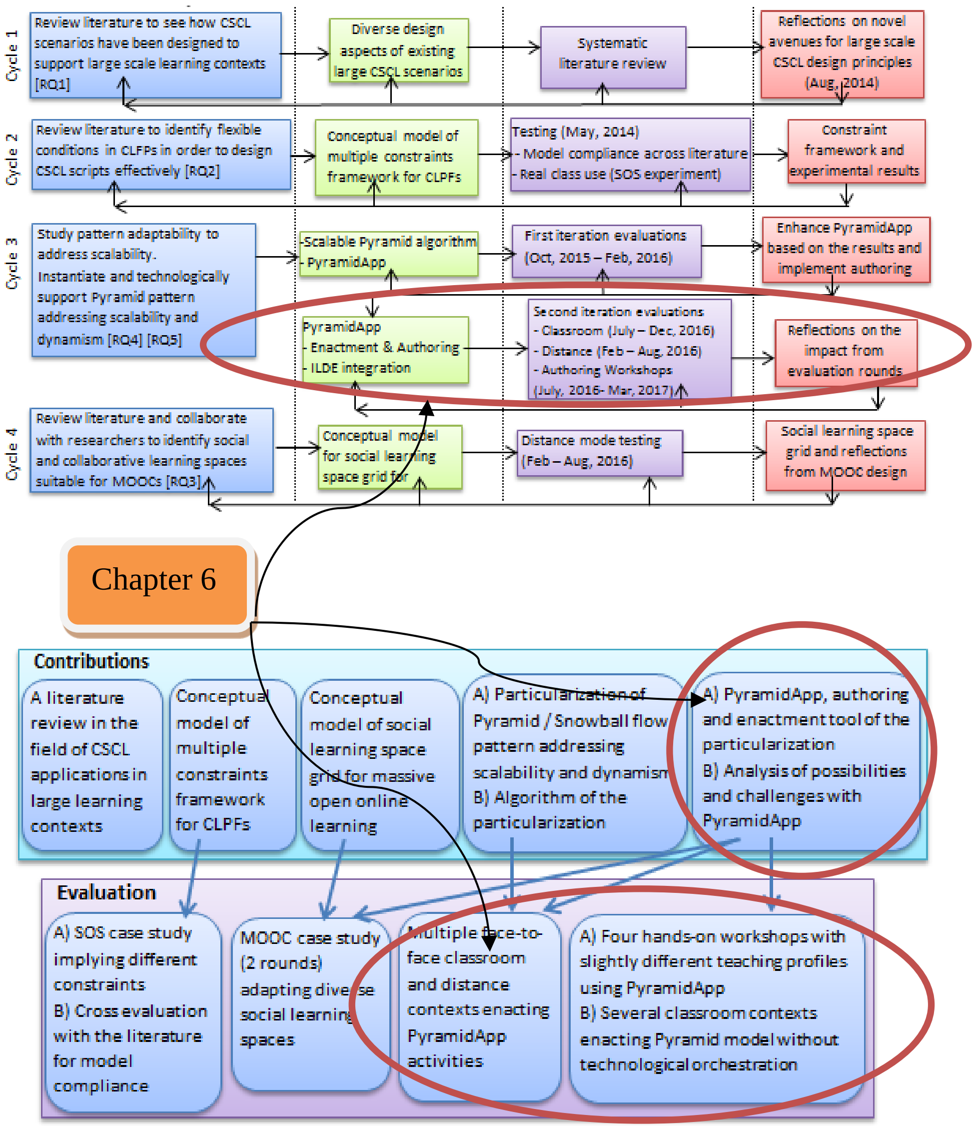


Figure 6.1: Part of the research process, contributions and evaluation studies covered by Chapter 6

Authoring and Enactment of Mobile Pyramid-based Collaborative Learning Activities

Kalpani Manathunga, Davinia Hernàndez-Leo

Abstract

Collaborative Learning Flow Patterns (CLFPs) formulate best practices for the orchestration of activity sequences and collaboration mechanisms (e.g., dynamic group formation, distribution of resources) that can elicit fruitful social interactions. Mobile technology features offer opportunities to support interaction mediation and content accessibility in educational scenarios. However, existing mobile collaborative learning research has mostly focused on simple activity orchestrations from the perspective of collaborative flow orchestration and flexibility requirements, predominantly in face-to-face pre-university educational contexts. This paper proposes a particularization of the Pyramid CLFP to support flexible face-to-face and distance mobile learning scenarios in which learners interact in increasingly larger groups along a sequence of activities (pyramid levels). PyramidApp implements this Pyramid CLFP particularization that provides both a web-based authoring tool and an enactment tool accessible through web or mobile devices. The authoring tool was evaluated in workshops where teachers appreciated the design of the authoring tool and the applicability of PyramidApp to their educational contexts. PyramidApp flows were enacted in three higher educational settings, mostly using mobile devices. Learners enjoyed the activities but usage and satisfaction varied depending on several factors like the epistemic tasks given, the education level and application mode (face-to-face in-class or distance).

Keywords

Collaborative Learning, Pyramid, Mobile Learning, Authoring, Enactment

Introduction

Collaborative learning scenarios can be designed to trigger desired social interactions that can lead to learning benefits (Dillenbourg et al., 2009). As mobile devices become part of everyday life (Kukulska-Hulme & Sharples, 2009; Sharples & Pea, 2014), various research have shown possibilities of mobile technologies to impact learning (Lai & Wu, 2006; Sharples & Pea, 2014; Sharples & Roschelle, 2010; Zurita & Nussbaum, 2004) and also to support learning activity design (Jaldemark & Lindberg, 2014; Zurita & Nussbaum, 2007). Most mobile devices available are not designed specifically for learning, instead for personal information management or communication. How such devices can be utilized in collaborative learning while supporting interaction mediation in formal educational contexts is underexplored (Hsu & Ching, 2013; Kukulska-Hulme & Traxler, 2005). More specifically, authors study challenging collaborative orchestrations incorporating dynamic circumstances in a real learning scenario. A flexible collaborative learning approach is proposed and evaluated in this paper that supports authoring and implementing structured learning designs where learner interactions can either be mediated via mobiles or other desktop devices.

Computer Supported Collaborative Learning (CSCL**)** promotes technology mediated peer interactions to result in fruitful learning experiences (Dillenbourg et al., 2009). A key purpose of CSCL environments is not only to mediate remote collaborations, but also to create conditions of collaborations and regulate or shape up group interactions (Dillenbourg et al., 2009). Mobile CSCL (mCSCL) is the notion of adding the mobility feature to collaborative learning with handheld devices (Zurita & Nussbaum, 2007). Mobile learning merges flexibly into contexts where teachers orchestrate learning activities, trigger and monitor activity progress while participants access content or enact upon mediation by mobile devices (Sharples & Pea, 2014). Many studies in the literature had exploited the feature of mobility for education successfully using mobile devices (Sharples & Roschelle, 2010). Yet, how collaborative applications can be extrapolated to suit distance, face-to-face or blended scenarios need to be studied further (Jaldemark & Lindberg, 2014). In the literature of mCSCL, many studies had experimented upon K-12 settings and there exists a need to study the impact of mobiles on collaborative learning in different levels of higher education where mobile technologies play significant roles in students’ daily lives (Hsu & Ching, 2013; Lindell, Hrastinski, & Inga-Britt, 2015).

Mobile devices can be utilized as means of coordination for negotiation substituting or complementing face-to-face communication (Naismith et al., 2004). Different studies reveal approaches to intersect mobile learning and collaborative learning in formal education contexts. Handheld devices were used by young students to solve mathematical tasks in groups to achieve a common goal and collaborative scaffolding like suggesting peers for groups and teacher facilitation was provided in a mobile application (Boticki, Looi, & Wong, 2011). In another study, wirelessly intercommunicated handhelds were used in maths and language learning addressing challenges in coordination, negotiation, organization of materials and lack of mobility that exist in a non-technology supported collaborative environment (Zurita & Nussbaum, 2004). Students in a nursing school used PDAs as supporting tools to share concept maps in a Jigsaw collaborative learning activity and the study showed positive results in learner perception of using mobile handhelds (Lai & Wu, 2006). These studies exploit face-to-face mobile collaborations in particular activities that are parts of longer activity flows which are not fully supported by the mobile devices; hence those do not facilitate complex orchestrations. Challenge exists when dynamic modifications are required in a pre-created collaborative activity design (Dillenbourg et al., 2009; Hernández-Leo et al., 2006) due to unexpected situations like increase or decrease of activity participants or frequent disconnections of mobile devices. Hence, it is required to study how orchestration can be facilitated in a mCSCL environment where dynamic flow changes are expected.

In CSCL, collaboration scripts are used to define and orchestrate expected collaborations in pedagogical scenarios by defining the activity sequence and assigning roles (Dillenbourg et al., 2009). Collaborative Learning Flow Patterns (CLFP) capture the essence of well-known collaboration scripts to produce effective interactions (Hernández-Leo et al., 2006) by orchestrating diverse aspects such as group formation, role allocation and rotation, resource distribution, etc. Some examples of CLFPs are Jigsaw, Pyramid, Think-Pair-Share. Pyramid method (a.k.a. Snowball) has been recognized as good practice in collaborative learning that can be particularized and applied iteratively to multiple epistemic tasks and educational levels (Davis, 2002; Hernández-Leo et al., 2006). This paper presents a prospective viewpoint of Pyramid flow pattern particularized for their application to learning scenarios supported by mobile devices. A Pyramid flow is initiated by students attending a given task individually and proposing solutions. Then these proposals are discussed in small groups and agreed upon a common proposal. Such small groups then form larger-groups iteratively and discussions in larger groups will continue till a consensus is reached upon at the global level. Pyramid flows foster individual participation, accountability and balanced positive interdependence (Hernández-Leo et al., 2006). PyramidApp is a technological implementation of a particularization of the Pyramid CLFP in which learners propose solutions to a task, discuss and rate the solutions in increasingly larger groups. PyramidApp provides an authoring tool for teachers to design Pyramid flows and an enactment tool for students to participate. The Pyramid model behind PyramidApp and a preliminary version of enactment tool was evaluated in (Manathunga & Hernández-Leo, 2016). Preliminary results showed that important challenges identified in collaboration scripts, such as dynamism (flexibility to modify pre-created scripts while maintaining effectiveness) and scalability (ability to cope with growing numbers of students), are addressed successfully with PyramidApp. This paper presents the authoring tool of PyramidApp and a revised version of the enactment tool. The specific research question that guides this study is how feasible and usable it is to create flexible Pyramid flows using PyramidApp authoring tool and how learners perceive such activities across different types of epistemic tasks, different educational levels in Higher Education and in different application modes (face-to-face in-class or distance).

In the next section of this paper, a detailed overview about the PyramidApp is provided starting from the authoring functionality along with the underlying algorithm. In the same section, PyramidApp activity enactment functionality is described. The third and fourth sections reveal about several experiments conducted using three different populations and acquired results followed by discussions with an emphasis on the highlighted research questions above. Finally the article is concluded with a summarized discussion proceeded by future research directions along the line.

PyramidApp – Authoring and Enactment

The structured cumulative collaborative activities promoted by Pyramid Collaborative Flow Pattern inspired the model behind the conception of PyramidApp, which is a web-based scalable, dynamic collaborative learning application, integrated within the Integrated Learning Design Environment (ILDE) (Hernández-Leo et al., 2013). Design of potentially effective collaborative learning activities should consider offering students opportunities for individual explanation, group argumentation/negotiation and mutual regulation (Dillenbourg et al., 2009; Hernández-Leo et al., 2006; Zurita & Nussbaum, 2007). In PyramidApp these dimensions are addressed by orchestrating activities in which participants can express their individual solutions to a task followed by cumulative negotiations in increasingly larger groups (pyramid levels) to select the most appropriate solution. The orchestration is done automatically considering the pedagogical constraints of the CLFP and a set of mechanisms that achieve flexibility in terms of flow “dynamism” and “scalability”. PyramidApp has two components: the Pyramid flow authoring (i.e., design and monitoring component for teachers to create and observe on-going or previously finished activities) and the Pyramid activity enactment for learners to engage with the activity. The application was designed and evaluated by following design-based research methodology (Amiel & Reeves, 2008). Initial findings of a preliminary iteration are briefly described in (Manathunga & Hernández-Leo, 2016).

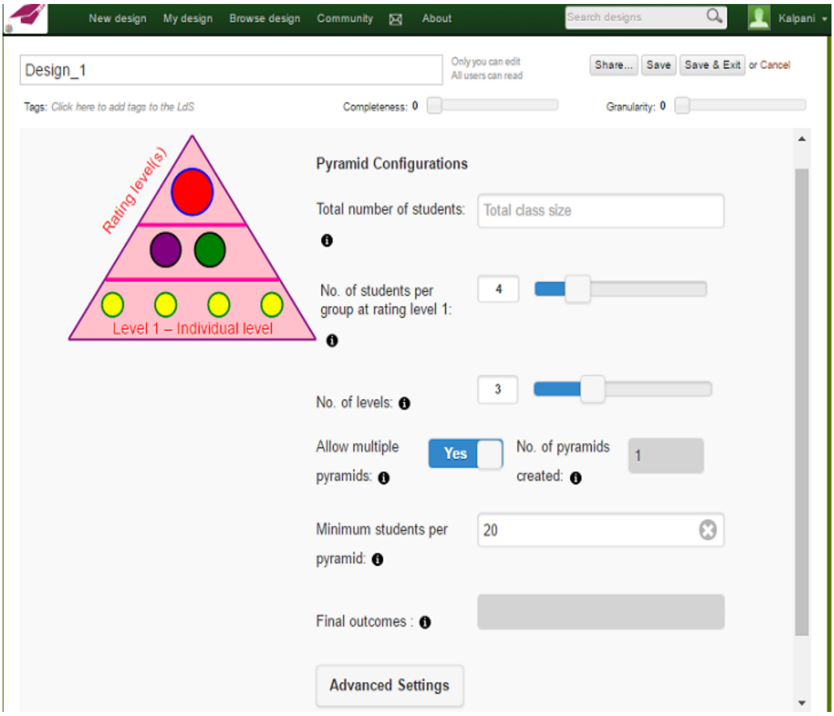
Pyramid flow authoring

Pyramid activity flow creation interface is used to input activity details such as task, activity mode (either face-to-face or distance), enable or disable chat feature and other important parameters affecting the pyramid algorithm to formulate pedagogically meaningful and flexible activity flow. The algorithm uses three types of rules and parameters;

- Flow creation rules are used to configure the size of the pyramid and groupings in each pyramid level. Parameters used are number of pyramid levels (2..n), students per group at rating level 1, number of students per pyramid, maximum number of students per pyramid calculated as (students per pyramid *2) -1
- Flow control rules are used to orchestrate flow progression along pyramid levels. Parameters used are time limit for option submission, time limit for rating and discussion, percentage of minimum active users before triggering timer notifications
- Flow awareness rules are used to trigger signals of flow status. Parameters used are level progression, group peers, timer notifications, email notifications for distance mode, options submitted by the other groups in the waiting screen, finally selected most popular options

These flow creation, control and awareness rules contribute to maintain “dynamism” and “scalability” in a tool-supported orchestration of the Pyramid CLFP. Scalability is the capability of elastically accommodating growing numbers of activity participants while maintaining pedagogical and practical effectiveness. Dynamism means the ability to keep activity progression while preserving enthusiasm and usability. Flow control rules are applied to achieve dynamism while flow creation affects scalability. Using the total class size and the amount of participants accessing the PyramidApp enactment tool as inputs, the algorithm is capable of creating multiple pyramids to accommodate the actual crowd. Therefore, number of students per pyramid and maximum number of students allowed to a pyramid are contributing to achieve scalability. Number of levels, two time limits (initial option submission and rating time limit) and active user percentage help to maintain dynamism of the activity without freezing pyramid branches in case participants are not active for whatever reason (e.g., they need to leave, they are late to participate or their device batteries are exhausted). Flow awareness rules are useful to elevate learner engagement and usability of the application.

Fig.1 depicts PyramidApp authoring tool view. In the activity design component an animated illustration of Pyramid flow is visible depicting how a pyramid progresses for novices to be familiarized. Level 1 is the individual option submission phase where activity participants attempt the given task individually. Level 2 onwards are the collaborative steps, where participants are grouped iteratively generating accumulated interactions among groups to enrich the collaborative learning experience. In groups, they discuss/negotiate and rate option(s) to put forward a collective suggestion from the group to be levelled up. Therefore, each participant has the opportunity to participate (solving the task, rating and discussing) and to see multiple solutions to the tasks from their peers. Authors have to specify required parameter values to design the desired pyramid progression using the PyramidApp authoring user interface (Fig.1). Most of the parameter fields are presented with default set of values as configurations which the designers are free to modify based on their requirements. Further description about each field is available as a tooltip (see “i” icon) to understand the purpose of the parameter field for the configuration of the pyramid flow. “Advanced settings” button at the bottom of Fig.1 loads the timer values and an active user percentage in order to trigger timer notifications by the algorithm. Fig.2 illustrates aforementioned input parameters. Maximum time limits for option submission and rating can be specified from minutes or even days (e.g., in a distance or blended setting). Countdown timers are used by the algorithm (countdown timer at level 1 < time limit for level 1) to add more dynamism. After a minimum number of active participants finished the task, timer notifications are triggered alerting participants about the remaining time. If all finished the task before timer expires, activity will proceed to the next level quickly. PyramidApp activities can be monitored in real time during an enactment using “activity tab” of the ILDE interface. Teachers can monitor how many pyramids are formulated, which options are highly rated, which are the options in a particular pyramid, list of participants, their individual options, ratings and discussion lines.



Design_1

Tags: *Click here to add tags to the LdS*

Completeness: 0

Granularity: 0

Pyramid Configurations

Total number of students: Total class size

No. of students per group at rating level 1: 4

No. of levels: 3

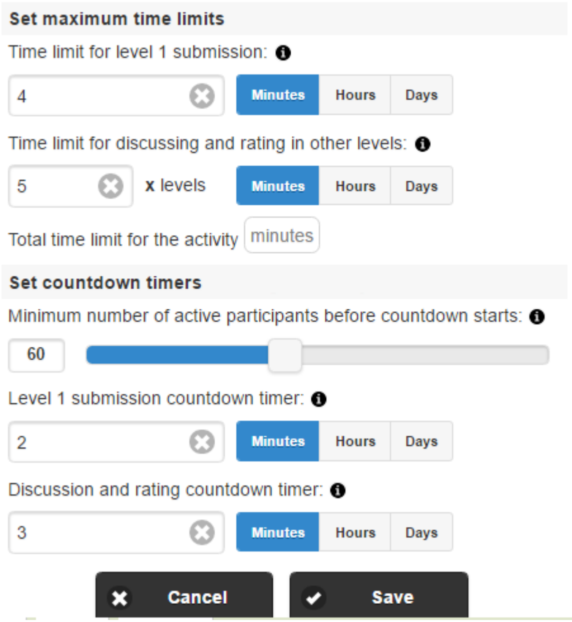
Allow multiple pyramids: Yes

No. of pyramids created: 1

Minimum students per pyramid: 20

Final outcomes :

Figure 1: PyramidApp design component (primary parameters and default values), accessible at https://ilde.upf.edu/pg/lds (new design -> authoring -> PyramidApp)



Set maximum time limits

Time limit for level 1 submission: 4 Minutes

Time limit for discussing and rating in other levels: 5 x levels Minutes

Total time limit for the activity minutes

Set countdown timers

Minimum number of active participants before countdown starts: 60

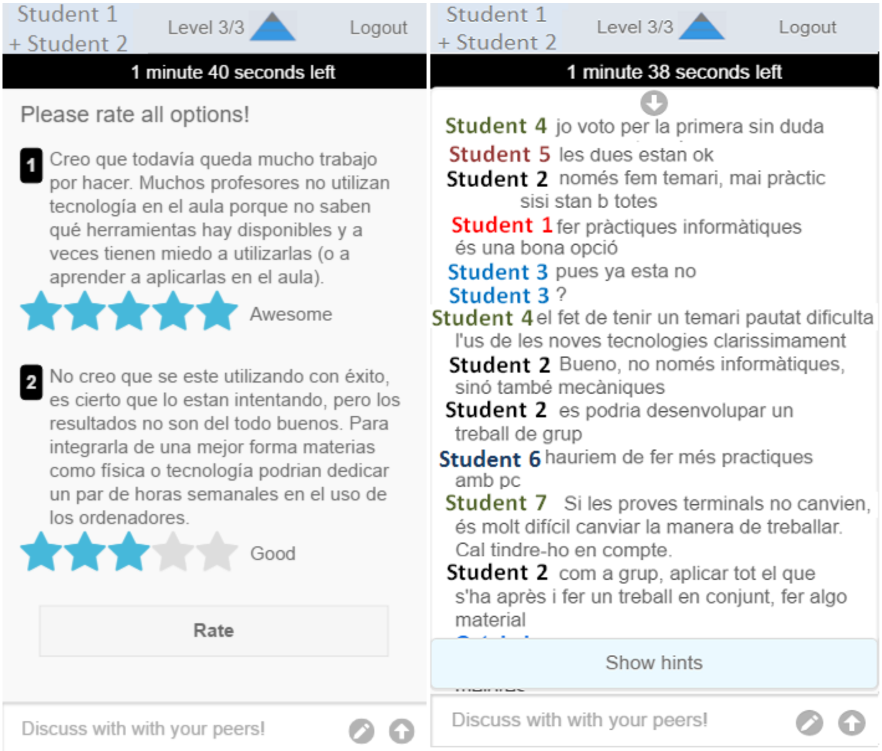
Level 1 submission countdown timer: 2 Minutes

Discussion and rating countdown timer: 3 Minutes

Figure 2: PyramidApp design component (secondary parameters and default values)

Pyramid flow enactment

PyramidApp authored designs are accessible via public URLs once the design is published in ILDE. PyramidApp activity enactment is available as a responsive web application or as a mobile application on Android platform. Fig. 3 depicts activity enactment (pyramid level 2) interface in a mobile device. After logging to the application by providing a username, an initial interface (pyramid level 1) shows the description of a given task and a space for individual response. In PyramidApp, individuals propose options or solutions to the given task (i.e. an answer to a question, a question about a given topic, a created artefact sharable as a web link, etc.) in level 1 of the activity. The pyramid algorithm then creates small groups (group size is specified in the activity configuration) for level 2, where participants share thoughts and concerns about the options suggested in the previous level by each member of the group, clarify and negotiate on the most interesting option before confirming ratings. Also participants can see who are their peers in the group, level indication and timer notifications (when applicable) at the top of the screen (Fig. 3). Highly rated options are promoted to upper levels and smaller groups grow larger following a pyramid/snowball structure. Rating and discussion propagate till the final level as the complete group of participants reach upon a consensus. At the end of the activity, finally selected options for each pyramid are displayed in the window (e.g., for further discussion in the classroom). Consider a class of 100 students (comparatively a large class) in which a teacher will not have sufficient time to address individual queries or answers to a question/task. Instead, addressing only 5 queries selected (20 students per pyramid * 5=100) is more feasible, while each individual still has the opportunity to express and discuss their contributions and comments with their peers, and to get to know, critically reflect and assess peer’s contributions. Besides, the teacher can monitor all contributions and decide to bring some of them to the discussion or revise them after the activity.



Please rate all options!

1 Creo que todavía queda mucho trabajo por hacer. Muchos profesores no utilizan tecnología en el aula porque no saben qué herramientas hay disponibles y a veces tienen miedo a utilizarlas (o a aprender a aplicarlas en el aula).

★★★★★ Awesome

2 No creo que se este utilizando con éxito, es cierto que lo estan intentando, pero los resultados no son del todo buenos. Para integrarla de una mejor forma materias como física o tecnología podrian dedicar un par de horas semanales en el uso de los ordenadores.

★★★☆☆ Good

Student 4 jo voto per la primera sin duda
Student 5 les dues estan ok
Student 2 només fem temari, mai pràctic sisi stan b totes
Student 1 fer pràctiques informàtiques és una bona opció
Student 3 pues ya esta no
Student 3 ?
Student 4 el fet de tenir un temari pautat dificulta l'us de les noves tecnologies clarissimament
Student 2 Bueno, no només informàtiques, sinó també mecàniques
Student 2 es podria desenvolupar un treball de grup
Student 6 hauriem de fer més practiques amb pc
Student 7 Si les proves terminals no canvien, és molt difícil canviar la manera de treballar. Cal tindre-ho en compte.
Student 2 com a grup, aplicar tot el que s'ha après i fer un treball en conjunt, fer algo material

Figure 3: Enactment view of PyramidApp in mobile devices (rating view and discussion space)

Evaluation: Designer's Experience

Experimental settings: Teacher training workshops

Four workshops were conducted with 40 teachers (from which the majority were high school and higher education practitioners). All workshops were structured similarly where an expert on Collaborative Learning (CL) initiated the workshop by giving an introduction to CL and flow patterns proceeded by types of CL activities with examples. Then workshop participants engaged in a PyramidApp activity to experience the essence of how Pyramid structured activity enactment was possible. Then they were presented with the authoring tool and each participant had the opportunity of designing their own PyramidApp activities suitable to their expectation and curriculum requirements. At the end of the workshop, a survey was administered to these practitioners, in which section 1 contained Likert scale questions from 1 (I don't like at all) to 5 (I like very much) and section 2 was open ended questions about the activity design experience.

Results

In all workshops, participants were very positive and enthusiastic about the application and some of them expressed their willingness to use it in their classrooms straightaway. Some suggested and requested different modifications in order to be able to apply it within their own teaching contexts. Mean values above 4.0 from the Likert scale indicate positive aspects in the authoring tool (e.g., showing default parameter values, pyramid structure animation, view activity summary and pyramid design requirements were met successfully). Over 78% accepted that default field values in the design window helped them to design easily (Fig. 4), yet all of them had changed more than one parameter value to suit their context. Many had overridden default values for basic pyramid settings such as number of levels or students per pyramid, but not many had changed advanced parameter values such as the active user percentage or timer values. Several mentioned comments like the application is very simple, cool, useful and effective. Two had suggested enabling blended mode pyramids where initial levels are done at home with different timer values and the final levels of the pyramid to be enacted at the classes with different timer values. Several others had suggested integrating evaluation mechanisms and different analytics to the system, so that they can assess students based on activity performance. 87.5% had stated that pyramid flow authoring is very easy using PyramidApp authoring system.

Evaluation: Learner’s Experience

Experimental settings:

PyramidApp experiments were conducted across three different education levels of engineering higher education studies, each using the PyramidApp several times / sessions with different types of collaborative tasks. The three diverse populations are: first-year undergraduate students (n = 194) taking Introduction to Information and Communication Technologies subject, second year students (n=43) in the subject of Network Protocols and Masters’ students (n=46) (several engineering programs), taking the Research Methodology course. In almost all these experimental settings students were using mobile phones (see Table 1) for activity engagement since most of the interactions happened during their usual face-to-face theory lectures. Only one session was conducted in a laboratory environment where they were using desktop machines and in some other cases some students used their laptops to access the activity. When the application was administered in distance mode, students preferred desktop devices than mobiles (Table 1). A feedback survey was administered at the end of experiments where they had to assess PyramidApp features and their learning experience based on a 1 (I don't like at all) to 5 (I like very much) Likert scale and an open space to provide comments. The sessions were observed by one or more researchers. Hence results and discussion are enriched by triangulating both quantitative and qualitative data gathered.

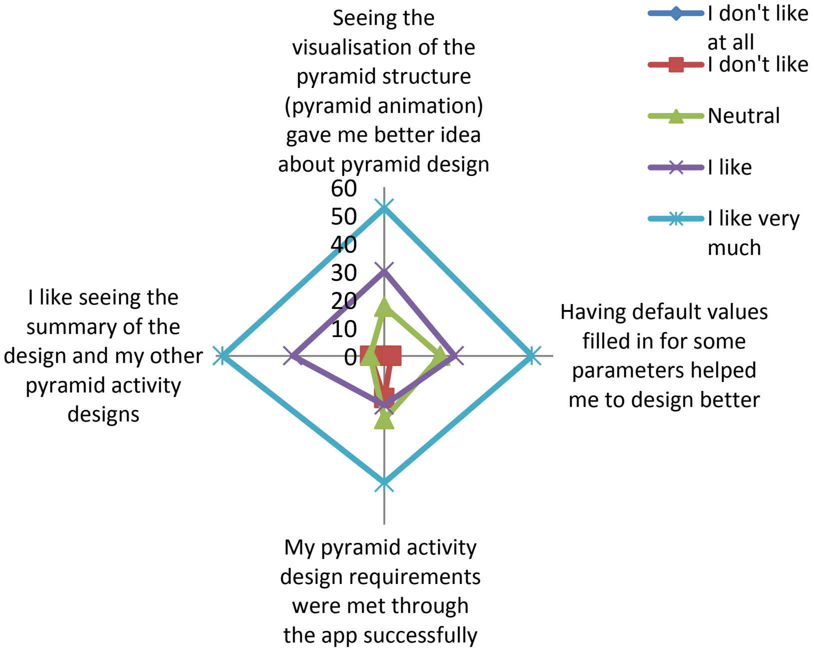


Figure 4: How teachers assess PyramidApp authoring features (Likert scale from 1 to 5)

Table 1: Device usage across populations during experiments

Education level	Face-to-face scenario		Distance scenario	
	Laptop or desktop computer	Mobile devices	Laptop or desktop computer	Mobile devices
First year (n=194)	15.3%	84.7%	72.5%	27.5%
Second year (n=43)	27.7%	72.3%	77.8%	22.2%
Masters' class (n=46)	26.8%	73.2%	Not applicable	

Results: Learner behaviours and satisfaction by education level

When a cross-analysis is conducted across these populations, to see different behaviours of using PyramidApp, it can be identified that all preferred gamification elements presented in the application such as rating peer options, pyramid progression (levelling up) and visualizing popular (highly rated) options. Furthermore, most of the samples had higher interface comprehension rate indicating that the application was not difficult to understand and engage in the activity. Since several rounds of PyramidApp activities were administered (3-6 Pyramid flows in 2-3 sessions), participants were able to familiarise themselves with the application. With the Master's class, very high appreciation of the activity was noted with higher values for activity enjoyment while learning. Some of them also stated that, "the selection and rating of the questions was self-explanatory and entertaining by itself", "I think the pyramid system was more enjoyable and useful as a whole". Though the teacher did not explicitly make the activity participation mandatory, First year students participated highly in the distance mode of PyramidApp flow. As shown in Table 2, results indicate that PyramidApp is easily understandable with a small learning curve to adapt and such collaborative learning leads to activity enjoyment and better learning opportunities.

Table 2: Gamification elements and activity enjoyment across three populations

Education level	Measurement	Rating peer contributions	Pyramid Progression	View highly rated options	Interface comprehension	Activity enjoyment
Masters class	Mean value (Likert scale - 1 to 5)	4.3	4	4.4	4	4.2
	Percentage of students preferring the feature	86%	67%	89%	75%	80%
Second year	Mean value (Likert scale - 1 to 5)	3.8	4	4.2	4.1	4.2
	Percentage of students preferring the feature	61%	74%	76%	74%	82%
First year	Mean value (Likert scale - 1 to 5)	3.6	3.4	3.8	4.3	3.7
	Percentage of students preferring the feature	53%	47%	65%	83%	64%

Results: Learner behaviours and satisfaction by application mode (face-to-face or distance)

Most of the PyramidApp rounds were conducted in face-to-face scenarios and two sessions (one with the first-year group and the other with the second-year group) were enacted using the distance mode of the application. In the distance mode, students were receiving email notifications notifying about the activity progress avoiding participants be online with the application all the time. Comparatively in face-to-face sessions, the discussions were rich and ample as stated by observers and a mean value > 4.0 for discussions in groups, unlike the distance mode across all populations. In the classrooms, sometimes even if the students were not using chat feature of the application, they were still discussing with their neighbours. Common observations of two distance scenarios were that students missing the initial submission phase due to either late access to the activity or ignoring timing values instructed in the email notification. Irrespective of the activity being distance or face-to-face, students had rated waiting timer a low score showing that they do not like waiting too much till others progress along the pyramid (Fig. 5). To address this issue, PyramidApp was modified to show other groups' options at the waiting screen providing them an opportunity to use the waiting time to reflect about the options submitted by their peers.

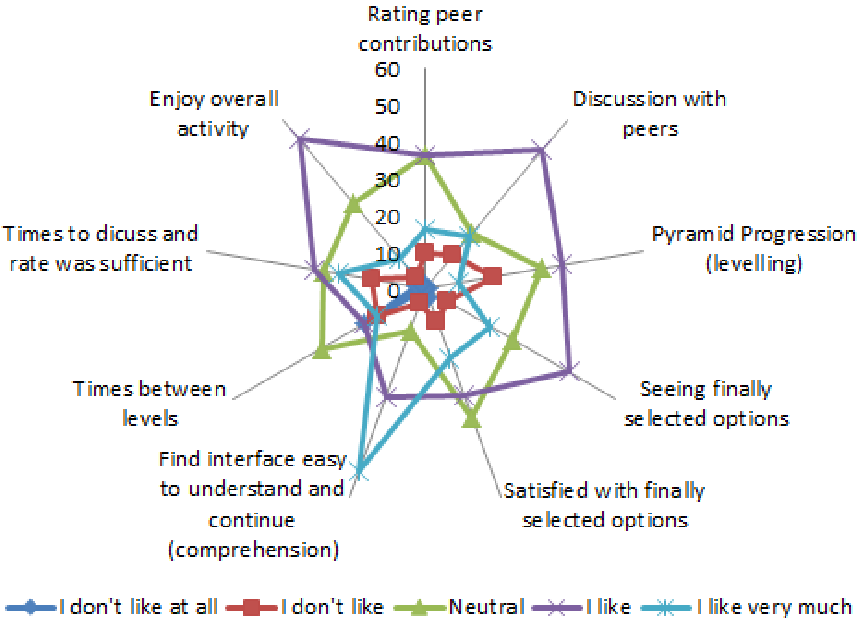


Figure 5(a)

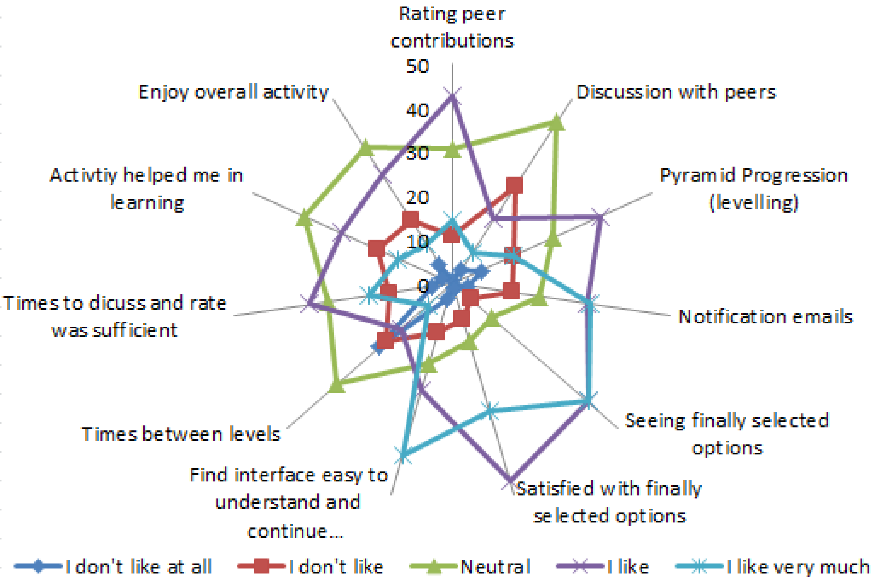


Figure 5(b)

Figure 5: Likert scale distribution in case study analysis tasks (First year group), a) Face-to-face, b) Distance mode

Results: Learner behaviours and satisfaction by type of epistemic task and activity duration

In the Masters' class, the activity was given a short time duration due to the time restrictions and the nature of the task (pyramid flows to propose and agree questions to peers after having presented a paper assignment). Results show students enjoyed the activities but had limited satisfaction with the timing values for this case, which also had an effect in their perception of usefulness of the discussion feature (Table 3). Second year group spent a bit longer time duration and the teacher also observed that, "the activity consumed fair time". The PyramidApp activity was configured with 5 minutes for submission phase and 3 minutes for discussing and rating intentionally by the teacher because the task was very challenging. Students enjoyed the activity but did not come up with the correct solution at the end of the flow; yet this was expected by the teacher, who proposed a challenging problem to emerge reflection, rich pyramid discussions and a final plenary discussion in the classroom. 76% of the first-year group agreed that they had sufficient time for discussion and rating and the activity durations were also very fair, but this differed sometimes based on the mode of the application (either being face-to-face or distance mode). In terms of the utilization of the discussion feature of the application, results indicate that the first-year group did not like it much, while the other two groups had appreciated it comparatively. But in the open ended opinion seeking task of the same first-year group had a mean of 3.7 (68% satisfaction) for discussion feature.

Table 3: Activity time and discussion comparison across three populations, three different tasks

Education level	Type of the task	Satisfied with finally selected options (mean value of 1 to 5 Likert scale value range)	Discussion with peers (mean value of 1 to 5 Likert scale value range)	Sufficient time to discuss and rate (mean of 1 to 5 Likert scale value range)	Activity enjoyment	Total activity duration
Masters' class	Question formulation after group presentations	4	3.6	3.2	4.2	5 – 6 minutes
Second year	Problem solving activity	3.4	3.9	4.1	4.2	12 minutes
First year	Case study analysis	3.6	2.9	3.6	3.2	2 -3 days
First year	Open ended opinion seeking	3.6	3.7	3.6	3.7	10 minutes

Results: Activity enjoyment once novelty effect passes

All three populations enacted PyramidApp activities on several days, in several rounds (3 to 6) in order to minimize the effect of introducing novel technology to the classroom. For first-year group, first round of Pyramid flows were conducted in their practical classes (from 26th – 29th Sept., 2016) where students were using desktop computers and one observer was taking observations. With numerous cases, it was observed that students were not paying attention for notification on timer expirations and were unable to submit options or rating timely. Some groups used the chat feature extensively where as some did not. In some sessions educators were also participating in the pyramids and it was observed that students were enjoying discussing and negotiating seeing that the educator was also active within the group. The second and third round of PyramidApp activities were conducted in October and November as shown in Table 4 Results indicate that a 23% improvement of application comprehension by the end of the third round and the opinion of neutral participants (from

Likert scale values) had been reduced from 34% to 12%. This indicates that any novelty effects that can exist by introducing PyramidApp to the classroom are surpassed when they are familiarised. Overall activity enjoyment shows a slight improvement due to the reason of applying different types of tasks in these rounds (second round was an open ended opinion seeking activity whereas the third was a case study analysis).

Table 4: First year experiments indicating learner familiarisation

Experiment date(s)	Ease of user interface comprehension		Overall activity enjoyment	
	Neutral	Like	Neutral	Like
5th Oct, 2016	34%	60%, mean = 3.7	35%	59%, mean = 3.5
2nd & 3rd Nov, 2016	12%	83%, mean = 4.3	31%	63%, mean = 3.7

Conclusion and Future work

In this paper, authors looked into potential mobile technology mediation in collaborative learning scenarios while providing flexible complex orchestration support in collaborative flow orchestration. A particularization Pyramid flow was adopted and implemented as PyramidApp incorporating flexibility aspects to cope with dynamic situations that occur in a real education context. PyramidApp authoring tool can be used by teachers for flow creation and monitoring. PyramidApp flow enactment tool is used by students to engage in pyramid activities. From several teacher training workshops conducted, it was observed that teachers valued flow creation and monitoring features positively and experienced that such collaborative activity authoring was feasible using the tool. Three populations from Higher education context were used as experimental settings to assess learner behaviours and satisfaction in PyramidApp activity enactment. Students enjoyed pyramid activities but the application utilization and user satisfaction varied depending on the education level, type of the task given or the mode of the application.

Higher the education level, higher the perception of activity enjoyment while realizing the utilization of novel technological applications in the class. When first rounds of the PyramidApp were administered passing the novelty effects, students were comfortable using the application in their classrooms. Further investigations would be interesting in lines of observing activity enjoyment and learner behaviour according to the type of devices used and to further study how to improve the usage of discussion feature. One such improvement had already being implemented using scripted buttons with cues or sentence openers like “these aspects are not clear” or “I agree” or “I propose” to structure participants’ discussions and negotiations (Dillenbourg et al., 2009; Weinberger, 2003). Also, it is important to look into different usability aspects of the application such as improved notifications feature to grab more learner attention and to implement ways to inject different types of tasks at different levels of Pyramid. In the PyramidApp authoring tool, usability aspects such as visual appearance of the activity monitoring and input parameters are concerns for further improvements.

Acknowledgements

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Appendix A: Analysis of the potential scalability of CLFPs

This appendix complements to Chapter 5 and 6 relating to the possibilities of CLFP extensions to be applicable in large class contexts (especially in MOOCs considering its dynamic, unpredictable and diverse nature). Most commonly used patterns are being considered for their adaptability in such contexts, for scalability and other related perspectives. A collection of use cases are elaborated illustrating potential collaborative learning opportunities, design requirements and initial screen designs of such activities and expected functionality descriptions for novel CSCL orchestration services. Contents of the appendix are from a paper accepted to be presented at the 9th International Conference on Education and New Learning Technologies (EDULEARN, 2017).

A.1: CLFPs within MOOC context

We have inspected how different collaborative learning strategies including CLFPs could be adapted within MOOCs. Mostly face-to-face large classrooms have a static behaviour in nature whereas MOOCs are so divergent and dynamic, thus we selected MOOCs to be the threshold of the analysis. Each strategy is studied further to inspect ***level of pedagogical appealing***, how far is it ***scalable from both students' as well as practitioners' perspectives*** and how this proposed technique is ***MOOC suitable***. As "*scalable*" aspects, here we have considered the practicality and feasibility of managing the learning scenario by practitioners and the ability for learners also to easily engage in the activity, irrespective of massive participant amounts. Even currently existing collaboration strategies in MOOCs are considered to normalize the analysis and assess the applicability. Descriptions of concerned CLFPs can be found at (Hernández-Leo et al., 2010).

Peer-assessment (already existing in many MOOC platforms)

a. MOOC learners those who are willing to participate will take up these assessments (e.g., Open response assessments in edX, peer-reviewed assignments in Coursera, peer review in FutureLearn)
b. The MOOC platform will guide and help participants to receive peer-assessments and feedback when the assignments are submitted. Practitioners are required to design assessment rubrics provid-

ing criteria and options. Depending on the level of platform implementation, settings like number of responses per student to grade and number of peer assessments per response (minimum number of students that must grade each response) etc. are modifiable once designed. The strategy adhered is over dimensioning to ensure that all responses get required amount of peer responses.

c. The mechanism is **pedagogically interesting** since every participant in the assessment will receive opportunities to evaluate other peers and provide feedback. MOOC platforms encourage giving useful constructive positive feedback and suggestions to improve promoting peer learning with guidance.
d. **Scalable** in terms of easy managing for practitioners since they do not have to evaluate massive numbers of assignments submitted. Based on the number of participants and the criteria specified by practitioners, the resources (assessments) will be automatically allocated by the platform.
e. **MOOC suitable** as participants only willing to take peer assessment task are considered. Furthermore, peer-assessment is "over dimensioning" and used as a part of grading (penalty) or a condition to be graded. Since learners who do not participate are not considered, minimal effect for a participant to not to receive feedback.
f. Further, the massive amount of assessments are handled and assigned automatically when designing the activity and top scoring responses can be made visible globally with feedback (edX) or responses and feedback could be shared with all participants as either forum posts or using a different public URL (Coursera) or a new discussion can be emerged among the reviewer and the author once feedback is submitted (FutureLearn). Likewise the peer-assessment has been implemented in a quite flexible and pedagogically meaningful manner in MOOCs.

Pyramid-based activity enactment within MOOCs

a. MOOC participants willing to participate in this activity will access.
b. A possible instantiation of a Pyramid flow following a "discussion bus" approach (Ferguson & Sharples, 2014), where participants individually propose a solution which then will be shared with peer solutions in small groups. They would discuss in the local forum and agree on a common solution to be posted to the next level

of the collaboration by voting according to their preference. Iteratively, they are required to discuss and vote in much larger groups next. Likewise, groups will grow larger; thus the collaborations too till only few set of final solutions will be remaining. Solution(s) having highest votes are posted in the global forum to be seen by all participants (or even a highest reviewed response is valid) and to be addressed by the MOOC facilitators.

c. **Pedagogical:** Everybody has the equal opportunity to express and discuss their ideas (individual accountability), social interactions, negotiation, accumulated consensus and mutual agreement with reasoning (positive interdependence).

d. **Scalable approaches :**

   ■ From practitioners' perspective, it is scalable since there will be only few final answers/solutions chosen for the global forum, irrespective of the massive number of participants.

   ■ As for the learners too, this mechanism would filter out thousands of responses into few most relevant and pedagogically valid replies as a collaborative knowledge building effort (Scardamalia & Bereiter, 2006; Weinberger & Fischer, 2006) where everyone has equal opportunity to participate and raise their voices.

e. **MOOC-suitable**: Only the participants interested in the pyramid activity will participate and other MOOC participants are not being considered. Pyramids are formulated on demand without violating pedagogical interests and conditions like having a minimum number to initiate and interact.

f. Pairing and grouping can be more interesting and meaningful by applying soft constraints (Dillenbourg & Tchounikine, 2007; Manathunga & Hernández-Leo, 2016a) into the context. For example, when finding pairs or suitable peers elements such as previous experience or their expertise or friendship (obtained from a social network) can be used. Grouping can be homogenous to promote knowledge sharing or heterogeneous to promote richer interactions with conflict resolutions.

Jigsaw activity suggestion for MOOCs

a. Jigsaw activity can be enacted when a task can be divided into sub problems. Those who like to participate will only be considered as activity participants.

b. Orchestration services will guide learners to get into Jigsaw and Expert groups in respective stages of the activity. Experts will be assigned different subtasks of a global problem (e.g., solving one aspect of a question or studying one dimension of an essay type project) with separately allocated collaboration tools like forums dedicated only for these small group discussions. In the Jigsaw stage, these experts will share their ideas/knowledge in their common forum of the Jigsaw group as peer tutoring and building awareness. These Jigsaw discussions can be made visible globally, so that all participants can view and comment.
c. **Pedagogical**: Every participant has the capability to actively participate in knowledge sharing and co-construction.
d. **Scalable** :
   - ■ From educator's perspective this idea is not a scalable approach since educators still have to deal with large numbers of Jigsaw groups. Also this situation depends on the role of the teacher played within the Jigsaw activity (e.g., individual vs group feedback or activity monitoring only)
   - ■ From student's perspective, this can be seen as scalable when local small peer groups are considered. But not with global level Jigsaw discussions.
e. **MOOC-suitable**: Participants can join the activity only if they are willing to proceed. Further, the pedagogical constraints of the pattern definition will be preserved as group computation will be done dynamically.
f. The approach can be made more interesting using different constraints to derive more meaningful groupings like "selecting experts based on their expertise derived from learner profiles" or "Jigsaw belonging to same regions/countries" or "Jigsaw groups preferring to work outside MOOC platform, even using social networks such as FB". Services can also help students to locate their peers easily by suggesting list of peers belonging to their location (or this can be based on social network public details) following the same MOOC and doing the current activity.

Thinking Aloud Pair Problem Solving implementation model for a MOOC

a. MOOC participants willing to participate in the TAPPS activity would be paired using the orchestration service. Participants are paired as “listeners” and “solvers” by the TAPPS implementation service to solve specific tasks.

b. The service will guide them to continue solving the problems while listener continues commenting for solver’s solutions and the roles are interchanged alternatively. Another way of implementing TAPPS is by having groups of “solvers” and “listeners” interacting in groups rather than individuals. These interactions could be either synchronous or asynchronous in which comprehensive technological support has to be provided through the platform to maintain synchronicity (eg: online chat rooms or video conferencing, etc.)
c. **Pedagogical**: Participants willing to take the task will take part in the assigned role to express their views and to debate and discuss. If groups of “solvers” and “listeners” are implemented, individual accountability on the discussions are not ensured, thus the actual pedagogical value gained will be doubtful from individual’s perspective.
d. **Scalable**:
    - From teacher’s perspective, this approach is not scalable since there will be massive numbers of pair discussions to handle or to monitor and provide feedback (if they’re supposed to do so).
    - For the students, this is scalable considering their two roles only, but this is only possible without teacher monitoring or providing feedback for the discussion/activity flow as it is impractical.
e. **MOOC suitable**: The implementation is challenging since the pattern definition states that the solver reads aloud and talks about the solution for the listener to follow and comment. In order to maintain a synchronous communication, comprehensive task supported environment with video conferencing or voice and chat features are needed (e.g., Tandem (Fondo Garcia, 2016) enables synchronous communication in MOOCs). On contrary, typical discussion boards could also be used if only asynchronous communication is valued.
f. Pairing could be more interesting by conditioning. For example, when finding pairs, friendship (obtained from a social network) or the location (since they can even meet up if they prefer) can be considered.

Think-Pair-Share application to a MOOC context

a. Orchestration services will pair the students after giving them enough time to attempt a task individually. As the next stage of the pattern, pairs will post in a global discussion forum to which other peers would vote or comment.
b. **Pedagogical**: This would be interesting as every participant individually attend a task which will gradually be brought into global forum, giving an opportunity to learn from others and critically evaluate peers.
c. **Scalable**:
    - From teacher's perspective, this approach is not clearly scalable. It will result in massive number of postings by many pairs that the teacher has to monitor and provide feedback.
    - From student's perspective too, it is not scalable to follow massive amount of discussion posts.
d. **MOOC suitable:** Yes, because only those who are willing to participate will be considered while preserving the pedagogical constraints of the pattern.
e. Pairing could be made more interesting and meaningful using constraints like friendship (in social networks) or learner profile factors like location or their expertise, etc.
f. Also, can achieve scalability in both aspects if the pattern is complemented with a concept like pyramid-agreeing or pyramid-voting.

After scrutinizing above presented detailed descriptions, following observations are derived:

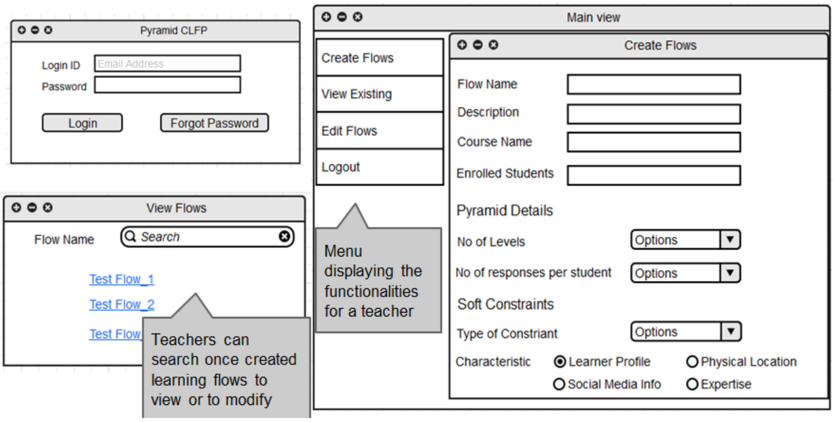
1. The Pyramid CLFP can be identified as more appropriate in the context of a MOOC that shows more potential scalability from both practitioners and MOOC participants' perspectives.
2. The most applicable type of activity is open discussions where learners connect with others to generate knowledge. A possible collaborative mechanism is reaching upon consensus with accumulated interactions by voting and reviewing content. The suggestions are inspired by concepts like integration oriented consensus building (Weinberger & Fischer, 2006) where learners establish shared conceptions of a subject matter and use discourse for

collaborative problem solving (Scardamalia & Bereiter, 2006) by seeking common understanding rather than mere agreement.
3. There is a possibility of implementing diverse types of CLFPs within MOOCs considering that these would complement with another (e.g., Pyramid) in order to make the CSCL activity well-applicable.

A.2: Use cases for potential CLFP orchestration services

This section expresses different use case scenarios derived from the above analysis and illustrates educator-learner interactions, sample user-interfaces with explanations and the rationalization. Each use case describes what practitioners will do during the design stage using the orchestration service and how students can engage.

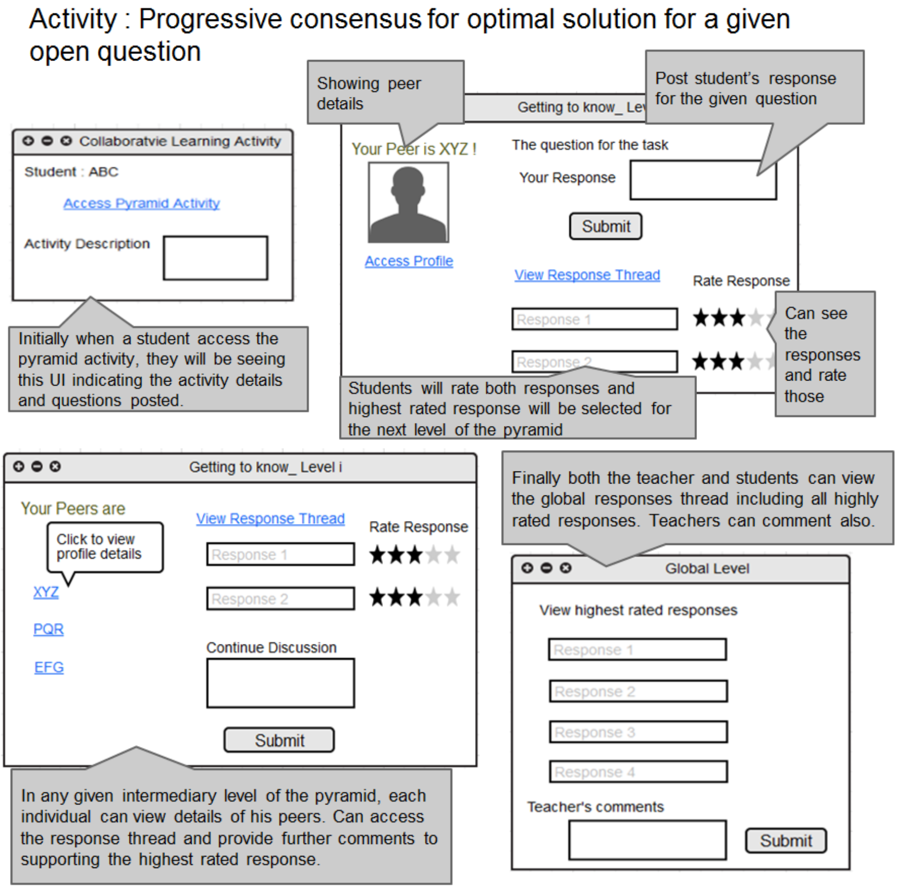
- **Pyramid CLFP**– Case 01
    - Design a pyramid collaborative learning flow activity in which **students rate peer responses.** Practitioners become active participants only at the activity design stage and in the final stage of the pyramid (Figure A.1). This activity can be considered as *quick consensus collaborative knowledge construction* (Weinberger & Fischer, 2006) with everyone's engagement.
        a. Want to set or adjust the levels of pyramid
        b. Want to define activities for each level (e.g., Rating peer responses and responding to given question/s)
        c. Define grouping criteria
        d. Edit the learning flow
    - Engage in the pyramid activity - students willing to participate are the actors (Figure A.2).
        a. Take / sign up for the pyramid activity
        b. Start the activity
        c. Rate the peer response (local and global levels)
        d. Access respective collaboration tools provided (e.g.,: response thread / forum, social network, etc..)



Teachers can search once created learning flows to view or to modify

Menu displaying the functionalities for a teacher

Figure A.1: Pyramid case 01 interface designs for educators



Showing peer details

Post student's response for the given question

Initially when a student access the pyramid activity, they will be seeing this UI indicating the activity details and questions posted.

Can see the responses and rate those

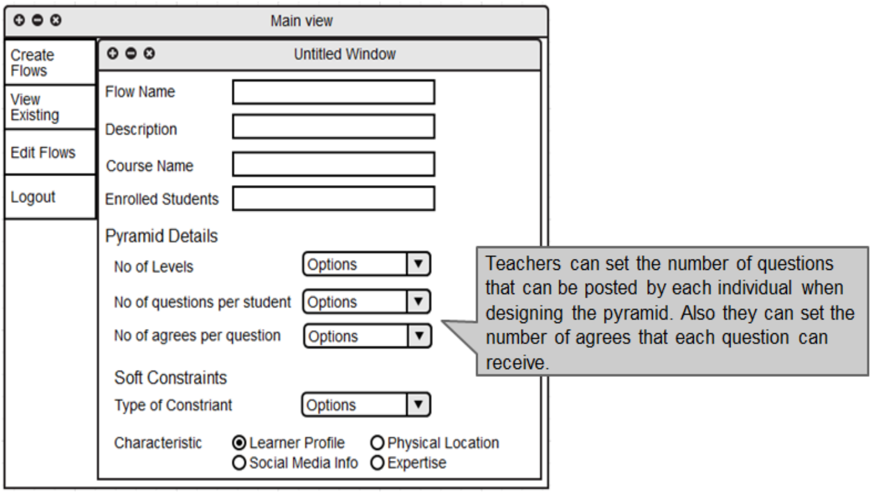
Students will rate both responses and highest rated response will be selected for the next level of the pyramid

Finally both the teacher and students can view the global responses thread including all highly rated responses. Teachers can comment also.

In any given intermediary level of the pyramid, each individual can view details of his peers. Can access the response thread and provide further comments to supporting the highest rated response.

Figure A.2: Pyramid case 01 interfaces for students view

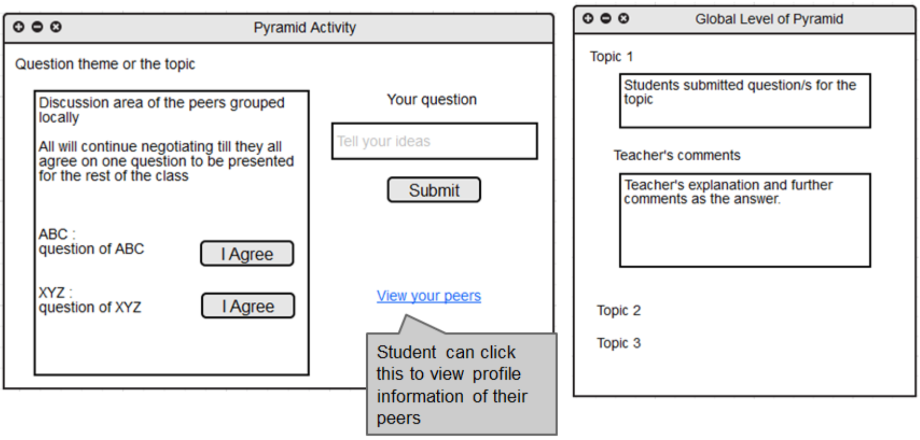
- **Pyramid CLFP** – Case 02
    - Design a pyramid collaborative learning flow activity **promoting conversational theory and negotiation with positive interactions** to achieve a global consensus and select the most valid question to be presented (Figure A.3). This follows *integration-oriented consensus building* (Weinberger & Fischer, 2006) and create knowledge collaboratively.
        a. Teachers set the levels of pyramid
        b. Activity type: Define the question themes for each unit to be enacted as pyramid activities (this type of activity can be repeated with every topic)
        c. Define soft constraint criteria for pairing or group formation
        d. Edit the learning flow
    - Engage in the pyramid activity - students willing to participate are the actors (Figure A.4).
        a. Sign up for the pyramid activity
        b. Start the activity
        c. Access discussion forum and negotiate the question to be posted



● Learner Profile ○ Physical Location
○ Social Media Info ○ Expertise

Teachers can set the number of questions that can be posted by each individual when designing the pyramid. Also they can set the number of agrees that each question can receive.

Figure A.3: Pyramid case 02 interface design for educators



Discussion area of the peers grouped locally

All will continue negotiating till they all agree on one question to be presented for the rest of the class

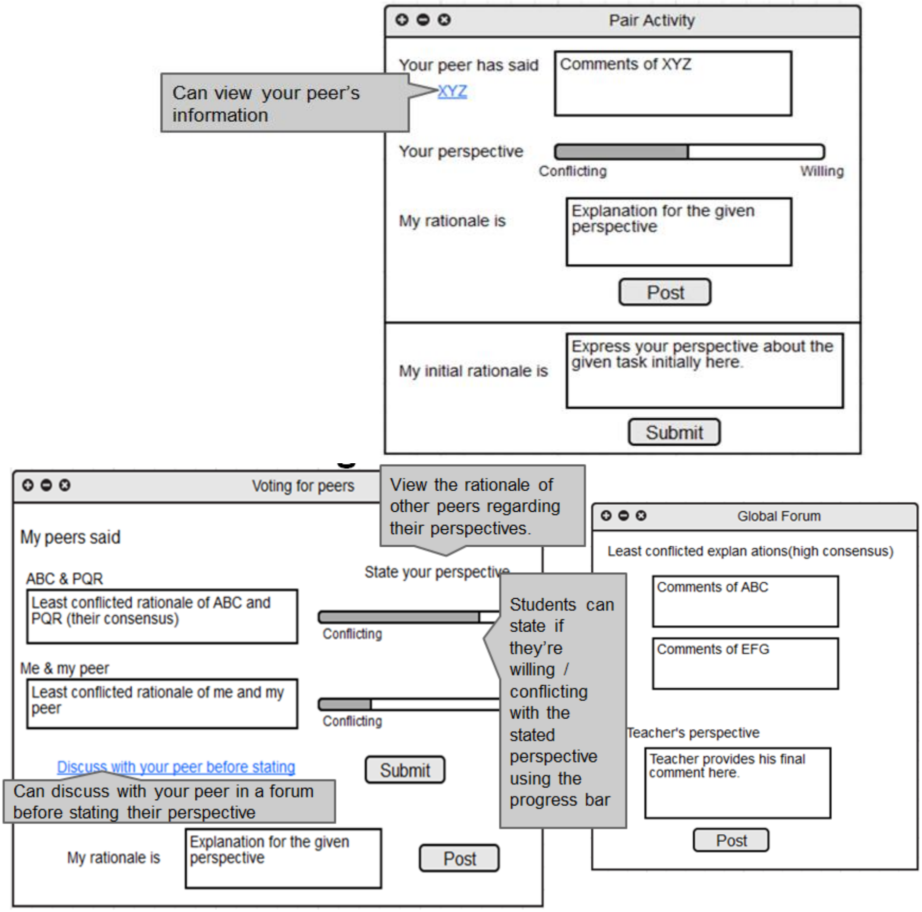
Student can click this to view profile information of their peers

Students submitted question/s for the topic

Teacher's explanation and further comments as the answer.

Figure A.4: Pyramid case 02 interface designs for students

- **Pyramid** – Case 03
  - Design a pyramid collaborative learning flow enabling progressive knowledge construction via stating their willingness or conflict regarding peer’s perspectives while providing individual argument (Figure A.5). This methodology of knowledge construction is *conflict - oriented consensus building* (Weinberger & Fischer, 2006) in collaborative learning which could be enacted as a weekly basis on-going activity.
    a. Teachers set the levels of pyramid
    b. Define activities in each level
    c. Define soft constraint criteria for pairing or group formation
    d. Edit the learning flow
  - Engage in the pyramid activity - students willing to participate are the actors.
    a. Take/Sign up for the pyramid activity
    b. Start the activity
    c. State willingness or the conflict for the comments and provide the rationale (individual perspective)
    d. Access the forums



Can view your peer's information

View the rationale of other peers regarding their perspectives.

Students can state if they're willing / conflicting with the stated perspective using the progress bar

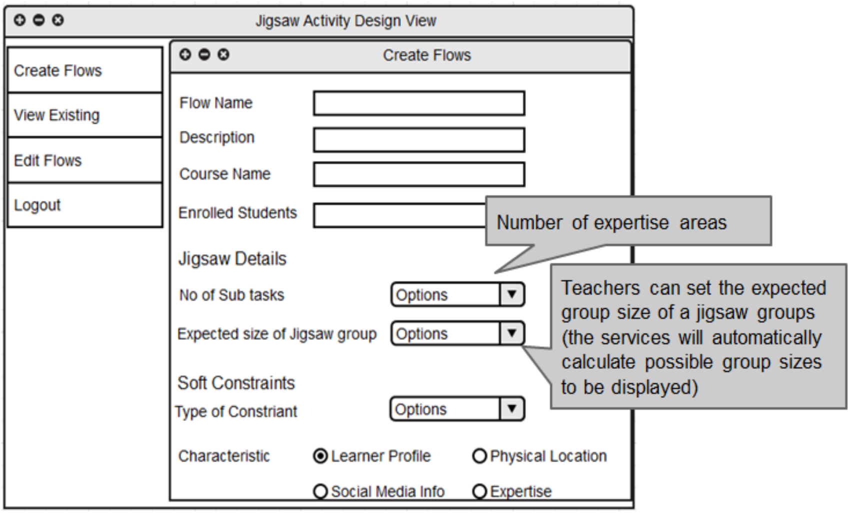
Can discuss with your peer in a forum before stating their perspective

Figure A.5: Pyramid case 03 interface designs for students

- **Jigsaw CLFP** – Use case
  The approach would be applicable and scalable only if the practitioners' involvement is less or filtered only for the higher levels, the activity can be sub divided and that the pattern is complemented with a pyramid structure to avoid lengthy forums discussions. Jigsaw promotes individual accountability (Hernández-Leo, 2007), hence the initial levels of Jigsaw will allow students to engage more fruitfully at individual levels contributing towards the final goal while sharing conceptions and learning from the massive community.
  - Design a Jigsaw activity to collaboratively create knowledge with peers by exchanging their specific knowledge obtained as experts to educate others (Figure A.6).
    a. Teachers create the Jigsaw activity

    b. Create the sub tasks for expert groups (discussion oriented tasks on sub topics or any task that could be sub divided or even project tasks and idea generation activities)
    c. Set soft constraint conditions if required
    d. Edit the learning flow when required

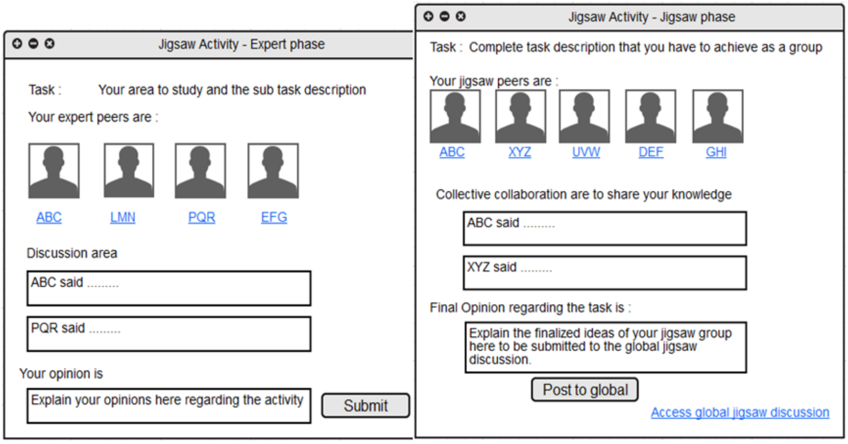
- Engage in the Jigsaw activity - students willing to participate would access the activity (Figure A.7).
    a. Students register with the activity
    b. Access individual Expert and Jigsaw groups
    c. Discuss captured knowledge in forums or other collaborative learning tools
    d. Access global forum to view responses and comment



Number of expertise areas

Teachers can set the expected group size of a jigsaw groups (the services will automatically calculate possible group sizes to be displayed)

Figure A.6: Educator interface for a Jigsaw activity design



Task : Your area to study and the sub task description

ABC said ....

PQR said ....

Explain your opinions here regarding the activity

Task : Complete task description that you have to achieve as a group

ABC said ....

XYZ said ....

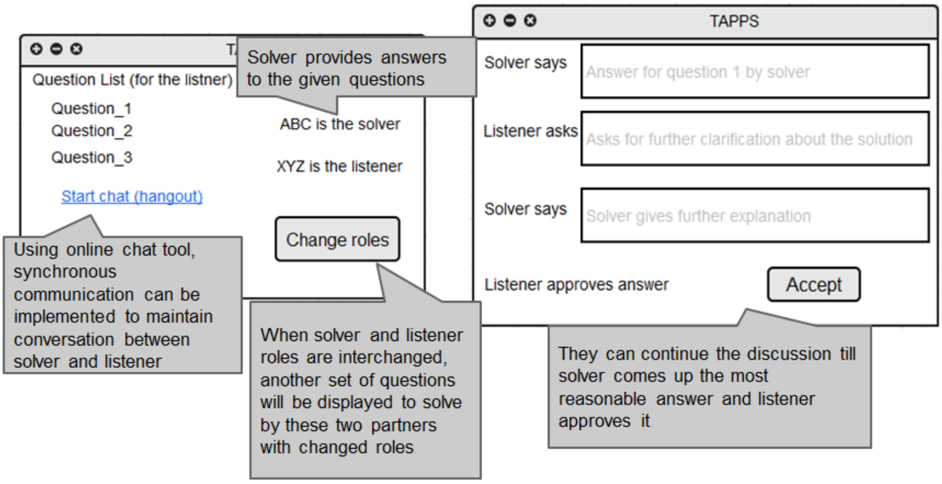
Explain the finalized ideas of your jigsaw group here to be submitted to the global jigsaw discussion.

Figure A.7: Student interfaces for Jigsaw use case

- **TAPPS CLFP-** Use case

  To overcome the limitations of this proposed use case and to introduce diverse types of activities using TAPPS, a comprehensive technological environment should be presented as highlighted under section A.1 in order to maintain “aloud” feature in the pattern precisely (e.g., provide synchronous communications mechanisms, etc.). If the activity is implemented as asynchronous, following suggestion will be suitable. Further, to make the pattern scalable from practitioners’ point of view, it can be complemented with a pyramid or the educator becomes a mere observer during the activity enactment.

  - Design a series of questions as the task with interchanging problem solver/ listener roles enabling knowledge construction through conversing among themselves.
    a. Teachers create the TAPPS activity.
    b. Create the task / question list related to the topic to guide the process
    c. Set soft constraint conditions if required
    d. Edit the learning flow when required.
  - Engage in the TAPPS activity - students willing to participate will be actors (Figure A.8).
    a. Students register with the activity
    b. Identify partners and distribute roles
    c. Access required collaboration tools for the activity (e.g., video conferencing or chat tool like hangout or the forum)



Solver provides answers to the given questions

Using online chat tool, synchronous communication can be implemented to maintain conversation between solver and listener

When solver and listener roles are interchanged, another set of questions will be displayed to solve by these two partners with changed roles

They can continue the discussion till solver comes up the most reasonable answer and listener approves it

Figure A.8: Interface design for students in a TAPPS activity

Appendix B: PyramidApp Design and Algorithm mechanisms

This appendix complements to Chapter 5 and 6 relating to the core of the main research question of the dissertation i.e., Pyramid pattern instantiation algorithm and the mechanisms addressing scalability and dynamism. Flow creation, flow control and flow awareness rules are discussed in detail. Then the section discloses further details about Pyramid authoring system which implements aforementioned mechanisms.

B.1: Algorithm mechanisms

Chapter 5 and 6 provide some explanations about the proposed Pyramid instantiation algorithm and the mechanisms. This section further describes about these aspects. When designing CLFP scripts for large uncertain learning environments, there are two main challenges identified in this dissertation as scalability and dynamism. In order to address these two aspects, we have incorporated three mechanisms (flow creation, control and awareness rules) along with Pyramid flow creation algorithm.

- Flow creation rules are used for Pyramid building. These rules are responsible for maintaining scalability by elastically accommodating students to Pyramids and by creating multiple Pyramids on-demand (Figure B.1). Once a Pyramid is configured, it can grow till a maximum number calculated as {(minimum students per Pyramid *2) -1}. Initially, Pyramids are formulated using the minimum students per Pyramid and filled till the maximum amount. Apart from this parameter, there are other values like total size of the class, number of levels, number of students per group that contribute for the Pyramid formulation. In the learning design, when a practitioner has allowed multiple Pyramid creation, automatically the system replicates the design specified with one Pyramid to generate several Pyramids.

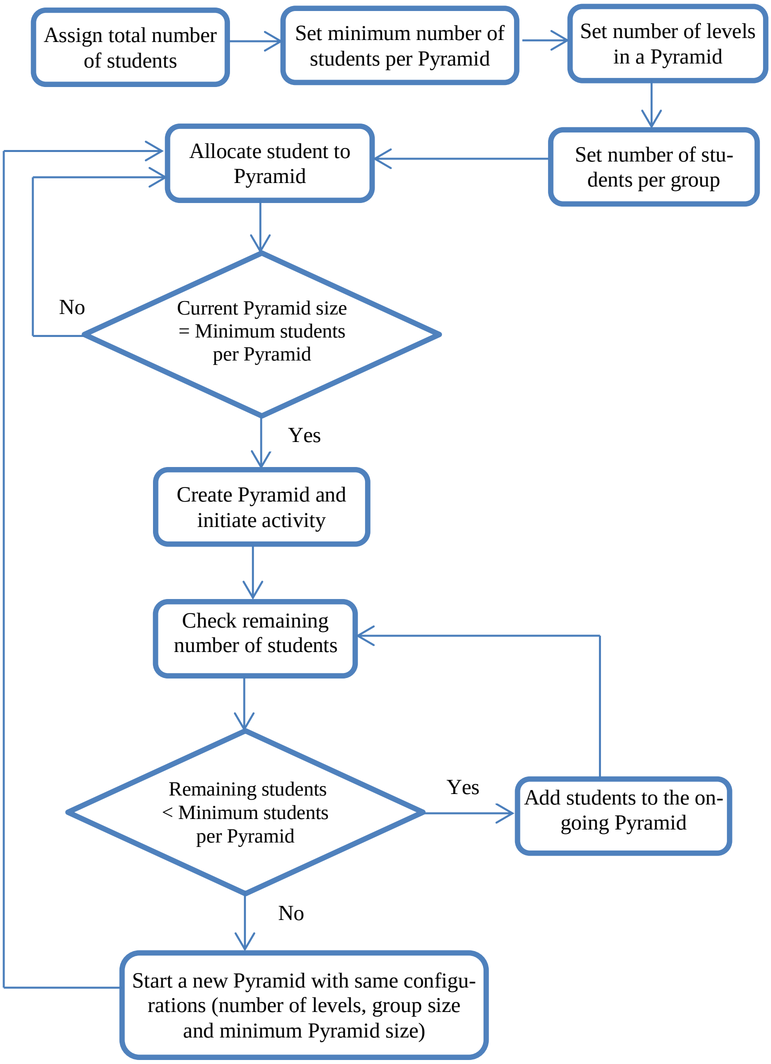


Figure B.1: Flow creation rules showing elastic Pyramid creation

- Flow control rules are used for the Pyramid progression. These rules maintain the dynamism of the flow. We introduced two timers for option submission and rating levels (Figure B.2) to avoid the issue of different submission times and drop outs affecting to freeze the Pyramid progression. These timers are the maximum allowed time given to complete that particular stage. In order to maintain more dynamic behaviour upon completion of Pyramid stages, we use a satisfaction percentage (minimum amount of active users completing particular task). Upon reaching the satisfaction percentage, a countdown timer (countdown timer < maximum allowed time per stage) will be activated until the maximum time allocated per stage. If all learners complete the task before timer expiration, the group is promoted to the next level.

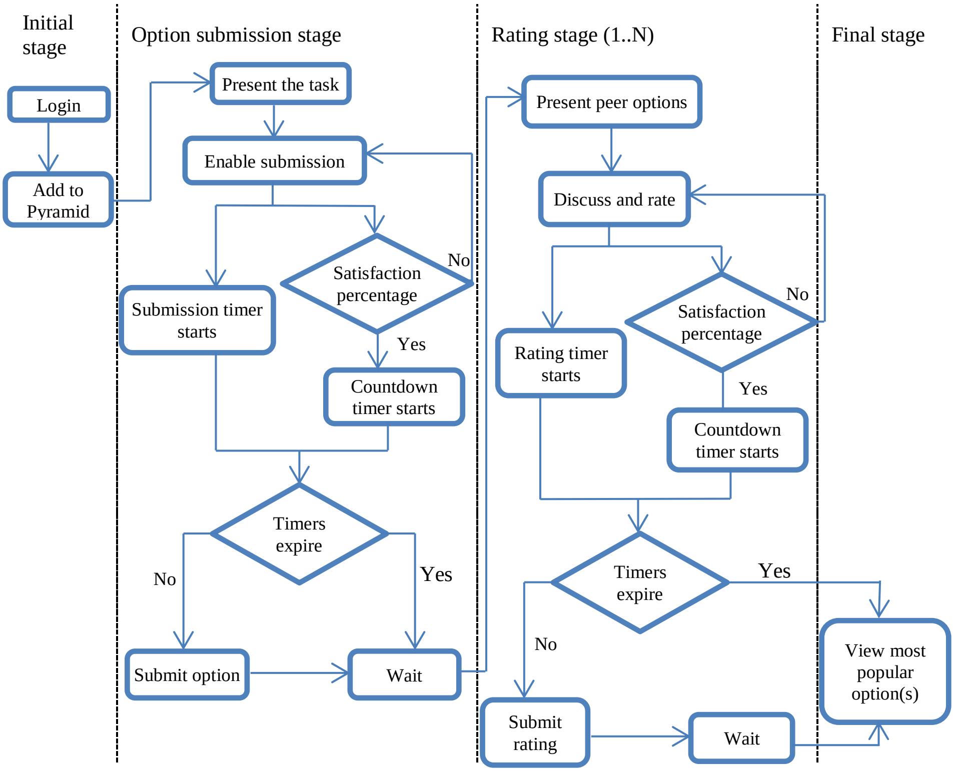


Figure B.2: Process diagram showing dynamic behaviour of the Pyramid flow

- Flow awareness rules are used for visualization purposes. These trigger information related to different status during the activity such as Pyramid levels, peers in the group, timer notifications and email notifications for distance mode. Also when Pyramid finishes, most popular options are visible too.

B.2: PyramidApp activity authoring

Complementing to Pyramid flow authoring as explained in Chapter 6 in the dissertation, this section provides further information. Pyramid CLFP with scalability support, we propose an instantiation inspired by the pattern, but using discourse for collaborative knowledge building and rating for the consensus reaching mechanism (Scardamalia & Bereiter, 2006; Weinberger, 2003). Figure B.3 illustrates the activity authoring process with multiple Pyramids to accommodate growing numbers of learners in a large learning environment and timers to maintain dynamism. As a result of the accumulating collaborations structured by such Pyramid flows, one or more options (e.g., a solution, a question, a link or an opinion) will result as the most acknowledged option(s) selected from the mass. This final number of options is a small quantity even if the initial class size is comparatively large, making it easier for the practitioner to attend.

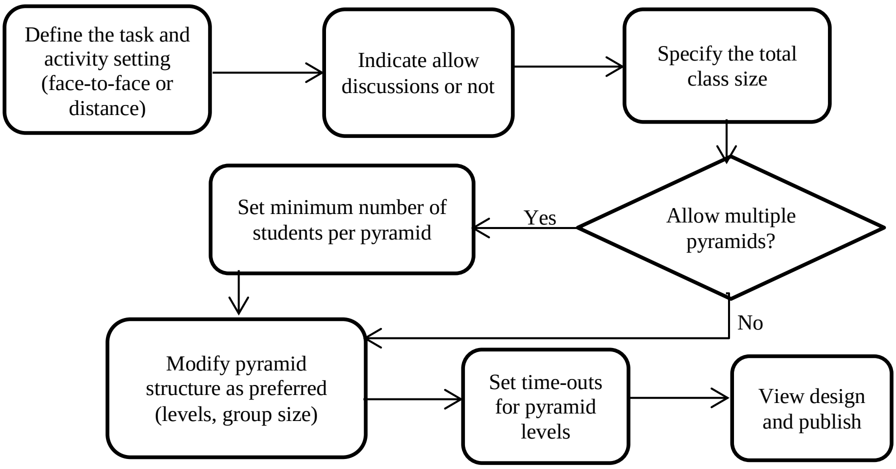


Figure B.3: Pyramid flow authoring process

In order to support practitioners in the flow authoring, some initiative have been introduced to the flow authoring interface. At the initial page load, an animated Pyramid progression is provided to make aware of the Pyramid process. Some fields are automatically populated with default values (e.g., minimum students per Pyramid, timer values, satisfaction percentage) and further more each filed is attached with an information bubble providing hints on particular field. Default values for the fields were extracted by initial pilot studies as mentioned in Chapter 5. Additionally, when a practitioner provides the minimum Pyramid size, possible values for Pyramid levels and group sizes are automatically populated based on the Pyramid size.

Appendix C: PyramidApp Evaluation Studies

Complementing to the Chapters 4 and 6, a detailed report of the evaluation studies is provided in this appendix, starting with the characteristics of the experimental settings, the nature of the study and data gathered. Evaluation studies conducted during the second main iteration of the thesis cycle 3 (see Figure 1.3 in Chapter 1) are analysed further by triangulating with survey data. Each case is explained along with the analysis. The MOOC rounds analysis is also given in this section. General templates of questionnaires administered to both practitioners and students are illustrated for further reference at the end of the appendix.

C.1: Experimental settings

Diverse educational settings were used during different evaluation stages of PyramidApp iterations, following DBR methodology. Several undergraduate levels from UPF Engineering school (e.g., first year, second year and third year), graduate students from several ICT Master programs, students from a vocational training centre, one secondary school context, MOOC experiment settings and details of different workshops too. Table C.1 shows further information of these experimental settings such as the study environment (experiment date, subject, sample size and education level), the epistemic task given, the mode of PyramidApp (whether it's being used or not, if used, then in face-to-face class or distance mode), types of data gathered in the study and significant observations, if there are any. These experimental details of the evaluation studies are required to understand the overall diverse behaviours and perceptions of participants (both practitioners and students) and also individual PyramidApp observations as explained in section C.2. Yet, secondary school and vocational training cases are already analysed and presented in Chapter 5. Workshop analysis is also included in Chapter 6 along with a cross-case analysis of undergraduate and masters level cases. Furthermore, cases without PyramidApp emulated the Pyramid model where the teacher was socially communicating the behaviour and further details can be found in section C.3.

Table C.1: Diverse experimental scenarios considered in PyramidApp evaluation studies in thesis cycle 3 and 4

Module	**Educational setting and date**	**PyramidApp (with / without) F2F Or Distance**	**Student task**	**Type of the task**	**Sample size**	**Resources in hand**	**Observations and comments**
Research Methods	Masters' level (28th Oct, 2016)	Without tool F2F	After completing a survey about individual research questions (aiming the master's thesis or not), get into groups (small and then larger) to discuss three questions given.	Questions answering reflecting a previous assignment	39	Observations by a researcher Questionnaires from 39 students	Ample of interactions and discussions within groups Leader dominance in groups
Research Methods	Masters' level (25th Nov & 2nd Dec, 2016) Each session 2.5hours	With tool F2F use of PyramidApp intertwined	Students wrote a paper and presented it in groups of 3 to 4 students. Several pyramid rounds - When one or several groups finished presentations, PyramidApp was used to pose questions for the presenting team(s) Around 5 or 6 rounds of pyramids	Question formulation after group presentations	46	5 ILDE designs with activity information Questionnaires from 46 students Observations by a researcher	One design was enacted but not completed within given time
Network Protocols	2nd year Engineering Undergraduates (20th Oct, 2016)	Without app F2F	<u>2 tasks (Looking at an example)</u> 1) Which are the ephemeral port number, source and destination port numbers of the given UDP header? 2) Consider two houses in east and west coast. They exchange mails. This household example serves as a nice analogy for explaining how	Problem solving	43	Questionnaires from 43 students Observations by a researcher	In task 1, 5 pyramids created finally by students. They didn't manage to form larger groups. In the class there were more than 40 students In task 2, even more pyramids were created as time was limited to find the way to join in larger groups

			the transport layer relates to the network layer. And 4 questions were given to answer.				
Network Protocols	2nd year Engineering Undergraduates (16th Nov, 2016)	With app F2F	TCP protocol problem: *A la vista de la tabla proyectada (con una captura de tráfico TCP), ¿detectas algún problema de control de congestión? Explica en una frase tu respuesta.*	Problem solving	39	ILDE design Questionnaires from 39 students Observations by a researcher	Most students used mobile phones individually. Only few partnering Both Pyramids had similar most popular answers. But both were wrong. It was easy to reach this (wrong) conclusion as it was a challenging question (problem). This conclusion conflict was sought by the teacher to trigger rich discussion in the classroom. Good in terms of timing
Network Protocols	2nd year Engineering Undergraduates (8th Nov, 2016)	With app F2F	For a given TCP traffic of a specific IP, A) How many TCP connections do you see? B) What is the confirmation number Ack for segment (31)? C) And for segment (32)?	Problem solving (Problem from a previous year's exam)	34	ILDE design Observations by a researcher	
Network Protocols	2nd year Engineering Undergraduates (14th - 16th Nov, 2016)	With app Distance	By looking at a table showing TCP traffic captured, and considering the TCP flow control mechanisms (see class B4.2 slides 29 through 36), why should the TCP segments exchanged be small (that is, they contain a small number of bytes of data)?	Problem solving (Problem from a previous year's exam)	40	ILDE design Questionnaires from 31 students (Only 18 actual participants & 11 non-participants due to varied reasons)	Selected options were the best ones from those provided. In class, some students reported problems with the application. They said that they tried to submit an option on Tuesday (15th) but they did not manage.
DAD course	3rd year CS undergraduates	Without app	Analysis of 2 case studies for Non- functional requirements	Case study analysis	23	Questionnaires from 23 students	Case 1: Though they were asked to discuss in groups of 3 to 4, they discussed in groups of 2. Hard for

	(18th Nov, 2016)	F2F	(2 rounds of Pyramid activities)				them to team up in large group Case 2: Only one group of 3, Many kept on working individually or in pairs
DAD course	3rd year CS undergraduates (18th Nov, 2016)	With app F2F	Ask the response for a given code problem	Problem solving (Code analysis problem)	23	ILDE design Questionnaires from 23 students	First design was a difficult task, submission timer expired. Duplicated design was a success. Selected answers were nice and correct. Other correct answer was not selected, but had proposed by a student. First trial may had an effect on their opinions
ITIC course	1st year undergraduate (23rd Sept, 16)	Without app F2F	Propose extracurricular activities you prefer.	Open ended Opinions	> 120	Observations by three researchers	
ITIC course	1st year undergraduate (26th to 29th Sept, 16)	With app F2F	Are there any aspects of the university or school organization or the studies that are not sufficiently clear or you may like to know more?	Open ended question answering	>80	8 ILDE designs	Conducted in laboratory environment
ITIC course	1st year undergraduate (5th Oct, 16)	With app F2F	What's your main expectation for block 2 of Introduction to ICT? What would you like to learn?	Open ended opinions	>96	Questionnaires from 96 students 2 ILDE designs	
ITIC course	1st year undergraduate (2nd Nov, 16)	With app F2F	Three case readings were given. Class was divided to two and given the first two readings ad they participated two different pyramid activities separately. Then the last	Case study analysis Open ended question	About 35 students	3 ILDE designs Questionnaires from 28 students	They used one device per initial team (2-3 people). Half of them one pyramid, other half other pyramid, last pyramid by all. Last Pyramid did not finish.

ITIC course	1st year undergraduate (2nd Nov, 16)	With app F2F	case study was for the whole class and all participated in a final pyramid activity	answering	About 31 students	3 ILDE designs Questionnaires from 31 students	They used one device per initial team (2-3 people). Half of them one pyramid, other half other pyramid, last pyramid by all.
ITIC course	1st year undergraduate (3rd Nov, 16)	With app F2F			About 19 students	3 ILDE designs Questionnaires from 16 students	They used one device per initial team (2-3 people). Half of them one pyramid, other half other pyramid, last pyramid by all.
ITIC course	1st year undergraduate (18th – 21st Nov, 16)	With app Distance	Watch a video (discussing ethical dilemmas in ICT) and indicate with which of the 24 imperatives in the ACM Code of Ethics and Professional Conduct are related.	Case study analysis (2 cases to analyse)	194	Questionnaires from 111 students ILDE design	
MOOC run 1	15th Feb to 20th Mar, 16	With app Distance	1) Pose a question about WebGLStudio, the state-of-the-art tool that was introduced in Week 1 2) Submit a question about Three.JS API that we are using to implement 3D scenes from Week 3. 3) Rate and discuss the links shared by fellow learners in previous “earth creation” activity step.	Open questions related to the topic Rating links of 3D creations	>70 accessed	19 online questionnaires	
MOOC run 2	4th July – 5th Aug, 16	With app Distance	1) How are your experiments with WebGL and 3D objects? 2) Talk about the programming experience in Three.js. 3) How are you doing so far with advanced 3D things?	Open questions related to the topic	76 accessed	8 online questionnaires	

Initial experiment rounds during the first iteration							
Escola Forestal	Vocational training 16th Feb, 2016	With app F2F	Propose questions about a) future career opportunities, b) curriculum of school c) suggest an outdoor activity a) No chat, b) &c) with chat	Open questions	43	43 questionnaires	Session was in an auditorium and they used mobile phones
ICT	Secondary school 25th & 28th Jan, 16	With app F2F	Ask any doubt or question about Scratch and HTML 3 Pyramid rounds with chat 3 pyramid rounds without chat	Open questions related to the topic	3 classes (51 in total)	49 online questionnaires	Experiments were conducted in Lab environment
ITIC	1st year undergraduates 19th & 20th Nov, 2015	With app F2F	Propose questions for peer presentations 8 pyramid rounds	Question formulation after group presentations	22	22 online questionnaires	Chat feature was not available. Students were using mobiles mainly. Resulting questions were relevant but somehow “sensationalist”
Distributed Applications	3rd year CS undergraduates 16th Nov, 2015	With app F2F	Propose a potential exam question	Question submission for a given theoretical content	23	17 online questionnaires	Students were deeply engaged, resulting questions were relevant. High interest in knowing answers. Activity consumes reasonable time but a bit more than desired by the professor

Practitioner workshops – for educator experience in PyramidApp authoring							
UPF_1	Masters' students from UAB program 1st July, 16	With app F2F	Design Pyramid activities suiting for their classroom contexts	Design activities	8 participants	8 questionnaires about authoring Activity logs with their Pyramid designs	Highly engaged in discussions Concerns about the monitoring of the activity
UPF_2	Teachers from Catalonia and UPF 6th Sept, 16	With app F2F	Design Pyramid activities suiting for their classroom contexts	Design activities	5 participants	5 questionnaires about authoring Activity logs with their Pyramid designs	Highly engaged in discussions
Ginebro school	Teachers from Ginebro (high) school 16th Jan,17	With app F2F	Design Pyramid activities suiting for their classroom contexts	Design activities	19 participants	Questionnaires from 19 about design view (1 left early) Activity logs with their Pyramid designs	Design tasks were mostly done in small groups and they showed high interest in monitoring section At least 3 teachers used PyramidApp with their students after the workshop. Others plan to use it in the short term
Dolmen school	Teachers from Dolmen (high) school 07th Mar,17	With app F2F	Design Pyramid activities suiting for their classroom contexts	Design activities	9 participants	Questionnaires from 8 participants Activity logs with their Pyramid designs	At least 1 teacher used PyramidApp with their students after the workshop. Others plan to use it in the short term.

C.2: Case based analysis

Experiments conducted during the cycle 3 (see Figure 1.3 in Chapter 1) are listed here. As mentioned in the above section, some experiments vary from the data gathered due to various reasons such as time limitations and being initial rounds of exploratory studies within the iteration. Such studies consist of more qualitative data and observations reported whereas other studies provide synopsis supported by both qualitative and quantitative data triangulated.

Research Methods Course (Questions answering - reflecting a previous assignment, MSc level, Face-to-face, without tool: desired flow is socially communicated by the teacher, n=39)

After individual level, small groups of 3 to 4 students and larger groups of 7 to 9 were created. Lots of discussions were observed, especially in small group contexts. In larger groups, leader dominance was observed where group leaders trying to convince their views when joined with larger groups. Small groups had consumed around 7 minutes whereas large group discussions were roughly 4 to 5 minutes duration and then whole class discussion moderated by the teacher, had consumed around 12 minutes. Small group discussions (87%) are preferred than larger group discussions (61%) and knowing peer ideas (85%) was more desirable factor for many participants (Figure C.1). More than 76% had enjoyed the overall activity and also higher mean values for negotiating, discussing in small groups and getting to know peer ideas (mean = 4.3) imply their interests in collaborations.

Network Protocols (Problem solving activity - question answering for theory concepts, 2nd year, Face-to-face, without tool, n=43)

In the class with over 40 students, still 5 pyramids were created when teacher asked them to formulate larger groups, leading to difficulties in forming larger groups (e.g., 20 students per group could have been ideal). In task 2, even more pyramids were created since time was limited to find the way to join as larger groups. Lots of discussions emerged in small groups, but when merged into larger groups still most of them were discussing within their small groups as observed. Over 94% liked discussing in small groups. Participants enjoyed discussing and negotiating with peers (mean = 4.5 and >90%) resulting higher satisfaction about the overall activity (mean = 4.7 and >96%) also (Figure C.2).

Enjoyed negotiating with others	Got to know ideas of my class-classmates	Discussing with others in the small group	Discussing with others in the large group	Getting into larger groups in the last level	Finally selected options	Time allocated for grouping, negotiating and discussing was sufficient	Enjoyed the overall activity
4.256	4.282	4.308	3.641	3.897	4.077	3.821	4.077

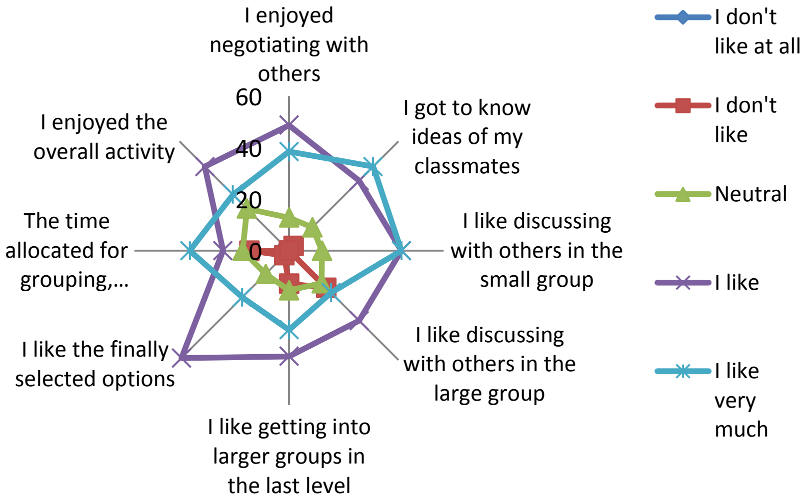


Figure C.1: Mean values and preferences spread in RM class (without tool)

Enjoyed negotiating with others	Got to know ideas of my classmates	Discussing with others in the small group	Discussing with others in the large group	Getting into larger groups in the last level	Finally selected options	Time allocated for grouping, negotiating and discussing was sufficient	Enjoyed the overall activity
4.488	4.372	4.581	4.07	4.047	4.512	4.395	4.674

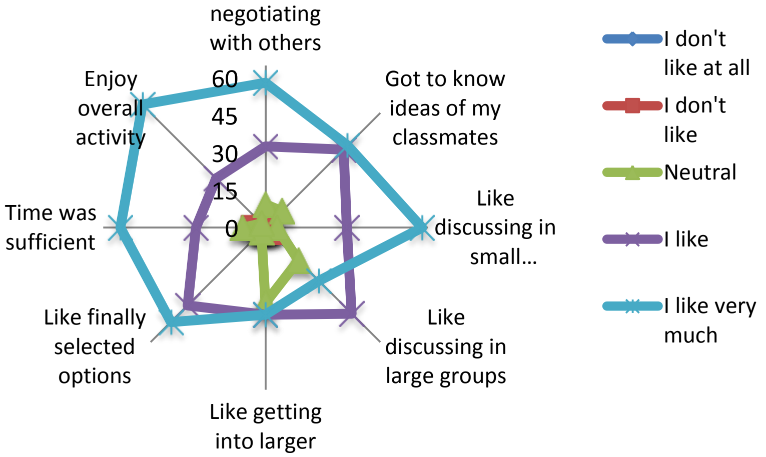


Figure C.2: Mean values and preferences spread in Protocols class (without tool)

DAD (Case study based learning, 3rd year, Face-to-face, without tool, n=23)

Students were presented with two cases and the activity was structured as a Pyramid. In case 1, though they were asked to discuss in groups of 3 to 4, they discussed in groups of 2. It was difficult for students themselves to get into large groups. In case 2 also, there was only one group of 3 and others kept on working individually or in pairs though the teacher gave instructions for group formation. Group formation difficulty was clearly indicated even in feedback data (more than 34% with mean value of 3.3 were neutral about large group formation). More than 70% enjoyed the overall activity which is emphasized with comments like, "it's a good idea to discuss/share your opinions with the classmates; it allows you to learn even more". As in Figure C.3, about 80% of the groups liked knowing peer ideas and 86% (mean = 4.5) agreed that sufficient time was allocated for the activity, starting from group formation up to reaching conclusions.

Enjoyed negotiat-ing with others	Got to know ideas of my classmates	Discussing with others in the small group	Discussing with others in the large group	Getting into larger groups in the last level	Finally selected options	Time allocated for grouping, negotiating and discussing was sufficient	Enjoyed the overall activity
4	4.182	4.13	3.478	3.348	4.409	4.478	4

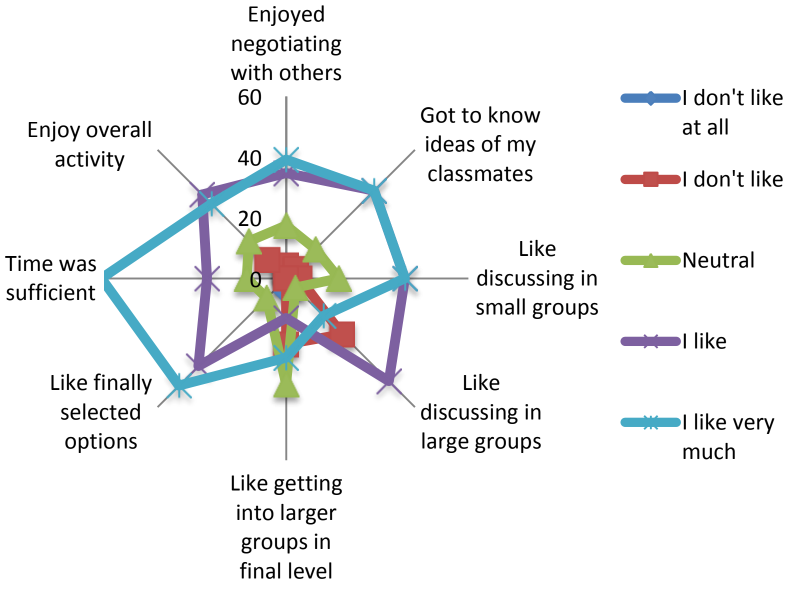


Figure C.3: Mean values and preferences spread in DAD (without tool)

ITIC (Open ended task – suggesting opinions, 1st year, Face-to-Face, without tool, n>120)

The same activity was repeated thrice since there were 3 sessions for 3 groups. 3 observers were taking notes in the sessions. All observers stated that lots of discussions occurred within small group settings when compared to larger groups. In one group, when teacher asked to form larger groups, several small groups gathered together forming a group of around 20 and all engaged in the activity very actively and interestingly, discussing as one group and consensus was reached by voting for the options by raising hands. Another common observation across sessions was difficulty in group formation when instructed. It was observed that most of the times, students form groups as they prefer irrespective of teacher's requirements. Also in the larger groups of higher pyramid levels (n>2), mostly the group leaders from previous smaller groups dominantly took the lead of the discussion rather giving equal opportunities.

RM (Question formulation after group presentations, MSc level, Face-to-face, with tool, n=46)

Multiple pyramid rounds (6) were enacted and depending on the amount of participants, either one pyramid or two pyramids were created. Majority of students had commented as a very interesting experience and stated that the activity helped in learning. Rating contributions (mean = 4.3 and >86%), pyramid progression (mean = 4 and >67%) and viewing highly rated options (mean = 4.4 and >89%) implying gaming effects were mostly appreciated (Figure C.4) and students mentioned that "really fun activity", "the selection and rating of the questions was self-explanatory and entertaining by itself", "I think the pyramid system was more enjoyable and useful as a whole". Many are not satisfied (mean = 3.1) with the timing values (e.g., time to discuss and rate and waiting time between levels). Some of them complained that the chat feature was not useful, mainly because they did not have sufficient time due to class time restrictions. Some liked the questions posed, "I really liked some of the provocative questions but then the answers didn't really seem to answer the questions, mainly because we were in quite a rush", and another had not liked finally selected options, "questions were not really good though rated by a lot of people". More than 70% believed such question formulation helped them to gain new knowledge about different topics presented whereas more than 80% had enjoyed the overall activity.

Rating peer contributions	Discussion with peers	Pyramid Progression	Seeing finally selected options	Satisfied with finally selected options	Interface comprehension	Times between levels	Sufficient time to discuss and rate	Activity helped in learning	Enjoy overall activity
4.261	3.565	4	4.391	3.957	3.957	3.109	3.196	3.978	4.196

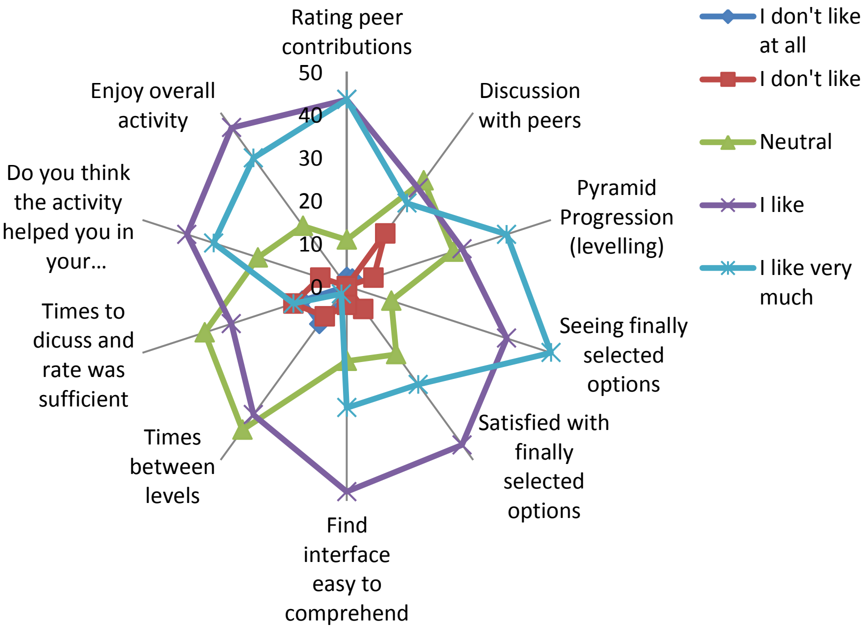


Figure C.4: Mean values and preferences spread in RM class (with tool)

Network Protocols (Problem solving activity, 2nd year, Face-to-face, with tool, n=39)

Most students used mobile phones individually. Only few were partnering. Both Pyramids had similar most popular answers which were wrong. It was easy to reach this (wrong) conclusion as it was a challenging question (problem). The teacher also stated that the activity consumed fair time duration and that students showed interest in the activity, initiating lots of discussions in class during the activity. Majority did not like the waiting time (mean = 3 and >41%), but they were happy with the activity allocation time (mean = 4 and >70%). The PyramidApp activity was configured with 5 minutes for submission phase and 3 minutes for discussing and rating intentionally by the teacher because the task was very challenging, but students did not utilize the allocated time fruitfully to come up with the correct solution. More than 81% (mean = 4.2) had admitted that the activity helped them in learning the concepts and more than 76% (mean = 4.2) had enjoyed the overall activity (Figure C.5).

Rating peer contributions	Discussion with peers	Pyramid Progression	Seeing finally selected options	Satisfied with finally selected options	Interface comprehension	Times between levels	Sufficient time to discuss and rate	Activity helped in learning	Enjoy overall activity
3.821	3.846	3.974	4.184	3.41	4.128	3.026	4.051	4.154	4.231

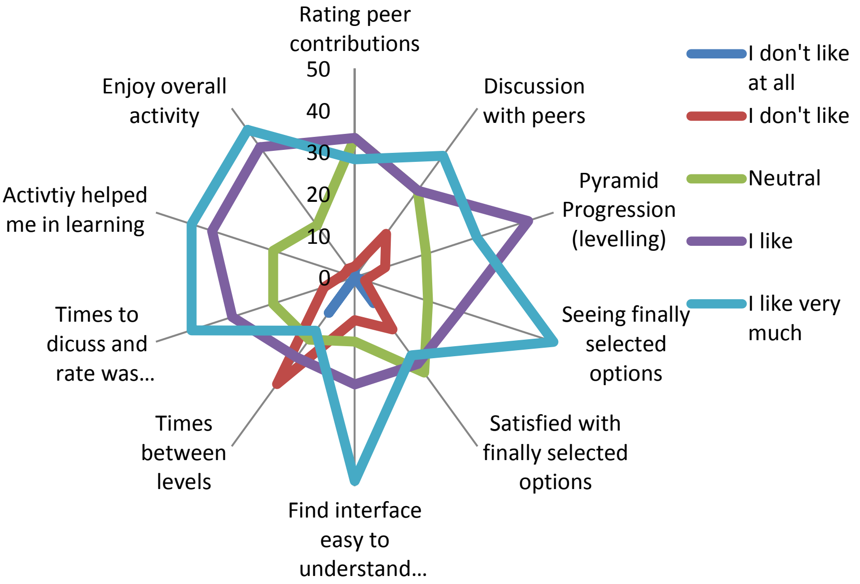


Figure C.5: Mean values and preferences spread in protocols class (with tool)

Network Protocols (Close ended problem solving task- questions from a previous exam, 2nd year, Face-to-face, with tool, n=34)

No questionnaires were administered during this experiment. 34 had accessed the application while 20 submitted answers. But observer stated that the students were not engaging with the activity much since students had an exam and many were concentrating on that, rather than PyramidApp. Also it was observed that mobile users faced connection problems during the activity that might affect their engagement but the students using laptops did not have any issue with the application.

DAD (Problem solving activity - Code analysis, 3rd year, Face-to-face, with tool, n=23)

Though two PyramidApp activities were planned, first one was not successful since the task was too difficult, thus the submission timer expired. But the second was a success in which, the selected answers were nice and correct as stated by the teacher. Though the other correct answer was not selected, it had been proposed by a student. Third round of PyramidApp activity received less students and though the teacher reconfigured the ILDE design accordingly, it was not republished and the activity was not successful. These partially unsuccessful trials may have an effect on student opinions. Irrespective of the unsuccessful attempts, over 90% are satisfied with the finally selected options (mean = 4.5) (Figure C.6) complying with the teacher's comment above. Over 70% had enjoyed PyramidApp activities and over 80% accept that the activity helped in learning (mean = 4.1).

Rating peer contri-butions	Discus-sion with peers	Pyramid Progres-sion	Seeing finally selected options	Satisfied with finally selected options	Interface compre-hension	Times between levels	Sufficient time to discuss and rate	Activity helped in learning	Enjoy overall activity
4.087	3.783	3.826	4.478	4.13	4.087	3	3.435	4.087	4.087

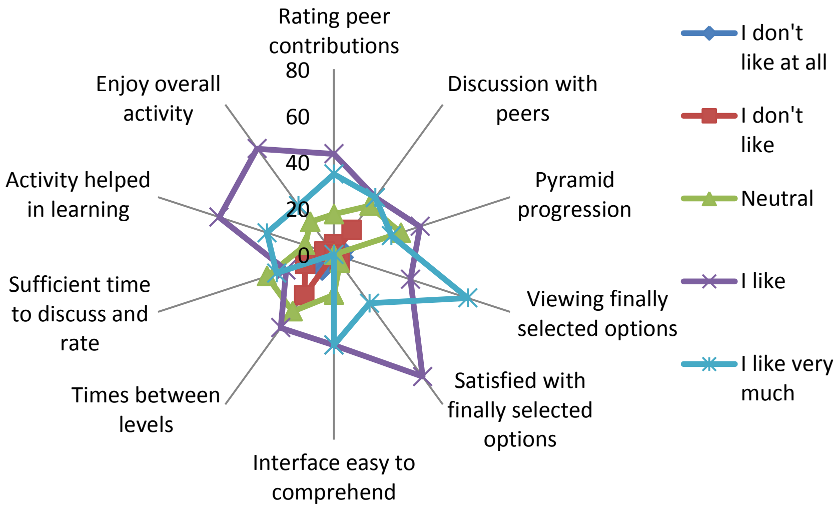


Figure C.6: Mean values and preferences spread in DAD class (with tool)

ITIC (Open ended opinions, 1st year, Face-to-Face, with tool, n>80)

There were several sessions of PyramidApp, where the same activity was repeated and the experiments were conducted during their lab sessions, so students were using desktop computers mainly. Questionnaires were not used; hence only observations from one researcher and activity logs serve as evidence. Some groups used the chat feature extensively where as some did not see any benefit of it. In some sessions educators were also participating in the pyramids and it was observed that students were enjoying discussing and negotiating seeing that the educator was also active within the group. When multiple pyramids were created, some pyramids finished sooner than the others, leading those participants to wait till others finish which might have led to boredom. In most of the rounds, it was observed that some students were not paying attention for timer expirations and that they could not submit opinions or rating timely.

ITIC (Open ended opinions, 1st year, Face-to-Face, with tool, n>96)

In the task, teacher was making them to think openly and letting them to decide what they are expecting from the topic. 96 students submitted questionnaires and as shown in Figure C.7, over 63% liked rating other's opinions (mean = 3.8) and over 59% (mean = 3.37) had enjoyed the overall activity. Results show interesting curiosity towards knowing the most popular opinions (>53%), may be because of the type of the task given. But they did not desire much the discussion feature (mean = 3.3) as shown in the graph. 76% had agreed that the activity time was sufficient for discussing and rating and another 62% had marked that they did not like the waiting time between levels.

Rating peer contributions	Discussion with peers	Seeing full discussion by the group	Pyramid Progression	Seeing finally selected options	Satisfied with finally selected options	Interface comprehension	Enjoy overall activity
3.844	3.323	3.219	3.406	4.126	3.531	3.708	3.37

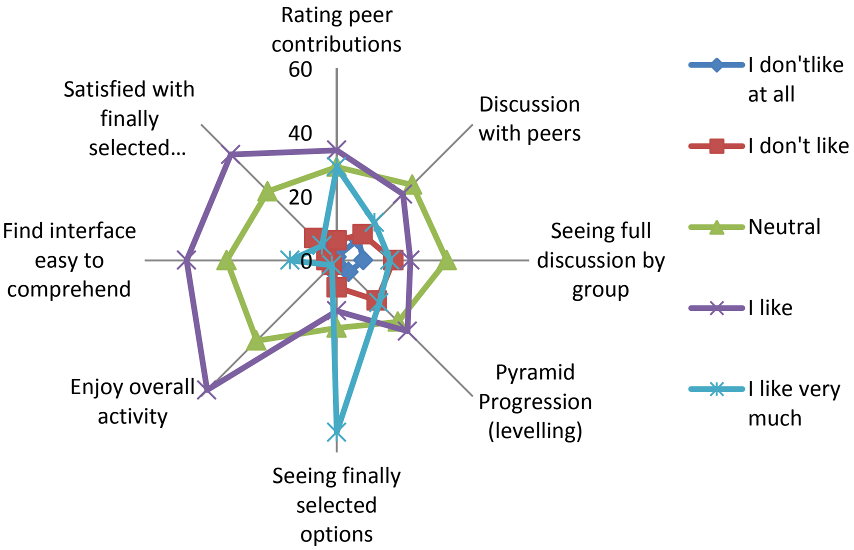


Figure C.7: Mean values and preferences spread in ITIC class (with tool)

ITIC (Case study analysis, 1st year, Face-to-Face, with tool, n>80)

In three different classes, a similarly structured activity was conducted, in which the class was divided to two and given two cases to read and participate in two pyramids separately. Then for a third case reading, the whole class participated in one pyramid after reading the case. Small groups of either two or three members, used only one device (either a smartphone or a laptop) to participate in the activity. This group of students were familiar with the functionality of the PyramidApp as shown with a higher value for the interface comprehension (mean = 4.32 and >83% satisfaction rate) as in Figure C.8, since they had used the application several times by the time of this activity. Over 63% (mean = 3.68) had enjoyed the overall activity, but they were not happy of the timer values in between pyramid levels (mean = 2.96).

Rating peer contribution	Discussion with peers	Pyramid Progression	Seeing finally selected options	Satisfied with finally selected options	Interface comprehension	Times between levels	Sufficient time to discuss and rate	Enjoy overall activity
3.568	3.747	3.351	3.795	3.56	4.324	2.959	3.587	3.68

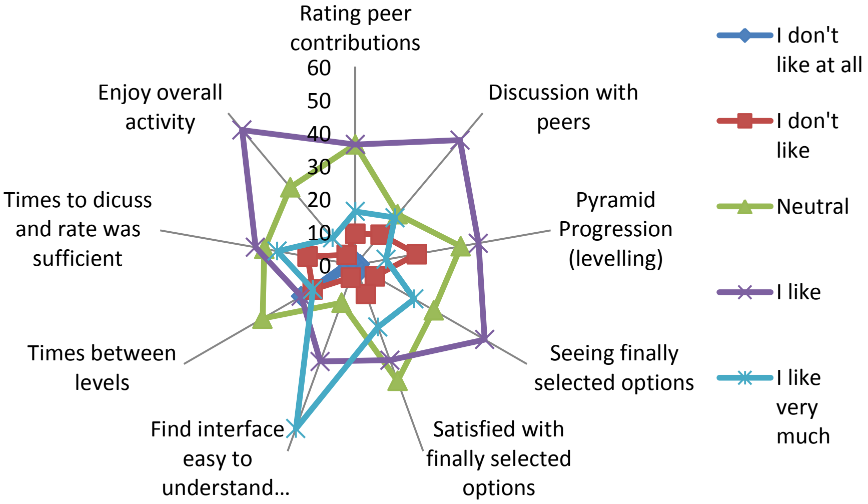


Figure C.8: Mean values and preferences spread of ITIC class case study (with tool)

ITIC (Case study analysis, 1st year, Distance, with tool, n=194)

Though the activity was initiated in a weekend, many (194) had submitted options, yet only 112 submitted questionnaires. Several pyramids were created accommodating students who accessed the tool different times, preserving scalability. As some had not paid attention for email notifications, they said that they could not submit because the timer had expired for submission when they were accessing the application. More than 75% liked the finally selected options while majority was neutral about waiting times (>34%) between levels. More than 65% (mean=3.9) had marked the interface was easy to comprehend (Figure C.9) and these participants have used PyramidApp several times and the result complies with their familiarity. Some of them did not like the email notifications saying that they have to be aware about the email all the time. Though email notification included the time values, some commented that they did not know when timer expires. Features adding gamification effect to the application like rating peers, levelling up, visualizing popular opinions and notifications attracted over 50% from the population. The experiment confirmed well the potential scalability considering a comparatively larger class, by allocating students to pyramids and letting them continue with the current level tasks while preserving dynamism.

Rating peer contributions	Discussion with peers	Pyramid Progression	Notification email	Seeing finally selected options	Satisfied with finally selected options	Interface comprehension	Times between levels	Sufficient time to discuss and rate	Activity helped in learning	Enjoy overall activity
3.559	2.946	3.378	3.703	4.117	3.901	3.874	2.613	3.414	3.306	3.234

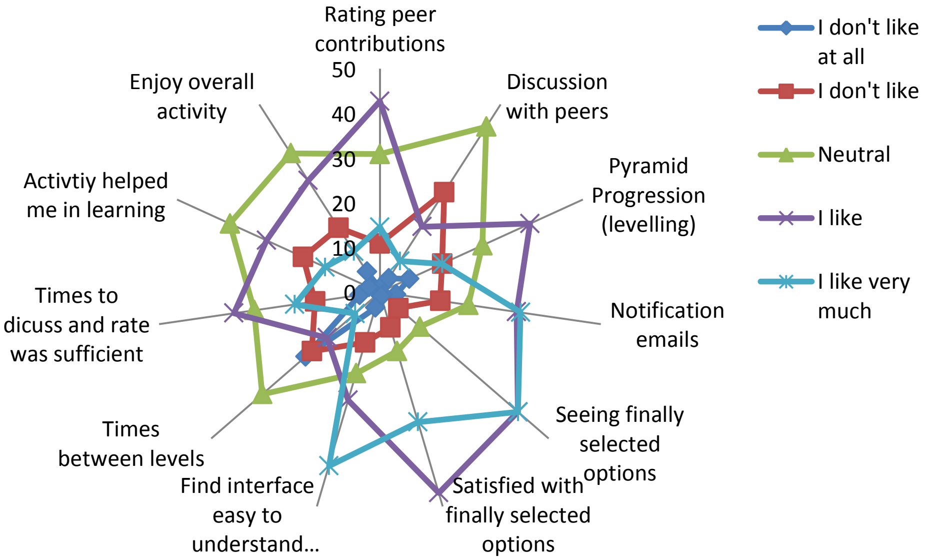


Figure C.9: Mean values and preferences spread of ITIC class (distance mode)

Network Protocols (Close ended problem solving task - questions from a previous exam, 2nd year, Distance, with tool, n=40)

Among 31 questionnaire submissions, only 18 had actually participated in the activity, 2 had not marked the survey and other 11 had not participated due to varied reasons. Teacher stated that the selected popular options were the best from those provided. Feedback survey was administered on the next day face to face class and some students reported problems with the application. They said that they tried to submit an option on the following day but they could not manage to. This could be attributed to submission timer expiration and delayed logins as some had mentioned, “I participated late, I could not vote for any option” or “it did not allow me to answer in level 1”, “it’s related with 1 day delay to access”. With timer expirations, preserved dynamism helped active participants to continue the activity even in the distance mode. From 18 participants, more than 53% had enjoyed the overall activity and 83% are satisfied with finally selected options from the pyramid (Figure C.10).

Rating peer contributions	Discussion with peers	Pyramid Progression	Notification email	Seeing finally selected options	Satisfied with finally selected options	Interface comprehension	Times between levels	Sufficient time to discuss and rate	Activity helped in learning	Enjoy overall activity
3	2.846	2.308	2.538	3.385	3.769	2.769	2.692	3.385	3.462	3.231

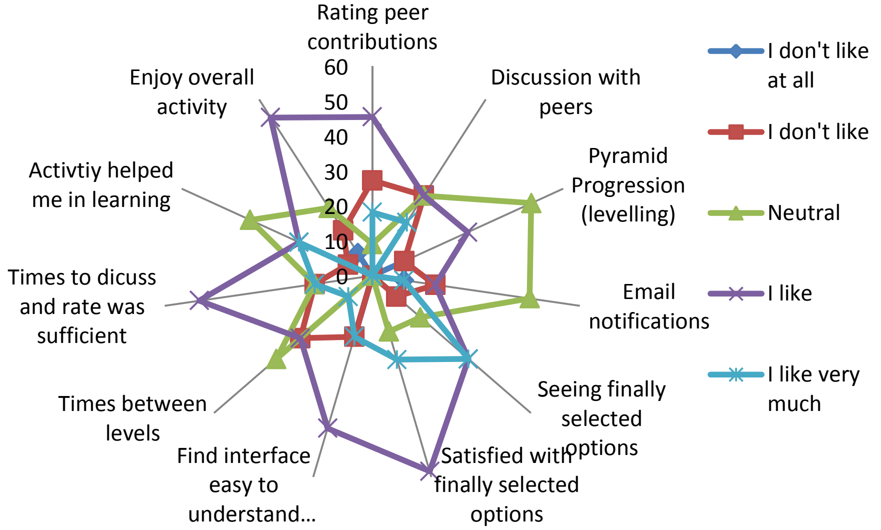


Figure C.10: Mean values and preferences spread of Protocols class (distance mode)

C.3: Analysis of with/without technology orchestration

Few cases, mentioned in section C.2, were enacted by emulating the Pyramid model, orchestrated by the class teacher, without any technological mediation. The objectives of conducting these experiments were to assess the feasibility of the proposed model and to identify strengths and weaknesses in each approach (with/without technology mediation) in face-to-face classroom contexts. Following is the summarised discussion on how does implementing Pyramid activities in class can be compared without using PyramidApp tool.

Set of experiments were carried out in each selected population, emulating the Pyramid model but without PyramidApp during face-to-face classrooms. Participants were given instructions about the activity before presenting the task at the beginning. The teacher was giving instructions to structure the Pyramid orchestration at each level while being conscious about timing values between levels too, trying as much as possible to mimic the proposed Pyramid model. During these sessions, several observers took notes and students completed a survey at the end of the activity. For all the cases, initially a common task was given to attend individually and then after sometime (e.g., 5 - 10 minutes), the teacher instructed them to formulate small groups (e.g., 3 or 4 in each) to discuss and come-up with an agreed solution. As these were typical lecture rooms there were space limitations for moving around. Thus neighbouring students formulated groups most of the times. Then again after some minutes, teacher asked them to merge those near-by small groups to form larger groups and finally to speak up their agreed option for the given task. Lots of interactions and discussions were observed almost in all the populations at the small group level, overwhelmingly richer than small group interactions observed through PyramidApp. Many were comfortable opening up and discussing in small group contexts. This was not the common behaviour when groups were merged into larger groups. According to observers' notes, still most of them were discussing within their small groups even if they were in large groups.

Group formation was not easy and straightforward in such classroom contexts during collaborative learning enactment. They were not following teacher's instructions correctly most of the times (e.g., if the instruction was to discuss in groups of 3 to 4, but students discussed in groups of

2). Larger group formation was even more difficult, once class of 40 students ended up having 5 larger pyramids where teacher was expecting either 2 or 3 large groups. It was also observed that most of the times, students form groups as they prefer in these large groups irrespective of teacher's requirements and comparatively less amount of interactions were observed. Mostly the group leaders from previous smaller groups dominantly took the lead of the discussion rather giving equal opportunities to every member in the larger group. On the contrary, through PyramidApp, each individual gets the opportunity of speaking up irrespective of the group size. Very interesting interaction behaviour was observed with one of the first year groups. When the teacher asked to form larger groups, several small groups gathered together forming a group of around 20 (relatively the largest from all other populations) and most of them were engaging in groups discussions very actively and interestingly as one group and consensus was reached by voting for the options by raising hands.

Masters students, second and third year engineering undergraduate populations clearly indicate that they enjoyed the exercise with an overall activity enjoyment mean being above 4.0 and over 70% satisfaction percentage. Also they had appreciated the negotiation process of options and knowing peer ideas (mean = 4.2). The results show the feasibility of the model in a face-to-face classroom with higher interactions and engagement to a certain extent. Yet the orchestration of the desired flow is not always achieved. Thus, how far the situation is feasible to monitor and orchestrate while forming the groups with no support from technology is questionable. This issue can be even more challenging when large classes are considered.

C.4: MOOC rounds analysis

PyramidApp was presented as one collaborative activity in the "3D Graphics for Web Developers" MOOC by UPF in the FutureLearn platform. Main objectives of the experiment were to evaluate dynamism mechanisms proposed by the model, scalability approach and the distance mode of PyramidApp and its features like email notifications. The application was offered as an external link within the course page in each week. Also it was mentioned as an optional activity explicitly in the MOOC. Within the course design, there were five rounds of PyramidApp activities (Three in the first run and two in the second run of MOOC). Figure C.11 shows the level of participation in different stages of PyramidApp interactions. New logins are the unique activity participants, total number of accesses count everyone who logged into the application irrespective of participating or not in the Pyramid flow. A feedback survey was attached at the end of the activity and summary of results is given in Figure C.12.

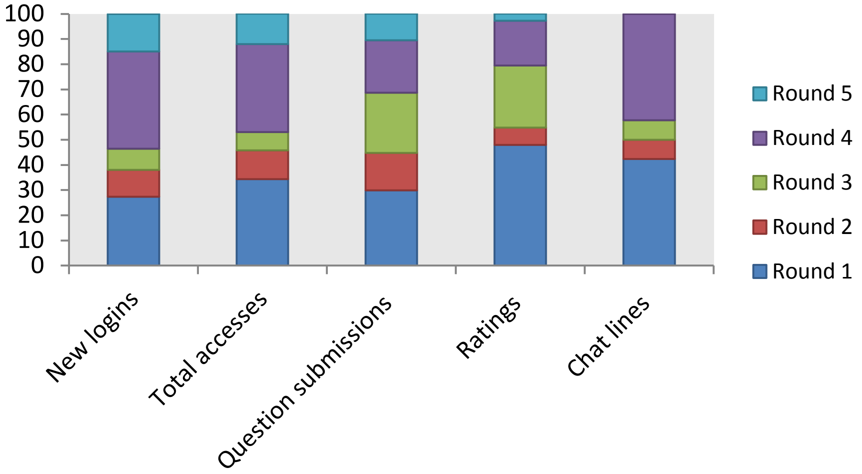


Figure C.11: Percentages of participation of MOOC learners at different levels of PyramidApp

Rating peer options	Discussions (chat feature)	View full discussion	Pyramid progression	View finally selected options	Interface was easy to understand	Satisfied with final options	Enjoy activity
3.26	3.15	3.48	3.04	3.56	3.04	3.52	2.89

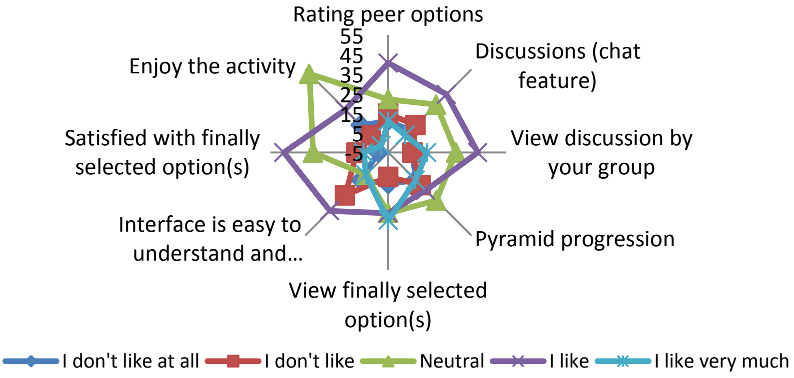
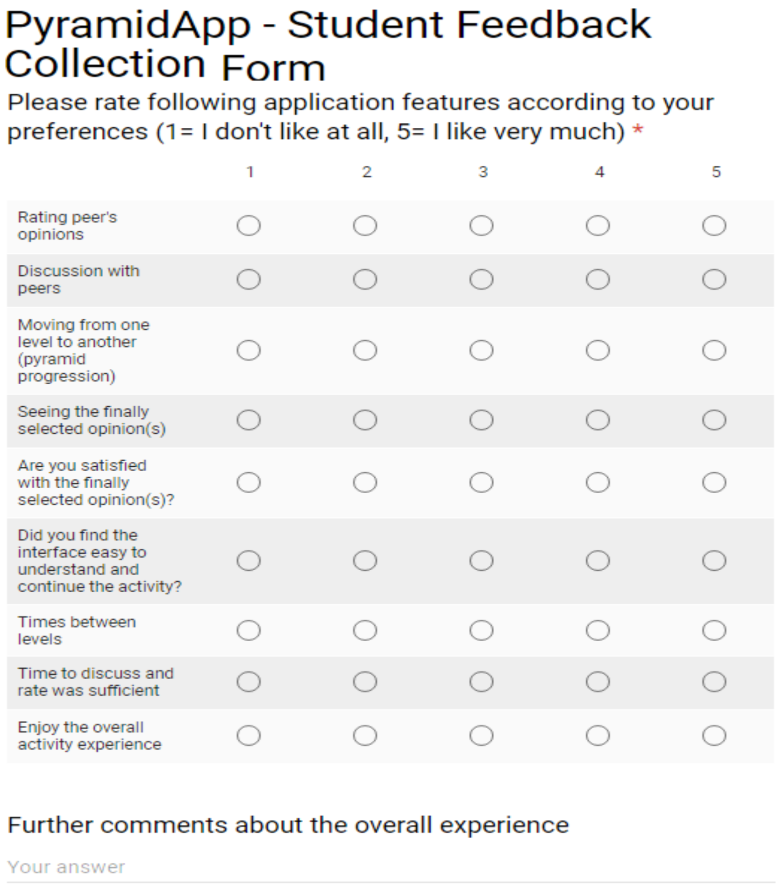


Figure C.12: Mean values and preferences spread of MOOC participants

Some interesting comments received from learners are, “very useful tool when there are too many students”, “I was keen on voting” and “include a history of all questions that were posed by a user”. Diverse learner preferences were found; some did not like the timing, “time constraints were tight considering a FutureLearn course” whereas another stated “seeing one question for the whole day is inefficient and frustrating”. Some did not like the structure of the flow since it is filtering their options and some mentioned that they did not understand how the Pyramid flow works. Considering lower mean values (Figure C.12), it’s worthwhile to study whether further technological improvements in user-friendliness and ease of understanding can overcome these hindering issues.

C.5: Generic questionnaire template for PyramidApp enactment system



PyramidApp - Student Feedback Collection Form

Please rate following application features according to your preferences (1= I don't like at all, 5= I like very much) *

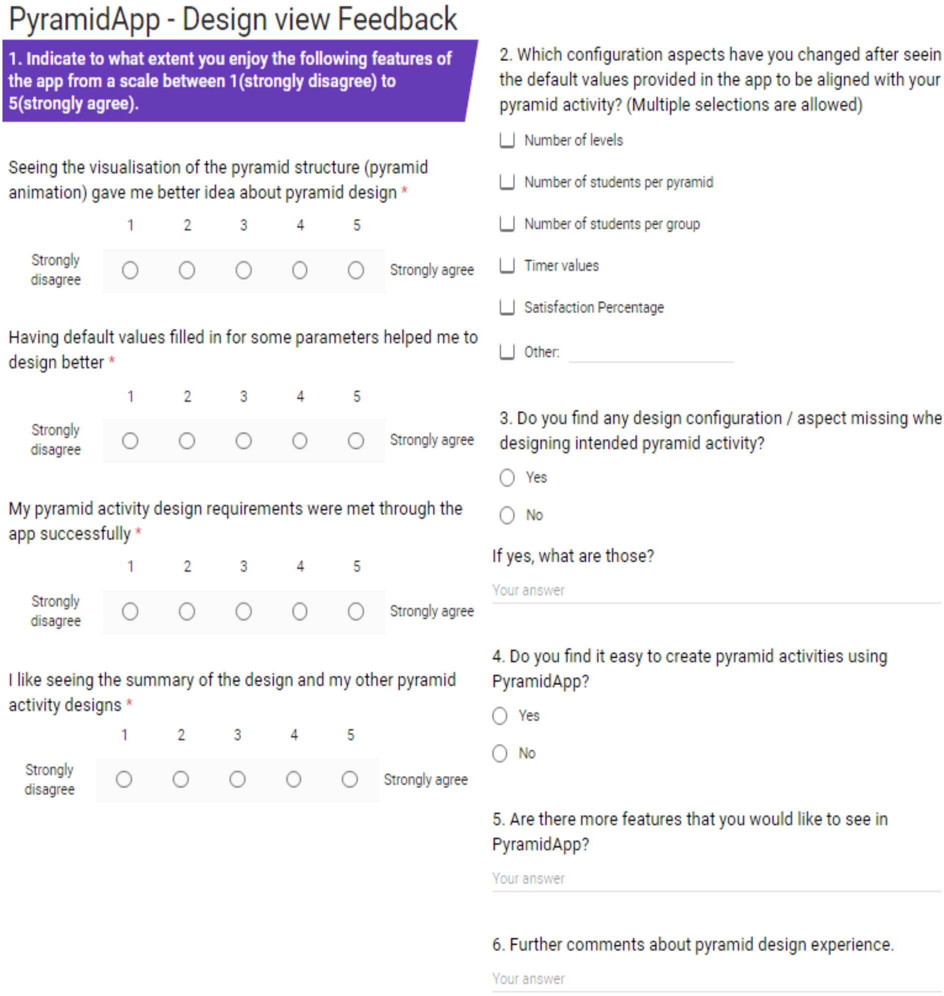
	1	2	3	4	5
Rating peer's opinions	○	○	○	○	○
Discussion with peers	○	○	○	○	○
Moving from one level to another (pyramid progression)	○	○	○	○	○
Seeing the finally selected opinion(s)	○	○	○	○	○
Are you satisfied with the finally selected opinion(s)?	○	○	○	○	○
Did you find the interface easy to understand and continue the activity?	○	○	○	○	○
Times between levels	○	○	○	○	○
Time to discuss and rate was sufficient	○	○	○	○	○
Enjoy the overall activity experience	○	○	○	○	○

Further comments about the overall experience

Your answer

This is a generic template of the questionnaires used during the evaluation studies of PyramidApp enactment system. Customized, particular questionnaires were used depending on the case study and the nature of the study. For example, when PyramidApp tool was not used, but the Pyramid model was adopted, some of the questionnaire elements were changed. Also in the distance mode of the application, another version of the questionnaire was used. The questionnaires were translated to Catalan and Spanish and the understandability of the items cross-checked by the teacher.

C.6: Generic questionnaire template for PyramidApp authoring system



PyramidApp - Design view Feedback

1. Indicate to what extent you enjoy the following features of the app from a scale between 1(strongly disagree) to 5(strongly agree).

Seeing the visualisation of the pyramid structure (pyramid animation) gave me better idea about pyramid design *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

Having default values filled in for some parameters helped me to design better *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

My pyramid activity design requirements were met through the app successfully *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

I like seeing the summary of the design and my other pyramid activity designs *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

2. Which configuration aspects have you changed after seein the default values provided in the app to be aligned with your pyramid activity? (Multiple selections are allowed)

☐ Number of levels

☐ Number of students per pyramid

☐ Number of students per group

☐ Timer values

☐ Satisfaction Percentage

☐ Other: ________

3. Do you find any design configuration / aspect missing whe designing intended pyramid activity?

○ Yes

○ No

If yes, what are those?

Your answer

4. Do you find it easy to create pyramid activities using PyramidApp?

○ Yes

○ No

5. Are there more features that you would like to see in PyramidApp?

Your answer

6. Further comments about pyramid design experience.

Your answer

Appendix D: Additional Related Publications

In addition to the key publications mentioned in above main chapters, additional exploratory or complementary work related to the dissertation was carried out and published during the dissertation time as following:

- Manathunga K., Hernández-Leo D., Caicedo J., Ibarra J.J., Martinez-Pabon F., Ramirez-Gonzalez G. (2015) Collaborative Learning Orchestration Using Smart Displays and Personal Devices. In: Conole G., Klobučar T., Rensing C., Konert J., Lavoué É. (Eds.) Design for Teaching and Learning in a Networked World. Lecture Notes in Computer Science, vol 9307. Springer.

Abstract

Pervasive classroom environments with interconnected smart devices permit enacting diverse pedagogical models in education. This paper proposes an extensible architecture integrating smart display, smart phones and wearable devices to support flexible orchestration of dynamic collaborative learning activities in face-to-face educational scenarios. The paper motivates an architectural design and describes its main components based on existing systems like Signal Orchestration System (SOS) and a multi-screen cooperation middleware. An applicable scenario illustrates the usage of proposed architecture in which wearable devices are used to indicate orchestration mechanisms (group formation, change of activity), a shared display visualizes tasks with summary of the orchestration and activity progress for collective awareness and smart phones are used to interact with the shared display and complete the activities.

- Michos K, Manathunga K, Hernandez-Leo D (2016) Connecting pattern-based learning designs with analytics: The case of the PyramidApp. *Connecting Learning Analytics and Learning Design (CLAD 2016) workshop* co-located with 11th European Conference on Technology Enhanced Learning (EC-TEL 2016). Lyon, France

Abstract

This paper presents preliminary work aiming to identify learning analytics that can be presented to teachers or learning designers to support (re)use or (re)design of learning scenarios based on the pyramid (a.k.a. snowball) pattern by using the PyramidApp. A pattern-based analytics approach considers teacher´s metacognition in three levels, t*he pedagogical intent, pedagogical method/structure* of a CLFP pattern and the *practicalities* to implement a learning scenario. Learning analytics are proposed to inform these three dimensions. A case scenario where $N = 38$ secondary school students in a face to face classroom used the PyramidApp was analysed from the log files of the App. The recommended analytics for teachers are visualized in such a way that are hypothesized to foster decision making for customization of specific design elements of the pyramid pattern.

- Melero, J., Hernández-Leo, D., & Manathunga, K. (2015). Group-based mobile learning: Do group size and sharing mobile devices matter? *Computers in Human Behavior, 44*, 377-385.

Abstract

Within the field of Game-based Learning (GBL) location-based games are based on pervasive and mobile learning to allow the creation of in situ learning activities considering gamification mechanisms. In these learning activities collaboration often plays an important role. Usually, groups of students have to perform different tasks with single mobile device. This paper studies the effects of sharing a mobile device within groups and the size of groups in students' engagement and their activity performance in an indoor location-based learning activity. In particular, the paper focuses on a game designed by a secondary education teacher to support a learning activity in a contemporary art museum. The teacher's design has been implemented using "QuesTInSitu: The Game" technology. A total of 76 students played the game during a 3 hours activity in the museum. The analysis of the data shows that while there are not important differences in the satisfaction with the activity of the students carrying and not carrying the mobile device within their groups, carrying the device does have a significant (positive) impact in their performance. Group size (4 vs. 5 members) does not seem to be a variable affecting individuals' performance but students in 4-member groups express higher levels of engagement.

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