

Authoring and enactment of mobile pyramid-based collaborative learning activities

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Abstract

Collaborative learning flow patterns (CLFPs) formulate best practices for the orchestration of activity sequences and collaboration mechanisms that can elicit fruitful social interactions. Mobile technology features offer opportunities to support interaction mediation and content accessibility. However, existing mobile collaborative learning research has mostly focussed 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 particularisation 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 particularisation 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 its design and applicability to their educational contexts. PyramidApp flows were enacted in three higher education settings. Learners enjoyed the activities but usage and satisfaction varied depending on several design and contextual factors like the epistemic tasks given, the education level and application mode (face-to-face or distance).

Introduction

As mobile devices become part of everyday life (Kukulka-Hulme & Sharples, 2009; Sharples & Pea, 2014), various research works have shown possibilities of mobile technologies to impact learning (Lai & Wu, 2006; Sharples & Pea, 2014; Sharples & Roschelle, 2010) 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 (Sharples & Pea, 2014). How such devices can be utilized in active learning (Prince, 2004) supporting interaction mediation in formal educational contexts is underexplored (Hsu & Ching, 2013).

Computer Supported Collaborative Learning (CSCL) promotes technology-mediated peer interactions to result in fruitful learning experiences (Dillenbourg, Järvelä, & Fischer, 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.,

Practitioner Notes**What is already known about this topic**

- Technology can support design and enactment of structured collaboration leading to fruitful learning.
- Collaborative learning flow patterns (CLFPs) characterise well-known techniques to structure the flow of learning activities leading to potentially effective learning.
- Mobile devices can mediate interactions, allocate and access content in Computer Supported Collaborative Learning activities.

What this paper adds

- Pyramid CLFP particularisation for its implementation in learning scenarios supported by mobile devices while achieving flexibility in face-to-face and distance modes.
- PyramidApp authoring and enactment tools implement a particularisation of Pyramid CLFP; the tools facilitate an agile design and technology-mediated orchestration of Pyramid-based collaborative learning activities.
- Evidence of positive perception in using PyramidApp authoring and flow enactment using mobile devices in three higher education contexts.
- PyramidApp leads to effective technological orchestration; yet, learner satisfaction and enjoyment can vary depending on the learning design and the context in which PyramidApp is used.

Implications for practice and/or policy

- Teachers can design and enact Pyramid structured flexible collaborative learning activities easily to be implemented in the web or using mobile technologies.
- Learning design aspects (eg, epistemic task, activity duration, activity mode) authored in PyramidApp have an impact in the perceived usefulness and enjoyment.
- Learners participating in PyramidApp flows have the opportunity to express and discuss their contributions with peers, and to know, critically reflect and assess peers' contributions.

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 research studies in the literature have exploited the feature of mobility for education successfully (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, & Skogh, 2015).

Mobile devices can be utilized as means of coordination for negotiation, substituting or complementing face-to-face communication (Sharples & Pea, 2014). For example, in Boticki, Looi, and Wong (2011) students used handheld devices to solve mathematical tasks in groups to achieve a common goal; the mobile application was providing scaffolding like suggesting peers for groups

and teacher facilitation. In another study, wirelessly intercommunicated handhelds were used in maths and language learning to address challenges in coordination, negotiation, organisation of materials and lack of mobility that exist in a nontechnology supported collaborative environment (Zurita & Nussbaum, 2007). Students in a nursing school used Personal Digital Assistants as supporting tools to share the final concept maps which 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 portions of longer flows but are not fully supported by the mobile devices.

In CSCL, collaboration scripts are used to define and manage expected collaborations in pedagogical scenarios by defining flows (or sequences) of activities, distributions of groups, roles and resources (Dillenbourg et al., 2009). Collaborative Learning Flow Patterns (CLFP) capture the structure of well-known collaboration scripts that can potentially lead to effective interactions (Hernández-Leo et al., 2006). Some examples of CLFPs are Jigsaw, Pyramid and Think-Pair-Share. Orchestration, in CSCL, refers to the real-time management of complete flows of collaborative learning activities (Dillenbourg, 2013), including group formulation and allocation, resource distribution and activity sequencing. Complex orchestration situations can be facilitated by technologies, but those should be flexible to support dynamic modifications of pre-designed flows (Dillenbourg et al., 2009; Hernández-Leo et al., 2006) caused by unexpected situations like increase or decrease of activity participants, disconnections of mobile devices et cetera. Such circumstances cause problems for a real time adaptive compliance with the pedagogical constraints (eg, regarding meaningful group formation or activity progression) of the CLFP. For example, in Jigsaw CLFP (Hernández-Leo et al., 2006), at least one student with certain profile (expertise gained in a previous activity working within expert groups) is expected as a member of a final jigsaw group, so the group can solve a global problem. If experts are missing, smart modifications of groupings are required to comply with the flow constraints behind Jigsaw.

Pyramid is another example of CLFP since the Pyramid technique has been recognised as good practice in the structure of collaborative learning activities flows, which can be particularised and applied iteratively to multiple epistemic tasks and educational levels (Davis, 2002; Hernández-Leo et al., 2006). This paper studies Pyramid pattern and introduces a technological implementation (PyramidApp) that enables the orchestration of complete Pyramid flows in diverse scenarios (including formal higher education settings). A Pyramid flow is initiated with individual students solving a global task. Then, in a second level of the Pyramid, such individual solutions are discussed in small groups and agreed upon a common proposal. These small groups then form larger-groups iteratively and large group discussions will continue till a consensus is reached at the global level. Pyramid flows foster individual participation, accountability and balanced positive interdependence (Hernández-Leo et al., 2006). Furthermore, the Pyramid pattern promotes conversations in incrementally sized groups, clear expectations of reaching consensus and positive reinforcement mechanisms leading to desired positive behaviours in the learning process (Fluke & Peterson, 2013). There are some examples of technology-supported Pyramid-based activities in the literature. Group Scribbles (Roschelle et al., 2007) use tablets to engage in Pyramid structured learning activities whereas ColPad (Nussbaum et al., 2009) provides collaborative scaffolding from individual to classroom level using handheld devices. Yet, these approaches do not aim at facilitating scalability and flexibility in the flow orchestration aspects or at enabling more generic Pyramids to be designed by the teacher.

As scalability, we mean the capability of a learning technology orchestration approach to elastically accommodate growing numbers of activity participants while maintaining pedagogical and practical effectiveness. By dynamism, we mean the capability of a learning technology orchestration approach to flexibly keep activity progression while preserving a meaningful orchestration,

enthusiasm and usability. PyramidApp implements a particularisation of Pyramid CLFP, addressing scalability and dynamism in the flow orchestration where learners propose solutions to a task, discuss and rate the solutions in increasingly larger groups. Also, PyramidApp enables generic Pyramids as teachers can design diverse types of activities by using an authoring tool. The Pyramid particularisation behind PyramidApp and a preliminary version of the enactment tool was evaluated in Manathunga and Hernández-Leo (2016). Initial results showed that dynamism and scalability are addressed successfully with PyramidApp while pointing out the potential of PyramidApp to support active learning in classroom and distance settings. Lectures are effective means to motivate and introduce new concepts; yet there is a significant body of evidence showing that integration of engaging tasks during lectures improves learning (Herreid, 2006; Prince, 2004) and PyramidApp aligns with these previous research work.

Taking this knowledge as a basis and considering the challenge of how to enable technology-support for diverse types of Pyramid activities that can be designed by the teacher, with value for higher education settings, the specific research questions addressed in this paper are how feasible and usable it is to create flexible Pyramid flows using PyramidApp authoring tool, and how teachers and learners perceive such active learning across different settings in higher education (educational levels, sample sizes), with different designs of epistemic tasks and using different application modes (face-to-face in-class or distance). Next section presents an overview of PyramidApp authoring and enactment systems. The following section describes the evaluation methodology applied, followed by a presentation of results and a discussion articulated around the highlighted research questions above. The paper is concluded with a summarised discussion appended by future research directions.

PyramidApp: authoring and enactment

The structured cumulative flow of collaborative activities promoted by Pyramid CLFP inspired the model underlying PyramidApp, which is a web-based scalable, dynamic collaborative learning application, integrated within the Integrated Learning Design Environment (ILDE) (Hernández-Leo, Chacón, Prieto, Asensio-Pérez, & Derntl, 2013). PyramidApp is accessible at <https://ilde.upf.edu/pg/lds/neweditor/pyramid/> (registration is required). Design of potentially effective collaborative learning activities should consider offering students opportunities for individual explanation, group argumentation and negotiation as well as 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 (flexibility to modify pre-created scripts meaningfully) and scalability (ability to cope with growing numbers of students while being effective). PyramidApp has two components: the Pyramid flow authoring (ie, design and monitoring component for teachers to create and observe ongoing or previously finished activities) and the Pyramid activity enactment for learners to engage with the activity.

Pyramid flow authoring

Pyramid activity flow creation interface is used to input activity details such as task, mode (either face-to-face or distance), enable chat feature and other parameters affecting the Pyramid algorithm to formulate pedagogically meaningful and flexible activity flows. The algorithm uses three sets of rules for flow creation, control and awareness to maintain dynamism and scalability in the Pyramid CLFP orchestration. 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 a meaningful orchestration, enthusiasm and usability.

- Flow creation rules: 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 first rating level (after completing individual submission in Pyramid level 1), number of students per Pyramid, maximum number of students per Pyramid calculated as (students per Pyramid *2) – 1.
- Flow control rules: 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 activating countdown timers.
- Flow awareness rules: to trigger signals of flow status for participant awareness. 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.

Flow creation affects scalability while flow control and awareness rules achieve dynamism. Using the total class size, the amount of participants allocated to a Pyramid with other flow creation parameters, the algorithm is capable of creating multiple Pyramids to accommodate the actual crowd. Likewise, number of students per Pyramid and maximum number of students allowed to a Pyramid are the parameters used to achieve scalability. Number of levels, two-time limits (initial option submission and rating) and active user percentage help to maintain dynamism of the activity without freezing Pyramid branches in case participants are not active for whatever reason (eg, 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.

Figure 1 depicts a portion from the PyramidApp authoring system (for additional details, PyramidApp user manual can be found at <https://www.upf.edu/es/web/edutec/pyramidapp>). Level 1 is the individual option submission. Level 2 onwards are the collaborative steps, where participants are grouped iteratively generating accumulated interactions to enrich the learning experience. Most of the parameter fields are presented with default configurations, which the educators can modify. A field description is available as a tooltip (see “i” icon) explaining the parameter. “Advanced settings” button loads the timer values and an active user percentage. Maximum time limits for option submission and rating can be specified from minutes or even days (eg, in distance or blended settings). Countdown timers are used (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 the enactment using “activity tab” of the ILDE interface. Teachers can monitor each Pyramid, highly rated options, participants list, individual options, ratings and discussion lines.

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. Figure 2 displays activity enactment (Pyramid level 3) interface in a mobile device. In PyramidApp, individuals propose options (ie, an answer to a question, a question on given topic, a created artefact sharable as a web link, et cetera) in level 1. The algorithm then creates small groups for level 2, where participants share thoughts and concerns about the options suggested in the previous level, clarify and negotiate the most interesting option before confirming ratings. Highly rated options are promoted to upper levels and smaller groups

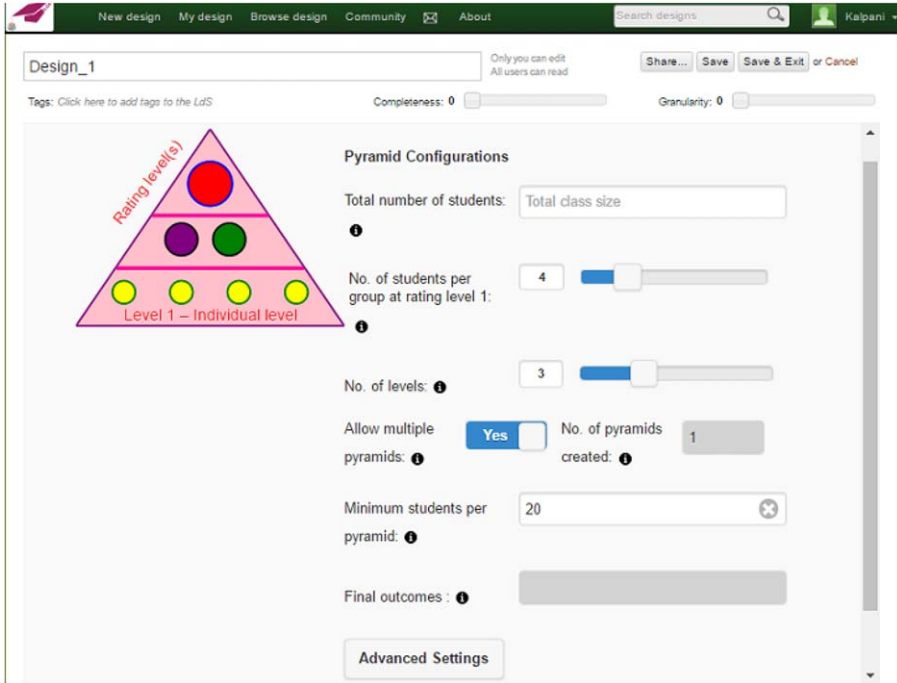


Figure 1: PyramidApp authoring accessible at <https://ilde.upf.edu/pg/lds> (new design - authoring - PyramidApp) [Colour figure can be viewed at wileyonlinelibrary.com]

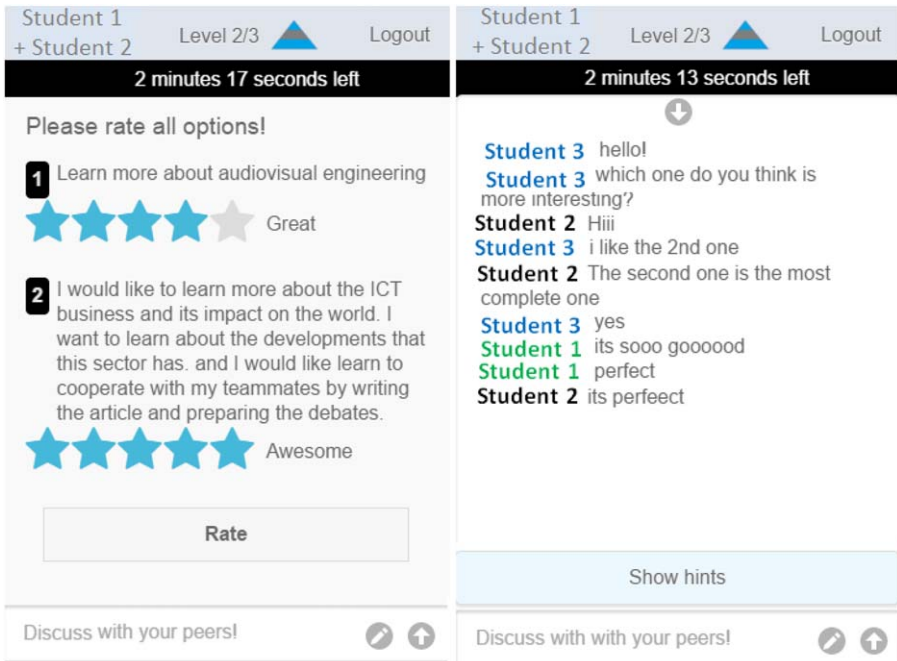


Figure 2: Mobile view of PyramidApp enactment (rating and discussion) [Colour figure can be viewed at wileyonlinelibrary.com]

grow into larger following a Pyramid structure. Rating and discussion propagate till the complete group reaches upon consensus at the final level. At the end, finally selected options for each Pyramid are displayed (eg, 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. Instead, multiple Pyramids of 20 students, each selecting 1 option as highly rated from 100 students (20 students per Pyramid * 5 options = 100) is more feasible. Each individual still has the opportunity to express and discuss their contributions with peers, and 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.

Evaluation methodology

Experimental settings

Three workshops were conducted with 32 teachers, of various educational levels (from secondary to higher education, having a higher representation (>70%) of high school teachers), with different subject matters and a diverse range of teaching experience (from 2 to over 30 years) to evaluate the PyramidApp authoring system. All workshops were structured similarly where an expert on Collaborative Learning (CL) initiated the workshop by giving an introduction to CL and flow patterns followed by a discussion of the types of CLFPs with examples. Then workshop participants engaged in a PyramidApp activity to learn 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 according to their expectation and curriculum requirements. PyramidApp enactment experiments were conducted across three different education levels of engineering higher education studies (from bachelor to masters level), each using PyramidApp several times in several 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. Most students were using mobile phones to participate in the PyramidApp activities especially in those cases where the activities were carried out in regular face-to-face lectures (see Table 1). Only one session was conducted in a computer lab where they were using desktop computers and in few cases students used their laptops to access the activity. When the application was administered in distance mode, students preferred desktop devices than mobiles (Table 1).

Data gathering

The experimentation was designed to evaluate the teacher-configurable Pyramid-based collaborative learning method using mobile devices, and to evaluate to what extent its features support a satisfactory active learning behaviour in different settings (educational levels, sample sizes), with different designs of epistemic tasks, and using different application modes (face-to-face in-class or distance). We conducted a mixed approach for data analysis triangulating both quantitative and

Table 1: Device usage across populations during experiments

Education level	Face-to-face		Distance	
	Laptop or desktop	Mobile devices	Laptop or desktop	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	

qualitative data to answer our research questions (Twining, Heller, Nussbaum, & Tsai, 2017). Different data collection instruments were used: informed consent surveys at the end of the experiments with Likert scale questions ranging from 1 (I don't like at all) to 5 (I like very much) and open-ended questions asking participant opinions about the experience; interviews with teachers focussed on the activity timing, their opinion about students' performance along the activity and the selected options in the top level of the Pyramid; direct observations by one to three researchers (depending on the course and the round) documenting behaviours of students, and activity logs generated by the application. The potential positive effects of the active behaviour (achieved by using PyramidApp) were analysed from the perspective of the didactic intentions of the educator. Some of these intentions were common in all cases: enacting initial reflection about the proposed task, having access to and reflecting about peer's ideas and motivating an overall discussion led by the educator. Additional intentions depended on the epistemic task (eg, raising common mistakes in difficult problems).

Results and discussion

Designer's experience

In all workshops, participants appreciated positively the application and some expressed their willingness to use PyramidApp in their classrooms. However, others suggested several modifications 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 (eg, showing default parameter values, Pyramid structure animation, view activity summary and Pyramid design requirements were met successfully). Over 80% accepted that default field values helped to design easily (Figure 3), yet all of them changed more than one parameter value to suit their contexts. Many had overridden default values for basic Pyramid settings like number of levels or students per Pyramid, but not many changed advanced parameters (active user percentage or timer values). Several

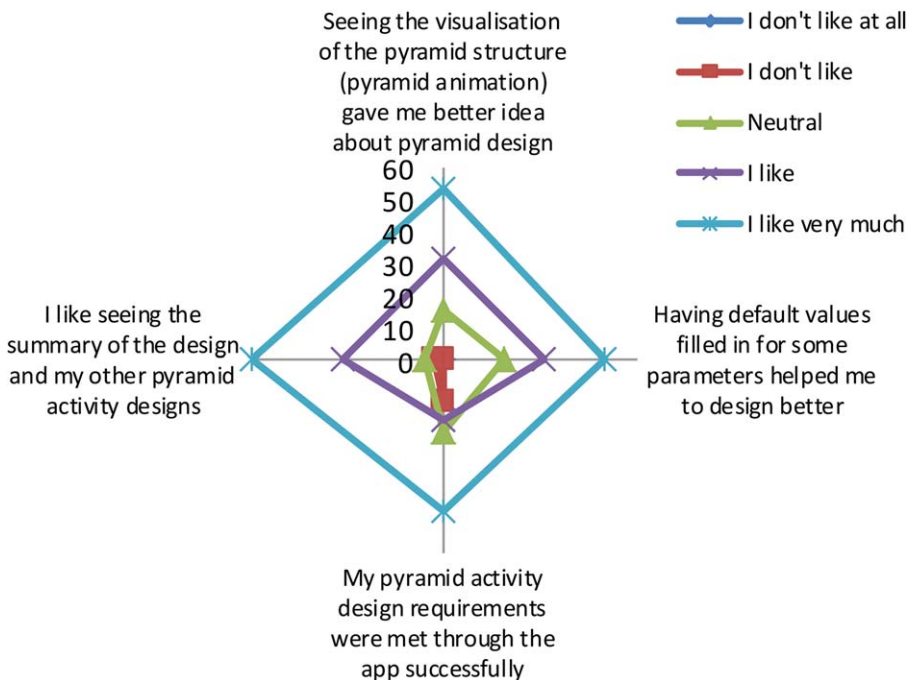


Figure 3: PyramidApp authoring features [Colour figure can be viewed at wileyonlinelibrary.com]

mentioned comments like the application is very easy-to-use, useful and effective. Two suggested enabling blended mode Pyramids using both f2f and distance modes with different timer configuration for each. They requested to have shorter timer values for the classroom f2f levels and longer values for the distance mode within the same Pyramid flow. Several others suggested integrating evaluation mechanisms and different analytics to the system, so they can assess students based on activity performance. 89% from the last workshop (in which 19 teachers participated) stated that flow authoring is easy using PyramidApp. Also the observer(s) stated that teachers were interested in using the application and appreciated its value. One observer said, "...participant #1, #2, #3 and #4 seemed very interested. They share many ideas on how to use PyramidApp..." and another stated that, "...they were taking pictures of their screens, they were happy. Many discussions happened with the workshop instructor. They seemed interested to see the monitoring view." It was also observed that some teachers used PyramidApp with their students few days after the workshop integrating active, engaging tasks to enrich the learning experience, as such active practices had shown learning benefits in the literature (Herreid, 2006; Prince, 2004).

Learner's experience

A cross-analysis is conducted for the three populations of higher education students, to understand different student behaviours of using PyramidApp and how educators and learners perceived this active learning method during the enactment. In the real scenarios studied, the effects of active behaviour were analysed from the perspective of the didactic intentions of the educator, as mentioned previously. Table 2 shows how PyramidApp enabled learning through collaborations with reference to the framework proposed by Szewkis, Nussbaum, and Rosen (2011) as observed during the experiments.

Table 2: Condition of collaborations

<i>Condition</i>	<i>Description</i>
Common goal	The groups had to collectively reach a consensus upon a common task.
Positive interdependence among peers	Participants were aware that they needed to achieve their common goal together. They could proceed only after all participants complete level by level within the time limit. Participants helped each other clarifying ideas to complete the ratings and progress to the next level.
Coordination and communication among peers	Peers had to discuss in order to reach a consensus to select the most appropriate option to proceed. Intensity of discussions varied across cases.
Individual accountability	In the individual stage, students should provide an option for the given task. Students were aware that they should contribute with ratings and discussion, so the better option is selected and the Pyramid progresses.
Awareness of peer's work	Students knew who were joining their Pyramid-growing groups. Starting from small groups, peers saw the options submitted by the others in the group. While waiting between levels, they saw the options from the other branches of the Pyramid groups.
Joint rewards	Students knew that the jointly selected answers would progress along the Pyramid. Groups saw how they were being able to progress along the levels in the Pyramid (eg, number of current level vs. total number of levels visualized). Teachers monitored the progress and discussed joint answers collectively.

Table 3: PyramidApp enactment features

Education level	Measurement	Peer rating	Pyramid Progression	View highly rated options	Interface comprehension	Activity enjoyment
Masters class	Mean value	4.3	4	4.4	4	4.2
	Percentage of students liking the feature	86%	67%	89%	75%	80%
Second year	Mean value	3.8	4	4.2	4.1	4.2
	Percentage of students liking the feature	61%	74%	76%	74%	82%
First year	Mean value	3.6	3.4	3.8	4.3	3.7
	Percentage of students liking the feature	53%	47%	65%	83%	64%

Learner behaviours and satisfaction by education level

All three populations valued the application features like rating peer options, engagement achieved by the Pyramid progression (levelling up) and visualising popular (highly rated) options (see Table 3). Furthermore, most groups rated the level of interface understandability high and stated that the application was useful and engaging. Since several rounds of PyramidApp activities were administered (3–6 Pyramid flows in 2–3 sessions), participants could familiarise themselves with the application. Master's students appreciated the activity highly with higher values for the activity enjoyment. Some of them stated that, “the selection and rating of the questions was self-explanatory and entertaining,” “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 well in the distance mode of the PyramidApp. As shown in Table 3, results indicate that PyramidApp is easy to comprehend and understand, requiring only few rounds to be familiarised. As shown in the related studies applying the Pyramid pattern (Nussbaum et al., 2009; Roschelle et al., 2007), these activities lead to students' enjoyment and active learning opportunities.

Learner behaviours and satisfaction by application mode

Most of the PyramidApp rounds were conducted in f2f scenarios. Two sessions (one with the first-year and another with the second-year) were enacted using the distance mode of the application. In the distance mode, students were receiving emails notifying about the activity progress, avoiding the need to be online all the time. Comparatively in f2f sessions, the discussions were rich and ample as stated by observers and further confirmed by mean values >4.0, unlike the distance mode across all populations. In the classrooms, sometimes even if the students were not using the chat feature integrated, they were still discussing with their neighbours. A common observation of two distance scenarios was that some students missed the initial submission phase due to either late access or ignored timing values instructed in the email notification. Irrespective of the activity being distance or f2f, students rated waiting timer a low score showing that they do not like waiting till others progress along the Pyramid (Figure 4). To address this, PyramidApp was modified to show other groups' options in the waiting screen so they can reflect on peers' options while waiting.

Learning impact, behaviours and satisfaction by type of epistemic task and activity duration

In the Masters' class, the activity consisted of brief time durations due to time restrictions and the nature of the task (Pyramid flows to propose and agree on the questions to peers after having

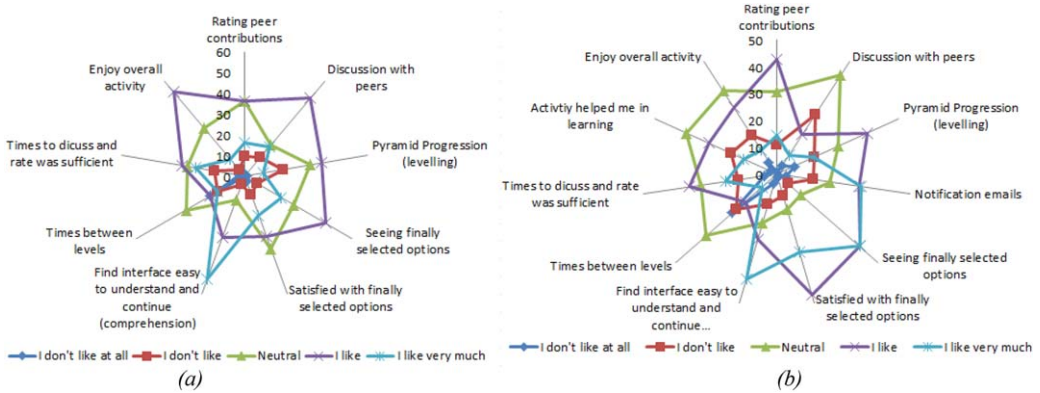


Figure 4: First year case study analysis, (a) face-to-face, (b) distance [Colour figure can be viewed at wileyonlinelibrary.com]

presented an assignment). Results show students enjoyed the activities but lower satisfaction for timing values in this case, which also affected their perception of usefulness of the discussion feature (Table 4). Second-year group spent (a bit) longer time durations, yet the teacher said that, “the activity consumed fair time.” That activity was configured with 5 minutes for submission phase and 3 minutes for discussing and rating deliberately by the teacher because the task was very challenging and wanted students to fail, to establish the conditions of a motivated and rich discussion in the classroom about why they failed and which would be the right answer. This approach follows the productive failure method (Kapur & Kinzer, 2009), which suggests designing conditions to solve complex tasks in which students may fail initially, yet including a hidden efficacy pertinent to learning. Students enjoyed the activity but did not come up with the correct solution at the end, as intended by the teacher. From the perspective of learning gains, 77% (mean = 4.2) of the second-year group and 72% (mean = 4) from the Master’s level believed that the activity helped them in learning which was further contrasted with the averages of the final exam grades for the courses taught in traditional lecture mode versus those taught with PyramidApp by the same teachers (Table 5). The results indicate that grade averages increased in two courses and was maintained the same in the third. In the second-year group, 62% (mean = 3.9) enjoyed discussing with peers and the teacher mentioned that the application helped to enact rich discussions during the class. About 76% of the first-year group agreed that they had sufficient time for discussion and rating and the activity durations were very fair, but this differed sometimes based on the application mode (f2f or distance). In terms of the utilisations of the

Table 4: Activity time and discussion comparison across populations and tasks

Education level	Type of the task	Satisfied with finally selected options	Discussion with peers	Sufficient time to discuss and rate	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
	Open ended opinion seeking	3.6	3.7	3.6	3.7	10 minutes

Table 5: Averages of student grades (out of 10) across three courses (using PyramidApp vs. not using)

Education level	Not using PyramidApp	Using PyramidApp
First year	6.8	7.4
Second year	5.4	5.4
Masters' class	8.2	8.5

Table 6: First year experiments indicating learner familiarisation

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

discussion feature, results indicate that the first-year group did not like it much, whereas the other two groups had appreciated it comparatively. Yet the open-ended opinion seeking task, of the same first-year group, had a mean of 3.7 (68% appreciation) for the discussion feature.

Activity enjoyment once novelty effect passes

All three populations enacted PyramidApp activities on several days, in several rounds (3–6) in order to minimise the effect of introducing novel technology to the classroom. For first-year group, first rounds of Pyramid flows were conducted in their practical classes (from 26 to 29th September, 2016) where students were using desktop computers and one observer was taking observations. Several students could not submit options or rating timely as they were not paying attention to timer notifications. Some groups used the chat feature extensively while some did not. In some sessions, educators were also participating in the Pyramids and it was observed that students were enjoying discussion and negotiation, seeing that the educator was also active within the group. The second and third round of PyramidApp activities were conducted later (Table 6). Results indicate an improvement of 23% 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 over the time, which may be attributed to the fact of changing the types of learning tasks in these rounds. The second round was an open-ended opinion seeking activity whereas the third was a case study analysis.

Conclusion

This paper has proposed and studied the impact of mobile orchestration technology in higher education collaborative learning scenarios. A Pyramid flow particularisation was adopted and implemented as the PyramidApp application. It includes an authoring tool for flow creation and monitoring, and an enactment tool to engage learners in activities across the flow. Teachers, participating in training workshops, valued positively PyramidApp features, the authoring experience and the applicability to their contexts. Three populations from the higher education context were used for experimentation to assess learner behaviours and satisfaction in PyramidApp activity enactment. Results show that PyramidApp was able to guide students through

proposing individual reflections or answers to a task, reading the ideas from their peers, giving their opinions and discussing iteratively, both f2f and distance classrooms. Students could join ongoing activities flexibly. The teacher discussed the answers selected as the most interesting ones through the collective effort and those answers that the teacher could monitor along the discussion and found worth mentioning to clarify concepts. Students enjoyed Pyramid activities, but the application utilisation and user satisfaction varied depending on the education level, epistemic task or application mode. In line with related work around active learning, data also showed positive perceptions and actual gains (average grades) regarding the impact on learning of PyramidApp-supported activities.

In some of the cases, rich discussions emerged outside PyramidApp. Besides, some students missed activity levels due to lack of attention for the application notifications, especially in the distance mode. Moreover, teachers provided several suggestions to enhance the applicability of the tool to their needs. Further investigations would be interesting in lines of improving usage of discussion feature and notifications to grab more learner attention as well as to implement ways to inject different types of tasks at different levels of Pyramid. One such improvement had already been implemented using scripted buttons with cues or sentence openers like “these aspects are not clear” or “I agree” or “I propose” to structure discussions and negotiations (Dillenbourg et al., 2009). In the PyramidApp authoring tool, usability aspects like visual appearance of the activity monitoring are aspects that require further improvements.

Statements on open data, ethics and conflict of interest

PyramidApp is available as an open source project in GitHub (Manathunga, Abenia, & Hernández-Leo, 2017). Due to privacy issues, experiment data will not be made publicly available. But, an electronic version of anonymized data will be made available and shared with interested researchers under an agreement for data access (contact: davinia.hernandez-leo@upf.edu).

All participants were informed well about the research objectives, contents and their right to easy withdrawal without reasoning and all gave informed consent. Data were treated anonymously and no personal identifiers were reported.

There are no potential conflicts of interest in the work.

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