

Some less obvious features of classroom orchestration systems

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Abstract

An orchestration system helps the teacher conduct a face-to-face class that includes small group work as well as activities by individuals and the whole class. The FACT (Formative Assessment with Computational Technology) system is an orchestration system designed to support formative assessment and collaborative learning. Students use tablets to edit electronic posters bearing movable cards. Teachers use a dashboard that both increases their awareness of their students' state and helps them move fluidly and easily among activities. The FACT system has undergone extensive iterative development, with 28 classroom trials so far. This chapter discusses some of the lessons we have learned about designing this orchestration system.

Keywords: Orchestration system, formative assessment, collaborative learning,

1 Introduction

Consider the following sample of technology for fostering learning:

- A *learning management system* is designed primarily for use by students working individually at home.
- A *classroom response system* (clicker) is designed primarily for use by students in a lecture hall.
- A *classroom management system* is designed primarily for use both by students in a computer laboratory and by the technicians who keep the lab's software up to date.
- A *tutoring system* is designed for use by individual students for doing homework or seatwork.
- *Synchronous shared media*, such as collaborative whiteboards or Google Docs, support small groups working simultaneously on a task; the members of the group can be face-to-face or remotely located.

All of these technologies can generate a stream of log data on students' activities. These data can be analyzed, perhaps in combination with other data such as students' self-reports, and then displayed on a *dashboard* as tables and graphics. Some dashboards are intended for teachers, whereas others are intended for both students and teachers (and often called "open learner models"). There is a rapidly expanding literature on dashboards for supporting learning—for reviews, see (Schwendimann et al., 2016; Verbert, Govaerts, et al., 2013).

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This chapter addresses *classroom orchestration systems*, which are designed primarily for use in a face-to-face classroom where students often work in small groups, but sometimes work individually or as a whole class. Classroom orchestration systems typically feature a dashboard used by the teacher and synchronous shared media used by students. They may also incorporate features of learning management systems, clickers, classroom management systems and tutoring systems.

The main design goal of a classroom orchestration system is to improve a construct called, not surprisingly, *orchestration*. The concept has been in the educational technology literature for several decades, but its meaning is still debated. Prieto et al. (2011) reviewed many conceptions of orchestration and listed 8 shared features, including (1) flexible regulation and management of the enactment of lesson designs or scripts, (2) the teacher's awareness of classroom events and learners' thinking, (3) a focus on pragmatic issues of authentic classrooms, and (4) good coordination of all the tools, social levels, scaffolding and resources in the classroom. Dillenbourg and Jerman (2010) began by equating good orchestration with teacher's feeling that the lesson "worked well." Dillenbourg (2013, pg. 485) later articulated the following widely cited definition:

Orchestration refers to how a teacher manages, in real time, multi-layered activities in a multi-constraints context. Many pedagogical scenarios integrate individual activities (e.g., reading), teamwork (e.g., problem solving) and class-wide activities (e.g., lectures). Some of these activities are computer-based, some not; some are face-to-face while others are online. This pedagogical integration is mirrored by the technical integration of different tools (simulations, quizzes, wikis, etc.) distributed over multiple artifacts (laptops, sensors, tablets). These integrated scenarios require forms of management referred to as orchestration.

Writers tend to agree that bad orchestration can prevent learning, but good orchestration does not necessarily foster good learning. Dillenbourg and Jerman (2010, pg. 2) point out, "For instance, the LOGO environment 'worked well' for many years but did not reach its promises in terms of learning outcomes (Pea, 1983; Tetenbaum & Mulkeen, 1984)." So good orchestration may be necessary but is certainly not sufficient for good learning.

Several orchestration systems were developed with the explicit goal of supporting small, face-to-face groups in a classroom context. Of these, *Group Scribbles* is perhaps the best known (Chen & Looi, 2011; Chen, Looi, & Tan, 2010; Hao, 2010; C.-J. Lin, Chen, Yang, Xiet, & Lin, 2014; C.-P. Lin, Wong, & Shao, 2012; Looi, Chen, Tan, Wen, & Wee, 2008; Looi, Lin, & Liu, 2008; Looi & Song, 2013). Students edit small cards on a private workspace then drag them into a group workspace, where cards can be moved but not edited. The teachers' dashboard lets them view any group's workspace as well as control the classes' activities in various ways.

MTClassroom is an orchestration system which supports small groups working around table-top computers (Kharrufa, Martinez-Maldonado, Kay, & Oliver, 2013; Martinez-Maldonado, Clayphan, Yacef, & Kay, 2015; Martinez-Maldonado, Dimitriadis, Kay, Yacef, & Edbaurer, 2013; Martinez-Maldonado, Kay, & Yacef, 2011, 2012; Martinez-Maldonado, Kay, Yacef, & Schwendimann, 2012; Martinez-Maldonado, Wallace, Kay, & Yacef, 2011). Four students sit around a table, one per side. A large touch-screen forms the surface of the table. Students

develop a concept map by creating nodes and linking them together. Teachers carry a tablet that is running a dashboard that displays the progress and collaboration activity of teach group.

Dillenbourg's group has explored several orchestration systems based on tangible user interfaces, such as paper cards with fiducials printed on them (P. Dillenbourg & Jermann, 2010; P. Dillenbourg et al., 2011).

This chapter describes a classroom orchestration system that we are developing called FACT (an acronym for Formative Assessment with Computational Technology). The chapter begins with a brief description of the current version of the system, then addresses some design issues. We picked issues that surprised us, either because we didn't know they were issues until we observed them occurring in our pilot classroom trials, or our initial solutions failed in unexpected ways.

Getting orchestration right is an incredibly complex problem. We have conducted over 28 classroom trials of the FACT system, and we are still discovering ways to improve it. This chapter shares insights gained from our experiences so far.

2 The goals of the FACT project

FACT currently implements 9 formative assessment lessons in mathematics. They were adapted from a collection of 100 paper-based lessons which were developed as part of the Math Development Collaborative (MDC). The paper-based lessons are called *Classroom Challenges*. They are freely available online (<http://map.mathshell.org>) and have seen millions of downloads. An independent evaluation of the implementation of the MDC in Kentucky found significant learning gains (Herman et al., 2015).

The Classroom Challenges aim to promote the practices of *formative assessment* (Black & Wiliam, 1998) and *collaborative learning* (Swan, 2006). A key feature of formative assessment is replacing corrective and summative feedback (right/wrong, scores, grades) with rich formative, diagnostic feedback that allows both teachers and students to understand and address their mistakes and misconceptions. As well as helping teachers adapt their teaching, good formative feedback prompts students to re-engage with their work to improve it.

In his work on collaborative learning, Swan (2006) developed a series of activity genres in which students work in small groups to develop joint solutions to problems. During these activities they are asked to justify their decisions to their peers and to critique the work of others. Some activity genres have students match or categorize sets of cards while justifying each card placement to their partners. The finished result is a poster, with the cards glued in place and surrounded by written explanations of the placements. Other activity genres, without card sorting, also use the group poster concept.

The Classroom Challenges are aimed at "changing the classroom contract" (Black, Harrison, Lee, Marshal, & Wiliam, 2002) from the traditional didactic mode where teachers rush to correct mistakes and students expect the teacher to supply answers, to a new mode in which the teacher offers probing questions that will help students find and correct their own mistakes. This is challenging for both teachers and students. Students are faced with tasks that are less clearly defined than a page of exercises and are called upon to question their own thinking and reasoning. Teachers need to come up with rich feedback and probing questions 'on the hoof',

making tricky judgments over when and how to intervene. Effective classroom orchestration is an essential part of meeting this challenge.

It is hoped that FACT can support aspects of formative assessment that teachers are find difficult, such as spotting evidence of misconceptions and providing appropriate formative feedback. FACT offers potential practical advantages, such as avoiding the need to cut out cards, or to collect, store and return posters. Of course, converting the Classroom Challenges from paper to electronic media faces many obstacles as well, which is what this chapter focuses on.

3 An overview of the FACT orchestration system

The FACT orchestration system is based on simple, familiar concepts. Authors create a *lesson*, which consists of a sequence of *activities*. Most activities involve students editing one or more *posters*. The activity determines whether students work individually or in groups and which posters are accessible during the activity. A poster is designed to look and operate like a large *posterboard* bearing movable *cards*. When the poster is given to students to work on, some of its cards have writing or images on them. For instance, there is always a card with instruction on how to do the activity. Students can create, delete, move, resize, write on, type on, pin or unpin cards. They can also write on the posterboard. Although a student can only view and edit one poster at a time, a group of students can edit the same poster simultaneously. Students view and edit a poster through a *viewport*, which can be scrolled and zoomed around the poster. In short, the FACT system supports only a few concepts: lesson, activity, poster, posterboard, card and viewport.

The current version (4.6) of FACT runs on just one device, a specific Samsung tablet. This made initial development easier. The next version (5.0) of FACT will be a web app that runs under common browsers on a variety of devices.

Figure 1 shows the student screen from the current version of FACT. The bar at the top indicates that Megan is in Group 2 and working on a poster named Card-Matching. The Sync button will be explained latter. If Megan tapped on the Cards button, FACT would raise a menu of card types, including blank table cards, blank grid cards, blank lined cards and completely blank cards. Selecting one would cause that kind of card to be added to the poster. The oval pair of buttons control how stylus touches are interpreted: as a pen or as an eraser. Lastly, there are the standard Undo and Redo buttons.

Insert “Orchestration Fig 1.png” about here with the caption:

Figure 1: The student’s screen, showing part of a poster from the Distance-time graph lesson

Below the black bar is the viewport. This viewport of Fig. 1 is showing 5 cards: a large green one, two beige ones with images of graphs on them, and two blue ones with text on them. These cards were on the poster when the students were given it. The black grid was also on the poster initially. An instruction card (not shown) indicates that students should place the blue story cards in the grid next to the matching beige graph cards. When they have finished pairing the graph and story cards, they should delete the big green card, which is hiding some table cards that should also be placed in the grid, next to the graph and story cards that they match. This is an example of a card-arrangement activity. About half the activities in the current FACT lessons

are card-arrangement activities. The others involve writing explanations, math or graphs on cards. We call these handwriting activities.

Students can scroll or zoom the viewport using two fingers. When a student touches a card with their finger or the stylus, it becomes selected, which means that the student can edit or move the card. When a card is selected, buttons appear on it that allow the student to pin the card, change its shape, change its background color, type on it or delete it. They can use the stylus to write on a selected card or erase writing they did previously. They can use their finger to move a selected card.

When a group of students is editing the same poster, and one student is editing or moving a card, the other students see a translucent lock on that card (see Fig. 1); this indicates that they cannot edit or move the card right now. When the student stops editing or moving the card, the lock disappears after a few seconds of inactivity.

Teachers conduct the class “orchestra” using their own tablet which is running an app called the *dashboard*. The Organize screen of the dashboard is shown in Figure 2. The black bar at the top has 4 buttons in an oval that control which of the four dashboard screens is displayed. The Organize screen shows students and groups. The students are the smaller cards, and the groups are the larger cards. The screen in Fig. 2 shows, for instance, that Harold, Jen and Sabrina are not in any group, that Steve and Robert are in Group 1. Teachers can modify this organization by dragging the student cards with a finger. The colors of the cards represent the state of the student’s tablet or work. For instance, Tom’s card is gray indicating that his tablet has gone offline. The other colors will be explained later.

Insert “Orchestration Fig 2.png” about here with the caption:
Figure 2: The Organize screen of the teacher’s dashboard

The big button on the top bar is white indicating that the system is in Open Enrollment mode. This means that students are seeing a menu of groups, and they can select which group to join. As they join a group, their card moves into that group’s card.

Just to the right of the Open Enrollment button is the Pause button. Tapping this freezes the student tablets and displays “Eyes on teacher” in their center. This allows the teacher to address the class. Tapping the Pause button a second time causes the student tablets to unfreeze.

To the right of the Talk button is the Project button. It causes whatever is currently on the teachers’ screen to be sent to the classroom projector and displayed to the whole class. Tapping the Project button a second time causes the projector to display a blank image instead of the teacher’s screen.

The next two buttons, +Student and +Group, allow the teacher to add a student or a group to the class. Because Open Enrollment allows teachers to quickly define the organization of the whole class, these two buttons are mostly used to accommodate students who arrive late.

An important feature of the organize screen is that the teacher can tap on a students’ card, and FACT will replace the Organize screen with an editor that is viewing the same poster that the student is editing. This teacher action is called “peeking” because teachers tend to use it to merely look at a students’ current work; they seldom change it. However, the editor has all the

features of the student's editor. It also has the Pause and Project buttons. This allows the teacher to show a student's poster to the whole class by peeking at it, then tapping Pause and Project.

Figure 3 shows the Activity screen of the dashboard. It allows the teacher to control which activity the class is working on. Each row of the table represents a distinct activity. The current activity is highlighted in blue. The teacher selects a new activity by tapping on its row. The first column indicates whether the activity is intended for individual or group work. The second column indicates the name of the activity. The next two columns name the posters that the student can view and edit. The other columns suggest durations for activities.

Insert "Orchestration Fig 3.png" about here with the caption:

Figure 3: The Activity screen of the teacher's dashboard

As the buttons at the top of the black bar indicate, there are two more screens that the teacher can view. The Review screen is for viewing and editing student posters off-line, as the teacher marks up student work outside of class. The My Sheet screen is for viewing and editing the teacher's own copy of a poster. Teachers sometime launch an activity by showing students how to do it using the My Sheet, Talk and Project buttons.

When FACT detects an opportunity to give formative feedback to a student or group, it can alert the teacher by coloring the corresponding card on the Organize screen. If the teacher taps that card, then FACT shows the students' poster, which is the normal peek action. However, because FACT has found something on that poster that is worth talking to the students about, it draws a dotted red rectangle around it. Often, this suffices to indicate to teachers what the feedback opportunity is. However, if teachers want to find out more, they may tap on the large blue "i" button which shows FACT's suggestion for what to say to the student. Figure 4 shows the teacher's screen at this point. If the teacher taps Send, then FACT will paste a card onto the students' poster with the annotation text. Alternatively, the teacher can tap Delete to get rid of the annotation, or Leave to leave it visible for the next time the teacher peeks at this poster.

Insert "Orchestration Fig 4.png" about here with the caption:

Figure 4: The teacher is peeking at a students' poster. FACT has indicated an opportunity for formative feedback with a red, dotted rectangle. The teacher has tapped on the blue "i" button, so FACT is showing the annotation that it recommends. Note the instruction card of this activity in the upper left.

In summary, students have an editor for posters, and teachers have a dashboard with several screens. One dashboard screen allows the teacher to select an activity for the class to do next. Other screens let teachers review student's work offline, and edit their own posters. The main dashboard screen, Organize, represents students and groups as cards, and uses card colors for alerts. Tapping on a card lets teachers peek (i.e., edit) the associated poster. Teachers may also pause the student tablets and project the teacher's current screen to the whole class. This design is a work in progress. The remainder of this chapter describes the lessons we've learned so far.

4 Increasing classroom awareness

Perhaps the most important function of an orchestration system is to increase the teacher's classroom awareness (Prieto et al., 2011). Classroom awareness involves monitoring a variety of information such as:

- Who is off-task vs. on-task?
- What interaction process is each group engaged in (i.e., collaboration, cooperation, one person doing everything, etc.)?
- How far along in the activity is each student or group? Which have stalled? Which have finished?
- Which students or groups have asked for help? How long ago? Which need help but have not yet asked?
- Have any devices crashed? Are any students not using the right application?

To help teachers maintain classroom awareness, orchestration systems typically provide the teacher with a *dashboard*, which is a display of some of the information listed above (Verbert, Duval, Kerkx, Govaerts, & Santos, 2013; Verbert, Govaerts, et al., 2013). Although dashboards are found on a wide variety of applications, dashboards used in classrooms have an unusual set of design constraints. This section discusses a few of them.

4.1 The ideal orchestration dashboard would augment reality

By just scanning a room of students working in groups, the teacher can gather considerable information about the class. The ideal dashboard would not compete with these naturally occurring cues, but instead would augment them. Conventional augmented reality technology (Kidd & Crompton, 2016) would require teachers to view the classroom through a head-mounted display, such as Google Glass, and perhaps require students to wear caps with fiducials or other easily recognized identifiers. To avoid such inconveniences, several other approaches have been used:

- One is to equip students with devices that are visible from almost anywhere in the classroom. The device's appearance indicates something about the state of its student or group. For instance, the Lantern system (P. Dillenbourg et al., 2011) consists of small lights mounted on each group's table. The color of the light indicates which problem the group is working on. The light flashes when the group has asked for help. The longer the students wait for help, the faster the light flashes.
- Another is simply to project some relevant information onto a screen that the teacher can see from across the room (P. Dillenbourg et al., 2011).
- Lastly, the teacher can carry a portable device such as a tablet (Martinez-Maldonado, Yacef, & Kay, 2015). This is the option that FACT is currently using.

Clearly this is an area where we can expect rapid advances. Wearable computers, flexible displays, augmented reality eyewear and other physical computation devices are under intense development.

Nonetheless, human attention is limited. If the teacher is focusing on the information presented by the dashboard, then no matter how the information is presented, some of the teacher's attention must be subtracted from the naturally occurring cues. Thus, even an ideal dashboard

should strive to present just exactly the information the teacher needs and no more. The rest of this section describes our experiences on trying to provide just the right information at just the right times.

4.2 Scrolling vs. strolling

When no students have their hands up, teachers tend to stroll around the classroom looking over students' shoulders to see how the work is progressing. When the students are working on a screen, it is difficult for the teacher to get close enough to see what has been done so far. Thus, FACT and other orchestration systems (e.g., group scribbles, C.-P. Lin et al., 2012; Song & Looi, 2012) let teachers use their own screen to remotely view the students' screens.

Just as one can scroll through pictures on one's cell phone by swiping sideways, a dashboard could let teachers scroll through the screens of every student in the class. Instead of visiting groups, teachers might instead send a message or yell across the classroom. That is, scrolling could replace strolling, which would be a disaster for FACT given its goals and context.

In order to encourage strolling, it should be made as convenient as possible. Suppose a teacher has decided to visit a group, either because it is next stop on a stroll or because naturally occurring cues (e.g., noise) suggest that the group needs a visit. In order to see the group's work, the current version of FACT requires the teacher to scan the Organize screen (Fig. 2), find the group's card, and tap on it. The scanning is a bit inconvenient, particularly when there are many groups. Our next design will use an alphabetical roster of student names. We believe that most teachers can easily name at least one student in the group that they are approaching, rapidly find that name in the alphabetical list, and tap on it. We think that this will save time, but we have not yet tested it in the classroom.

In short, the issue of scrolling vs. strolling is more subtle than it first appears. It remains an interesting area for further exploration and development.

4.3 Stealth assessment and progress indicators

Some orchestration systems can do stealth assessment. That is, they can assess the student's performance by monitoring the students' editor actions. Neither testing nor pop-up questions are needed. Students may even be unaware that their performance is being monitored, hence the term "stealth" (Shute & Kim, 2014).

Stealth assessment can be done in simple ways. For instance, MTFeedback (Martinez-Maldonado, Clayphan, et al., 2015) assessed groups of students constructing a concept map. It counted both the number of links in the students' concept map, and the number of links that matched the links of an expert's concept map. In like manner, FACT does stealth assessment with card-matching tasks by counting both the number of cards-pairs created so far, and of those, the number that matched an expert's pairings. For handwriting tasks, FACT counts the number of cards that have writing on them. Currently, it cannot understand the handwriting, so it cannot assess the quality of the student's explanations.

Both MTFeedback and an early version of FACT displayed their stealth assessments on the teacher's dashboard. In the case of FACT, the card that represented a group had a progress bar beneath it. The length of the bar represented the group's progress. That is, it represents the number of card-pairs or handwritten cards completed so far. In the case of card-pairs, a portion

of the bar was colored green and the rest was red. The green portion represented correct pairs, and the red portion represented incorrect pairs. MTFeedback used a similar display of both progress and correctness, but the measures drove the radii of circles instead of the lengths of bars.

FACT's clients did not like the progress bars, for two reasons. First, FACT is intended to support formative assessment. When progress bars are shown, teachers may mistakenly think that the goal of the activity is to get all the bars maximally long (all cards finished) and green (all cards correct). That is, the bars may seduce teachers into treating the activity as a standard drill-and-practice activity with an embedded corrective/summative assessment.

Second, an array of multiple progress bars isn't a good display of the information that teachers' need for the decisions they need to make. Teachers might use the progress bars to decide which group to visit and give formative feedback to. They might also use the bars to decide when to halt this activity and move the class on to the next activity. Both decisions require scanning all the bars, which is something that the dashboard could do for the teachers. That is, raising alerts is probably more convenient than displaying progress bars. Alerts are covered in the next section.

In short, although it is often feasible for dashboards to display the progress and correctness of groups or individual students, it may not be a good idea to do so. Nonetheless, stealth assessments can still be valuable, as the next section shows.

4.4 The art of alerting

Maintaining classroom awareness is part of the larger process of continually deciding what to do next. The stages are:

1. *Gathering* information, especially information that is not available naturally via the ambient classroom noise or a quick glance around the room.
2. *Assessing* the information against the teacher's goals, including both instructional goals and classroom management goals.
3. *Deciding* on a small actionable goal, such as providing help to a specific group.
4. *Implementing* the actionable goal, such as posing a provocative question to the group.

Whereas strolling and scrolling are part of the first stage, and progress bars are part of the second stage, alerts are part of the third stage. An alert is a visual or audio cue presented by the dashboard that indicates a small actionable goal. An alert only makes sense when the orchestration system can make accurate assumptions about what the teacher's goals are. Thus, there is an art to designing alerts.

Some device events, such as running low on battery power or losing connection to the internet, are clearly undesirable, so an alert is warranted. In many classrooms, teachers want students to use the orchestration system exclusively, so leaving that application and starting another should raise an alert on the teacher's dashboard. Teachers often want to respond promptly and fairly to raised hands, so some orchestration systems maintain a queue of hand-raising events (e.g., Pierre Dillenbourg, 2013; Rojas & Garcia, 2012). Beyond these types of alerts, it is hard to think of others that all teachers would want for every activity.

When the teacher's goal is that all students should finish an activity while minimizing errors, then stealth assessments of progress and correctness can be used to raise alerts. For instance, MTFeedback (Martinez-Maldonado, Clayphan, et al., 2015) raised a "slow-group" alert when a group's progress was less than half the progress of the second slowest group. It also raised a "misconception" alert when the group's concept map had several links that matched links flagged as misconceptions by an author. MTFeedback raised alerts about a group merely highlighting the icon that represented the group. When teacher's had a free moment, they could tap the highlighted icon and a short message would explain what the alert was about. Martinez-Maldonado et al. found that if teachers read such a message, then 88% of the time they would visit the group that triggered the alert within a few minutes. Moreover, for 70% of the misconception alerts, groups remedied at least one of the misconceptions that raised the alert within two minutes of the teacher's visit. This suggests that alerts are useful to teachers and can improve student performance. However, this usage assumes the conventional goals of maximizing progress while minimizing errors, and the Classroom Challenges do not have those goals.

As mentioned earlier, the goals of the Classroom Challenges are formative assessment and collaborative learning. Thus, alerts would be raised whenever FACT detected an opportunity for the teacher to increase a group's engagement in these practices. This is difficult, especially given that FACT cannot hear what students are saying to each other. Nonetheless, FACT is currently raising alerts for the opportunities that it can detect. It does so only for arrangements of cards, as it currently does not understand student's handwriting. Some card arrangements have been flagged as misconceptions by the authors of the activities. If a group's work matches such a misconception card arrangement, then FACT notes that it can raise an alert. However, to avoid spamming the teacher, it doesn't do so for every alert immediately. Using heuristics, which are still being tinkered with, FACT selects one of the potential alerts and colors that group's card red on the teacher's dashboard. When teachers have a free moment, they can tap on the red group card in order to peek at that group's work. When the group's poster opens, FACT places a red dotted rectangle around the card arrangement(s) that raised the alert. For some experienced teachers, this may suffice to indicate what they should do and how to do it. Less experienced teachers can tap on the "i" button, and FACT will pop up a message explaining the misconception, as shown in Fig. 4.

FACT teachers should not give *corrective* feedback to students, where corrective feedback indicates that the card arrangement is wrong and perhaps gives a hint about how to fix it. Instead, teachers should give *formative* feedback, which is a suggestion for an activity or line of reasoning that will cause students to discover the misconception on their own. Often this is a specific question, such as, "Have you tried plugging in specific numbers for the variables and checking whether the equation holds?" Sometimes it is a more general question, such as, "How could you explain that to another group?"

Teachers give corrective feedback so often that it is difficult to break the habit and give formative feedback. When teachers tap on the blue "i" button, FACT not only explains the misconception behind the card arrangement, it also presents several formative feedback questions that teachers can use. Thus, FACT is acting like a coach. It is giving just-in-time professional development advice that should help teachers become better at giving formative

feedback. Tapping on the “i” button suggests that the teacher may feel a need for such advice and thus be more receptive to it.

Thus, the alerts of an orchestration system can have a dual role. One is to help *students* learn. The other is to help *teachers* learn. In the long run, teacher-learning is probably more important as it may result in a larger impact on students. Clearly, the art of alerts is complex, and there is much to discover about getting it right.

5 Mapping devices to physical reality

Before an orchestration system can help with running a class, it has to learn the mapping between devices, people and groups. With paper, students write their names and/or their group’s name at the top of the page. This takes only a few seconds. With electronic media, the process can take much longer, but shouldn’t. This section summarizes some methods.

5.1 The ideal

In the ideal implementation, students would have their own devices so they would not have to log into devices owned by the school. Ideally, the devices would be location aware so that when students enter a classroom, the devices tell the orchestration system who is joining the class. Furthermore, the devices would sense the location of nearby devices, which would allow them to determine who the students are seated next to. Many teachers assign seating so that students are already seated in groups even if they are not yet doing a group activity. Lastly, if the teacher has students re-arrange themselves into new groups and the students take their devices with them, then the devices can figure out the new group memberships using their proximity detectors. In short, the devices have enough spatial sensing that they can sort out the mapping between their users, the class and the groups. Until this ideal is common (which hopefully will only be a few years), some of the techniques in this section may be used.

5.2 Mapping devices to people

It may seem simple to have students create an account on the orchestration system, with a user name and password. As usual, the system would send students a text or email if they forget their user name and password. However, many schools do not let students use text or email during class. Password and username recovery would need to involve the teacher, and that is not a convenient solution.

Many schools already use a Learning Management System or at least a school-wide authentication service. Although an orchestration system could perhaps use such a service, this would require that the school trust the orchestration system and the people behind it to maintain the privacy and security of the students’ data. Moreover, teachers could not just try out the orchestration system in their class a few times in order to see if they want to adopt it because they would have to get the approval of the school in order to do so. Being able to easily try out an orchestration system significantly increases the chance of adoption (Rogers, 2010; Sahin, 2006).

FACT and many other systems use a class code method. The system generates a code and displays it to the whole class perhaps via the teacher. The students enter this code and their name. To discourage false and duplicate names, teachers often project the Organize screen, so that everyone can see the emerging roster.

5.3 Establishing and maintaining groups

An early version of FACT was based on the idea that teachers would define an arrangement of students into groups before class began. In fact, they could define several different arrangements. When they started a group activity, they could select the arrangement that they wanted. Later, they could select a different arrangement if lesson plan called for it. None of the FACT pilot teachers took the time to do this. Thus, as their class began they wasted precious minutes using the Organize screen to arrange students into groups.

Thus, we added the Open Enrollment button, which when depressed allows students select a group to join from a menu. The teacher projects the Organize screen, which is a display of all groups and their members, so students can see if they got themselves into the right group. In practice, teachers usually have students seated in groups before this join-group activity happens, so there is little ambiguity about which group a student should join. Unlike some orchestration systems (e.g., Berland, Davis, & Smith, 2015), FACT does not offer advice on how to form groups.

5.4 Accommodating gallery walks and other mass movements

A common activity in Classroom Challenges is to have groups compare their work with other groups. One way to implement this comparison is to have every group send a member to another group, e.g., for group N to send one member to group $N+1 \bmod N$. When the teacher halts this visitation, the groups reunite and discuss what the visitor learned. This activity is sometimes called a *gallery walk* (Chen & Looi, 2011; Chen et al., 2010; Hao, 2010). When paper is used to record a group's work, then a copy must be made for the mobile member. This is necessary so that when the mobile members have settled into their new groups, they need not rely on memory alone to present their old group's work to the new group. With FACT, the mobile members take their tablet with them, so no photocopying or hand copying is necessary. This saves considerable time.

The gallery walk is just one example of many possible of “mass movements” of students among groups. The orchestration system needs to facilitate mass movements.

Another approach to mass movements is to keep students in place physically but change their access to media. For instance, Group Scribbles supports a type of “virtual gallery walk” where students remained seated in their groups, select a group from a menu, and view its work remotely. When comparing virtual gallery walks with physical ones, Hao (2010) found misbehavior was more common when students move physically between groups, but the engagement seemed to be deeper when it did occur.

FACT allows both physical and virtual “mass movements.” It is not clear yet when each is best.

6 Persisting and sharing work

When students work on paper, their work persists like any other physical object. If the paper is small enough, it can be displayed temporarily to the whole class using a document camera and projector; otherwise it can be held up or passed around. Paper can be displayed more permanently by posting it on a class bulletin board. Paper work can be included in a long-term portfolio of a student or class by placing it in a folder inside a filing cabinet. Teachers can take

student work home, mark it, and return it to the students the next day. Teachers can send the work home for parents to see. All these use cases must be accommodated with electronic media.

Although most of the issues and techniques of sharing and persisting electronic media are familiar, this section describes a few lessons learned by the FACT project that might be less obvious.

6.1 The almost-ideal solution: Files

Computer files are almost sufficient, in that they accommodate most of the use cases listed above. Moreover, students and teachers already understand files and how to implement the use cases.

However, there is one use case that current file systems do not support. FACT requires that all students in a group can edit the group's work at the same time. The teacher and FACT can also edit a group's work at the same time as the students are working on it. Some currently available shared-file systems, such as Google Drive, allow simultaneous editing of files, but only by editors that are integrated with the file system, such as Google Docs or Google Sheets. They do not allow external applications, such as FACT, such simultaneous access. This is a major missing feature in today's file systems that hopefully will be remedied soon.

Until then, the only work-around currently available to FACT and similar systems is to develop their own versions of files, duplicating many of the features found in file systems. This is a major headache and time sink, so the FACT project has tried to discover which features of file systems don't need to be implemented. The next section presents our current views.

To avoid confusing the users, the file-like persistent objects are called *posters* in FACT.

6.2 Dispensable features of file systems

Editors and file systems typically allow creating a copy of a file with a new name, renaming files and arranging them into nested folders. FACT does not. When an activity calls for editing a poster, every student (or group, if this is a group activity) gets their own copy of the unedited poster. This is the only copy they will ever get. It persists just like a regular paper poster. If a later activity calls for editing the same poster, users will see their poster with all the edits that they made to it. From a file-system point of view, every edited file is uniquely designated by a triple: the identifier of the class, the name of the poster, and the name of the student or group that owns it. From the user's point of view, FACT posters are just like paper posters. You get just one. If you edit it, go home, and return to work on it the next day, it is exactly how you left it. Moreover, a group's poster is a different poster than the posters that belong to individuals, even if the posters all have the same name.

This type of persistence has been easy for users to understand, and there have been no requests for "save as", "rename" or folder features. It also simplifies bookkeeping. For instance, when the teacher is marking or grading students' work, because every group/student has just one poster and not several copies with different names and time stamps, there is no ambiguity about which copy needs to be marked.

6.3 Some usability issues for simultaneous editing

FACT's posters consist of a large posterboard that has cards on it. Students can write or type on both the cards and the posterboard. They can create, delete, move, resize and color the cards.

We were surprised to see that sometimes a student would delete or move a card while another student was writing on it. In order to prevent this impolite behavior, FACT was modified so that when one student was modifying a card, no other student could make changes to it. This was called "locking" the card. When a card was in a locked state, FACT put a colored border on the card. If the student made no changes for a few seconds, then the lock was released.

Unfortunately, students often failed to discover this aspect of FACT. After trying in vain to modify a locked card, students would decide that either FACT or that particular card were "broken." To remedy this, FACT now puts a large translucent image of a padlock on a card whenever it is locked (Fig. 1).

Because writing can occur simultaneously, students sometimes tease each other by scribbling on top of writing that another student is trying to do. This is especially irritating in group of three or more, because the victim cannot easily tell who is teasing them. In order to facilitate identifying the perpetrator, FACT now assigns ink colors to students instead of letting them choose their own colors. Thus, if a student A sees green ink on top of his or her black ink, then A will know that the student who always writes in green is doing the teasing.

A related issue with shared work is that students sometimes delete or erase work that others would rather have kept. This is a problem with paper media as well, but seems to occur much more frequently with electronic media, perhaps because erasing writing and deleting objects (e.g., cards) happens so fast that other students don't have time to object. Also, the erasure or deletion may not be in the viewports of the students who would object and thus isn't noticed until later. We have not yet invented a method for dealing with malicious erasing and deleting.

Another issue occurs when students are editing a large poster with only a small viewport, namely the screen of a small tablet. This in itself is not a usability issue, as students are quite familiar with pinching to zoom and dragging to scroll. However, it can make deictic (pointing) reference much more difficult than it is with paper posters. Suppose student A wants student B to look at a particular location visible in A's viewport, so A points at it. B has to scoot over, look at where A is pointing on A's viewport. Typically, B can't see it well enough, so B tries to scroll and zoom B's viewport so that it is also focused on the location that A is pointing at. This is not easy, and can take waste dozens of seconds. We have not solved this issue yet with FACT, as we are still evaluating several options.

7 Managing classroom activities

Many educators understand "classroom management" to mean keeping students on-task and preventing disruptive student behavior. The newer term "orchestration" includes classroom management as well as many other features of a classroom that is working well (Pierre Dillenbourg, 2013; P. Dillenbourg & Jermann, 2010; P. Dillenbourg et al., 2011).

One such feature is that students transition from one activity to the next fluidly, with little wasted time and disruption. The teacher can control these transitions or delegate control to the students. With paper-based activities, such transitions can be awkward because they often involve handing

in or picking up sheets of paper or other physical material. An electronic orchestration system has the potential to simplify transitions, but it must be designed properly in order to do so. This section discusses the problem of making transitions between activities fluid and quick.

7.1 Pausing and Projecting

Of all the features that FACT offers teachers, the most popular are the Pause and Project buttons. When the teacher taps the Pause button, all the student tablets freeze and show the message, “Eyes on teacher.” When the teacher is done with the whole class activity, the teacher taps the button again, and the freeze on the student tablets is released. These transitions seem much faster than the teacher’s traditional oral commands.

When the teacher taps the Project button, FACT causes the classroom projector to show a copy of the teacher’s screen. Teachers use this feature for a variety of purposes. When students are joining groups, teachers show the Organize screen, which indicates which group each student is in. When the teacher is launching an activity, the teacher shows a copy of the poster that students will soon be editing.

7.2 Student presentations

The Project and Pause features dramatically improve a common activity, which is to have a student or group present their work to the class. When the teacher wants a student or group to present their work to the whole class, the teacher “peeks” at that poster, which causes it to be displayed on the teacher’s tablet. The teacher then taps Project and Pause. The teacher then calls on a student to explain the displayed poster.

When peeking at a student’s poster, the teacher can scroll, zoom or edit the poster, and moreover, when the whole class is frozen, the teacher is still free to scroll, zoom and edit the student’s poster. This often suffices for presenting student work, as the teacher can control what aspect of the poster the class and the presenting student should focus on. On the other hand, if the teacher wants the student to control what the class sees, then the teacher can hand the teacher’s tablet to the student. The student can then scroll, zoom and edit the student’s poster while the class watches. Letting a student manipulate the teacher’s tablet is an act that has considerable social meaning, but we have not yet observed it happening.

7.3 Working out of sync

The teacher’s dashboard of a typical orchestration system has a “next activity” button, a menu of activities or both. When the “next activity” button is pushed, all the students’ editors open the file (a poster, in FACT) that is needed for the new activity. No time is wasted handing in edited paper and handing out fresh paper. A menu of activities has the same effect, but also allows the teacher to skip activities or do activities in a different order than planned.

However, we found this convention to be a little too inflexible. Students often arrive late, sometimes for good reasons, and the teacher sets them to work on catching up with the class. Other students finish so quickly that the teacher wants them to work ahead of the class. Thus, FACT supports the concept of most students working “in sync” with the class and a few students working “out of sync” with the class.

In FACT, when the teacher taps the “next activity” button or selects an activity from the lesson plan, the only thing that happens on the student tablets is that a button labelled “Sync” highlights

in red. Students who are working in synch with the class should tap the Sync button, which causes their tablet to open the poster of the activity that the teacher just selected. Students who are working out of sync should not press the synch button. A teacher might say, “If you are not one of the debate team members that came in late, please press the Sync button now.”

The FACT dashboard highlights the names of students who are out of sync. Just after the teacher taps “next activity,” all student’s names will be highlighted. As students tap their Sync buttons, the highlighting disappears. This allows the teacher to nag laggards. When highlights remain on only the students who are legitimately working out of sync, the teacher can launch the next activity.

8 Conclusions

It will be hard to tell if FACT or any other orchestration system is a success. One cannot evaluate an orchestration system by simple measures such as learning gains from a pre-test to a post-test. Teacher’s opinions are important, but should probably not be the only measure. Naked-eye classroom observation is clearly needed, but has its limitations—for instance, observers cannot easily see the students’ written work. Video recording of individuals or small groups is feasible, but only captures a small part of the whole classes activity.

At this point, we are still focusing on improving FACT via a series of formative evaluations. We use most of the data sources mentioned: reports from teachers, observers in the classroom and analyses of videos of classrooms and small groups. We generally try out a new version of the system in two or more classrooms, then make changes to the system, and repeat.

By reporting a few of the more surprising (to us) issues uncovered during these formative evaluations, we hope to reduce the development time of future orchestration systems. In subsequent work, we hope to report on summative evaluations of the system. That will require developing operational measures of this important but ill-defined construct called orchestration.

9 Acknowledgements

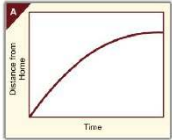
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10 References

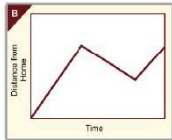
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1 Tom ran from his home to the bus stop and waited. He realized that he had missed the bus so he walked home.



2 Opposite Tom's home is a hill. Tom climbed slowly up the hill, walked across the top, and ran quickly down the other side.




ACTIVITY

ORGANIZE

REVIEW

MY SHEET

 class1

OPEN ENROLLMENT

TALK

PROJECT

+STUDENT

+GROUP

harold

jen

sabrina

GROUP 1

steve

robert

GROUP 2

tom

marcello

GROUP 3

holly

joe



	Activities for Distance Time Graphs	View Worksheet	Edit Worksheet	Start Time	Min	End Time
	Assessment Task	-	Journey-To-Bus-Stop	03.03	15	03:18
	Whole-class introduction	-	Graph-Story	03.15	10	03.25
	Collaborative activity: matching Card sets A and B	-	Card-Matching	-	20	03.45
	Sharing posters	-	Card-Matching	-	5	03.50
	Whole-class discussion: Interpreting tables	-	Graph-Table	-	20	04.10
	Collaborative activity: matching Card set C	-	Card-Matching	-	20	04.10
	Sharing posters	-	Card-Matching	-	5	04.15
	Whole class discussion	-	Blank-Graph	-	10	04.25
	Improving individual solutions to the assessment task	-	Review-Journey-To-Bus-Stop	-	10	04.35



ACTIVITY

ORGANIZE

REVIEW

MY SHEET

GROUP #1

CLOSE

PAUSE

PROJECT

ISSUES

CARDS

PEN

ERASE

REDO UNDO

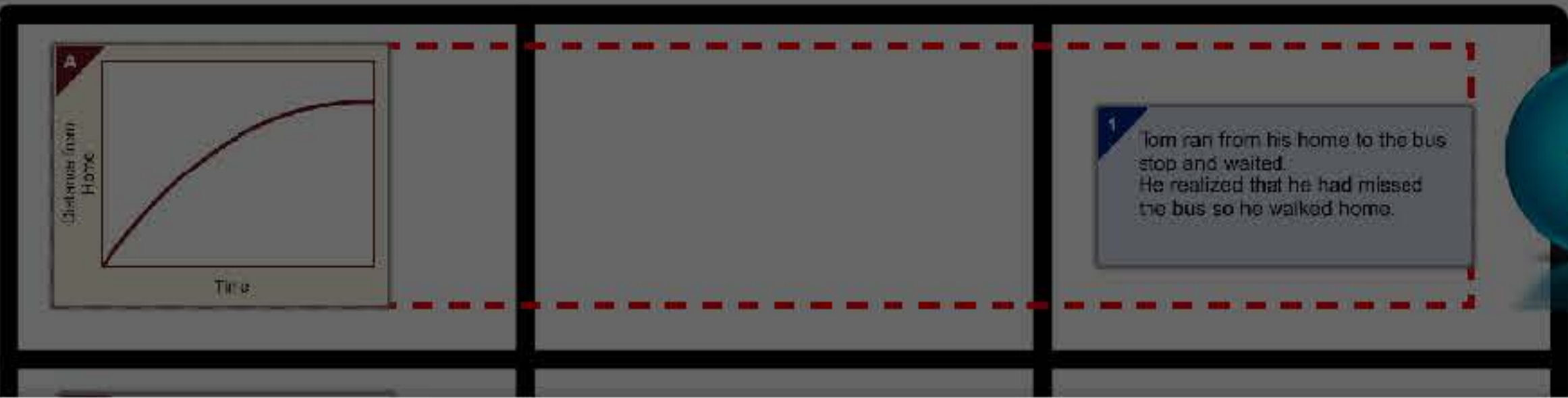
Matching Stories and Graphs

Choose a graph. Discuss which story matches it.

Match all the graphs to stories. Leave plenty of space.

Now find the label that matches each graph and story...

Time	Distance
0	0
1	10
2	20
3	40
4	60
5	120



1 Tom ran from his home to the bus stop and waited. He realized that he had missed the bus so he walked home.



Time	Distance
0	0
1	40
2	40
3	40
4	20
5	0

Time	Distance
0	0
1	18
2	36
3	54
4	81
5	120

Time	Distance
0	0
1	40
2	80
3	80
4	40
5	80

Time	Distance
0	0
1	20
2	40
3	40
4	40
5	0

Time	Distance
0	0
1	30
2	60
3	0
4	60
5	120

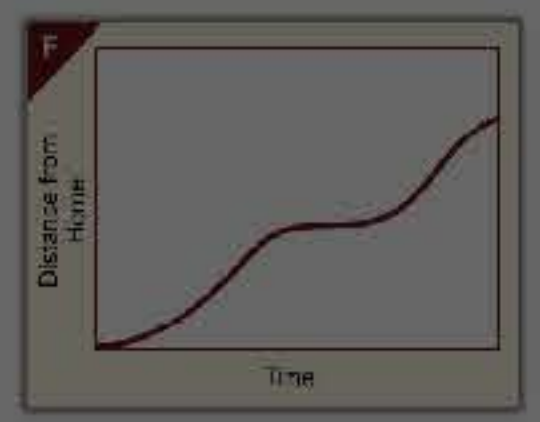
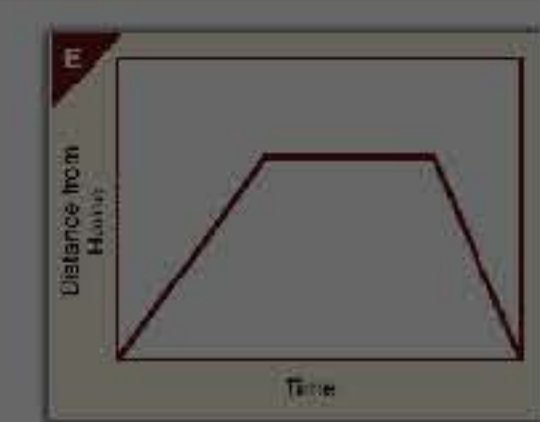
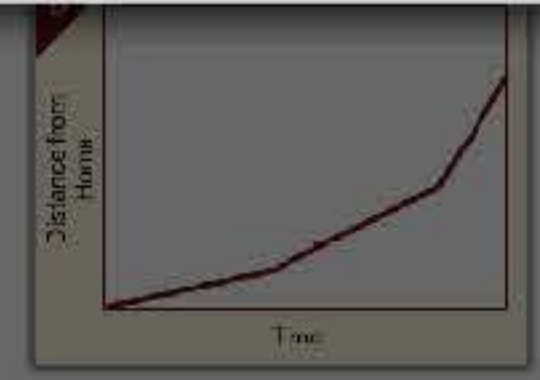
Time	Distance
0	

Time	Distance
0	

Annotations

How far is Tom away from home when he starts? How far is Tom away from home when he finishes? What exactly does the label on the vertical axis say?

Send Delete Leave



4 Tom walked slowly along the road, stopped to look at his watch, realized he was late, and then started running.

5 Tom left his home for a run, but he was tired and gradually came to a stop!

6 Tom walked to the store at the end of his street, bought a newspaper, and then ran all the way back.

10 Make up your own story!