International Journal of Latest Research in Humanities and Social Science (IJLRHSS)
Volume 06 - Issue 02, 2023
www.ijlrhss.com || PP. 139-151

Exploring patterns of implementation of educative curriculum materials aimed at enhancing elementary science teaching practices

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Abstract: Providing Educative Curriculum Materials (ECM) (i.e. exemplary lesson plans and teaching resources including their pedagogical rationale) is an extended professional development strategy. However, its effectiveness to enhance teaching practices relies on how teachers implement such ECM.

This study explores how 28 seventh-grade teachers implemented research-based science ECM within a professional development program in the city of Buenos Aires, Argentina. Using a Fidelity of Implementation (FOI) framework, we analyzed students´ science notebooks to measure: adherence (whether teachers used the ECM during their lessons), dosage (the time given to teaching ECM activities), and quality (whether teachers implemented the more cognitively demanding aspects of the ECM).

Beyond the average level of adherence (74%), dosage (23%), and quality (56%), we identified four patterns of FOI amongst teachers: non-compliant, low, medium and compliant. Noteworthy, less compliance was found in schools in disadvantaged contexts. We discuss the need to tailor ECM-based professional development interventions.

Keywords: educative curriculum materials; fidelity of implementation; teacher professional development; science education; elementary school.

Introduction

Increasing student learning outcomes in science is a priority in many education systems, given the importance placed on students' scientific literacy and development of 21st-century skills such as critical thinking, creative problem solving, communication and collaboration (Trilling & Fadel, 2009). As is the case in many regions, in Latin America (the context of this study) student achievement is consistently low (Furman, 2020; Gamboa & Walterberg, 2012; UNESCO, 2015; Vegas, Ganimian & Bos, 2014). These low results are often associated with current teaching practices, where studies have shown that teachers predominantly use traditional methods based on rote learning and memorisation of content, with few opportunities for students to engage in scientific practices and develop deep understanding and scientific thinking skills (Furman, Luzuriaga, Taylor, Anauati & Podestá, 2018; Valverde & Näslund-Hadley, 2010).

Within these contexts, several policies and interventions aimed at improving science education, among which professional development programs stand out, were emplaced, although in many cases their effects are unclear. One strategy that has been widely used to enhance science teaching practices and contribute to science teachers´ professional development is the development and provision of Educative Curriculum Materials (ECM).

ECM are instructional materials based on the written curriculum, aimed at guiding teachers in the organization, content and pedagogy of given topics, scaffolding the enactment of effective teaching practices (Davis et al., 2016; Davis & Krajcik, 2005; Remillard, 2005; Roblin, Schunn, & McKenney, 2018). They generally include detailed lesson plans, benchmark lessons, activities and worksheets for students, and even physical resources kits (such as lab materials) or softwares and web-based computer programs. As indicated by best practice research, science ECM typically include orientations for teachers to promote active thinking, such as by engaging students in inquiry-based activities, promoting a reflection on the nature of science and offering opportunities for metacognition (Davis & Krajcik, 2005).

Despite ECM being widely used as a tool for reform and professional development efforts in science education (Furman et al., 2018; Näslund-Hadley & Bando, 2016; Lin, Chang, & Chen, 2010), studies show mixed results in terms of how teachers use them in classroom contexts (Bismack et al., 2014; O'Donnell, 2007; Pringle et al., 2017). On the one hand, studies show that providing inservice science teachers with ECM can contribute to their professional development (Furman, Luzuriaga, Gómez & Duque,2022; Granger et al., 2018; Schneider & Krajcik, 2002), improve teaching practices and increase student learning (Lin, Chang, & Chen, 2010; Pringle et al., 2017; O'Donnell, 2007). Furthermore, it can be a cost-effective intervention (Albornoz, Anauati, Furman, Luzuriaga, Taylor & Podestá, 2020), which is particularly important when considering that large-scale interventions are needed for urgent and sustained improvements in Argentina as in many other countries in the region (Bruns & Luque, 2014; Ganimian & Murnane, 2016).

However, it has been also found that the overall effectiveness of ECM-based interventions can vary considerably, depending on how they are used and implemented in each classroom (Bismack et al., 2014; Buxton & Lee, 2007; Davidson, Fields, & Yang, 2009). In particular, studies show that during science ECM implementation teachers can introduce conceptual distortions or lower the cognitive load of the proposed activities, aligning them with more traditional, 'business as usual' teaching practices (Davis et al., 2016). Therefore, a key part of understanding the provision of ECM as a potential large-scale professional development strategy for improving science education involves analyzing how they are implemented in different contexts, and identifying what factors can explain, predict or influence implementation patterns.

Faced with a dearth of research on the matter, particularly at a larger scale and in the Latin American context, and the pressing need to enhance science education in the region, this study investigated how seventh-grade science teachers from a representative sample of elementary public schools in the city of Buenos Aires, Argentina, used ECM aimed at fostering and improving science teaching practices in their lessons. We used a Fidelity of Implementation framework to understand if, how much and which parts of the ECM were implemented by teachers, and whether this use varied according to school socioeconomic contexts.

Analyzing thoroughly how teachers use ECM, and whether differences exist depending on school contexts, is fundamental in terms of understanding the strengths and limitations of ECM-based strategies aimed to improve science teaching practices and student learning.

Using 'Fidelity of Implementation' to understand ECM use

One way of understanding ECM implementation in more detail is by using a Fidelity of Implementation (FOI) framework (Lee & Chue, 2013; O´Donnell, 2008). FOI provides a way to characterize and measure the distance between the suggested and enacted teaching practices, considering their original pedagogical intentions. FOI can combine several elements, the main ones being adherence (whether a program is delivered as designed), dosage or exposure (the amount of an intervention received by participants), and quality (the manner in which essential aspects of program are delivered) (Carroll et al., 2007; Mihalic, 2004).

While acknowledging ongoing discussions in the literature regarding how teachers should be expected to use ECM, in that it might be undesirable to promote enactment strictly 'by the book' (Davis et al., 2016; Milner, 2014; Ramatlapana & Makonye, 2012), we base this study on the premise that well-designed research-based ECM will have positive effects on student outcomes when implemented with high fidelity. However, such high fidelity may include teachers adapting some of the lessons or activities to best fit students needs in a particular classroom.

Also, teaching practices and learning outcomes are influenced by other factors such as school socioeconomic contexts, which can modulate the extent to which an intervention is undertaken as designed (Balu & Doolittle, 2016; Bassi et al., 2020; Bumen, 2014). Therefore, in this study we also take a more detailed look at the FOI of the ECM in schools from different socioeconomic contexts.

Understanding science ECM FOI across elementary schools in the City of Buenos Aires, Argentina

The present study is part of a larger impact evaluation on different models of inservice teacher professional development in science in the Autonomous City of Buenos Aires, Argentina (hereafter CABA, for its Spanish acronym), where we showed that providing seventh-grade science teachers with ECM on the topic of The Human Body significantly improved student learning (Albornoz et al., 2020). This confirmed the provision of ECM as an effective intervention in this context. However, student results also showed striking variability across teachers and schools, opening questions regarding the factors behind this.

Therefore, for this second study, we adopted a FOI framework to understand whether, how much of, and what aspects of the ECM teachers implemented in their classrooms. We analyzed how 28 seventh-grade science teachers from the 23 CABA schools used the provided ECM, using student science notebooks as evidence of teaching practices in each classroom. The research questions we addressed are:

(1) What was the overall Fidelity of Implementation (FOI) (considering adherence, dosage and quality) of seventh-grade research-based science Educative Curriculum Material (ECM) on the topic of The Human Body in 23 public schools in the city of Buenos Aires, Argentina?
(2) What different patterns of FOI were found when teachers implemented the ECM?
(3) How did these patterns of fidelity vary according to school socioeconomic contexts?

This study aims to understand the nuanced process behind science ECM implementation. Responding to calls in research to further explore program implementation within different classrooms, understanding how teachers from diverse school settings respond to ECM interventions could have profound implications for the improvement of science education, and provide information on how to best tailor public policy efforts towards that goal.

Materials and methods

This study is part of a larger impact evaluation on models of in service teacher professional development carried out by the researchers in collaboration with the Ministry of Education of CABA, Argentina (Albornoz et al., 2020). Here, we focus on one of the intervention groups in particular, which received science ECM as a professional development strategy.

The sample was composed of 23 randomly selected public elementary schools across six (out of 21) school districts in the CABA. These schools were representative of schools in the CABA in terms of socioeconomic conditions, their total school and seventh-grade enrolment, pass and repetition rates (i.e. students passing the grade each year, and the percentage of students who are currently repeating the school year), over-aged rate, and previous district test scores (see Albornoz et al., 2020 for full sample balances).

All seventh-grade (final year of primary school in the district) science teachers participated in the study. Some schools had more than one seventh-grade class with either one or different science teachers, which led to having a final sample of 28 science teachers across 32 individual classrooms, reaching 545 students in total. Teachers had 1 to 28 years of teaching experience (average =13.2 years, S.D.=5.9), which is representative to the teaching force in CABA. Their average age was 42.3 years (from 24 to 66 years, S.D. = 9.8).

Following an agreement with District superintendents and principals, all teachers in this intervention group received science ECM on a curricular topic (The Human Body). This intervention was mandatory but not enforced, in that there were no formal consequences if schools or teachers chose not to use the ECM (i.e. there were no financial or administrative incentives or penalties). As such, the wider intervention mimics Argentine public policies more generally, where ECM are distributed but used at teachers' discretion (which is why studying the degree to which teachers choose to use these materials is interesting, given the public investment in the strategy).

The provided science Educative Curriculum Materials

Science ECM covering the topic of 'The Human Body' (focusing on the basics of the digestive, circulatory, and respiratory systems) were developed by the team of researchers. This topic is a part of the seventh-grade national curriculum, which was used to select the content and level of detail reflected in the ECM (Secretaría de Educación, 2004). The design of the learning activities described in the ECM was also informed by research-based, best practice science principles (Davis & Krajcik, 2005; Davis et al., 2014; Harlen, 2013). Preliminary versions of the ECM were shared with non-participating teachers to receive their input and feedback, and the final version was validated by the curricular team of experts at the CABA Ministry of Education. (The Spanish version of the ECM can be found here).

The ECM were designed for implementation in an estimated 38.5 hours of science lessons over approximately 8 to 12 weeks. The ECM supported teachers by organizing and scaffolding science content, with detailed indications on how to guide science activities with specific learning goals, including their pedagogical and disciplinary rationale. As Table 1 shows, as well as more traditional activities such as reading from informative texts or diagrams and answering lower-order questions, the ECM included activities promoting 'higher-order thinking' skills (Anderson & Krathwohl, 2001), which were typically inquiry-based (Bevilacqua et al., 2001; Harlen, 2013). These higher-order activities offered opportunities for students to, for instance, ask questions, design experiments, gather and analyze data, debate their findings, analyze history of science episodes and reflect on the construction of scientific knowledge (Minner et al., 2010).

Table 1 Overall scope and sequence of the ECM

	Topic and objectives	**Overview of main activities**

1	**Are all bodies the same?** Understand that all cells need oxygen and nutrients to obtain energy To observe and measure physical characteristics of different people Design proposals to answer a research question Collect, analyze and communicate data	Read and answer questions on a text on energy production in cells **Propose a research question on students' physical characteristics and collect and analyze data to answer it (for instance: Are older students taller than younger ones?)*
2	**What happens to food when we eat it?** Understand that digestion is a process via which food is transformed into nutrients, which are then distributed across our body To observe our teeth, learning to connect form and function Understand that each organ in the digestive system has a specific role	Read about the importance of a balanced diet Write about the role of each organ in the digestive system **Observe and compare teeth on oneself and classmates, connecting form and function*
3	**What happens when our digestive system doesn't work?** Understand that ideas about the digestive system changed over history To analyze and interpret history of science texts Understand that, should an organ in the digestive system stop working, this would have consequences related to the role of that organ	Read about common illnesses of the digestive system **Discuss the investigations of William Beaumont on the digestive system, identifying research questions and analyzing data.*
4	**Why does blood circulate?** Understand that blood transports oxygen and nutrients to cells, and waste (such as carbon dioxide) from cells Understand that the heart pumps the blood around the body in closed, double circuit Understand how our knowledge on the circulatory system has changed over time	Observe a heart dissection and read a text on the form and function of the heart and blood vessels **Discuss the discovery of blood vessels by William Harvey, identifying the hypothesis and data analysis used in his discovery*
5	**Does our heart always beat at the same speed?** Understand that our heart rate changes depending on our actions, surroundings and emotions To design experiments in answer to research questions	Read a text and answer questions on the role of oxygen in our cells **Design and carry out an experiment on changes in human heart rate* **Interpret results from a theoretical experiment, suggesting improvements and further research*
6	**Why do we lose our breath when we exercise?** Understand that our lungs have a specific structure which facilitates gaseous exchange between oxygen and carbon dioxide To develop a research question and design an investigation	Read and answer questions on a text on the form and function of the respiratory system **Learn about the experiments conducted by Robert Boyle and the role of oxygen in living cells, explaining how his experiments led to changes in understanding at the time*
7	**How much air can we hold in our lungs?** Understand that lungs have a specific capacity which varies between people Understand that smoking is bad for our health in general, and lungs in particular To evaluate and improve an experiment designed by others	Learn about and discuss the risks associated with smoking **Improve a poorly-designed lung capacity experiment and measure their own lung capacity*

8	**How do our systems work together?** To consolidate and bring together our understanding of how the digestive, circulatory and respiratory systems work together	* *Compare the role of the three systems (digestive, respiratory and circulatory), and make a concept map on how they work together*

Note: *and italics denotes a higher-order task, later included in the 'quality' aspect of fidelity (total of 9 activities).

Measuring FOI: Using students´ class notebooks to understand adherence, dosage and quality

In order to assess teaching practices and ECM fidelity of implementation, student notebooks were used as sources of data. Although notebooks might fail to capture all aspects of teaching, they have been well-established as a trustworthy source for the recording of teaching practices, as they reflect teachers´ decisions regarding curriculum coverage and sequencing, and the types of activities carried out (Gibelli et al., 2011; Ruiz-Primo et al., 2004).

At the end of the intervention each teacher was asked to choose a student notebook they considered representative of their science lessons, considering a student with perfect attendance (i.e. the most 'complete' notebook in terms of reflecting classroom activities performed). Each notebook was photographed page by page, and each learning activity found in the student notebook was identified and recorded by researchers. As notebooks were not selected to measure student performance, but rather teaching activities, notebook selection was unbiased (i.e. we did not measure if the student had completed an activity correctly).

In each notebook we identified and counted the number of activities found, and determined whether or not the activity was taken from the ECM. An 'activity' was defined as a distinct task with a specific learning objective (for instance, reading a text and answering questions, or completing an experimental investigation) (Cañal de León, 2000). From this we calculated the FOI considering each classroom as one unit of analysis. We focused on three aspects of FOI (adapted from Carroll et al. (2007): adherence, dosage and quality, as we describe in further detail below.

Adherence – Did teachers use the ECM?

Adherence is a measure of the extent to which teachers taught activities taken from the ECM (i.e. whether teachers followed the request to teach using the ECM). In contexts of high teacher autonomy and low compliance with no state or national student examinations, such as in Argentina (Gorostiaga, 2007), this often gives a measure of how useful teachers find these materials, given that they are not formally obligated to use them.

Adherence was measured by identifying if the activities present in student notebooks were taken from the ECM. It was calculated as the proportion of taught activities taken from the ECM (i.e. number of ECM activities over the total number of activities taught). Therefore, a student notebook which only had activities taken from the ECM would imply a teacher with an adherence of 100%, whereas a teacher who selected four science activities from the ECM and then carried out six of their own science activities would have an adherence of 40%.

Dosage – How much time was dedicated to teaching science?

Dosage is a measure of the exposure or amount of the intervention received by participants. In other words, dosage contemplates whether the duration of the intervention was as full as designed. This is an important facet of FOI to study, as teaching time influences learning outcomes (Kruger, 2016). Furthermore, studies have shown that science is taught for fewer hours than stipulated by formal curricular prescriptions in Argentina and Latin America (Furman et al., 2018).

We measured dosage by calculating how much time was devoted to teaching science by estimating the time taken to complete each and every activity present in the notebooks. Based on experience of common teacher practices in this context, three possible values of time were allocated to different types of activity: for example, half an hour for closing activities to reflect on learning, one hour to complete a short set of questions based on a science text, or two hours for experimental activities.

This method of time allocation was also applied to the ECM, which indicated that the ECM was designed to be implemented in a total of 38.5 hours. Dosage was therefore then calculated as the percentage of the total time spent teaching science over 38.5. In this way, a teacher who taught exactly 38.5 hours would have a dosage of 100%, whereas one who only taught 25 hours would have a dosage of 65%.

Quality – Did teachers implement the more cognitively demanding activities of the ECM?

Quality is defined as how closely actual implementation reaches a theoretical implementation ideal. The ECM included two distinct types of activities: more traditional, lower-order activities (such as answering simple questions from content-based texts) on the one hand, and higher-order activities aimed at promoting the development of scientific thinking skills on the other (Anderson & Krathwohl, 2001). Higher-order activities constituted the core essence and differential characteristic of the provided ECM, considering that they are usually absent in the region's science classrooms (Valverde & Näslund-Hadley, 2010, Furman et al., 2018). As such, even though two teachers might only use only some of the ECM activities, it is important to consider which activities they choose to use. Quality is thus a measure of this choice and could be considered a proxy for the quality of students' exposure to opportunities to develop scientific higher-order thinking skills.

Quality was defined as the proportion of higher-order activities from the ECM that were implemented, taking into consideration how far teachers implemented the ECM overall. As indicated in Table 1, in total there were nine higher-order activities in the ECM. Therefore, if a given teacher covered all topics in the ECM but conducted only three higher-order activities over the 12-week period, then quality was set at 33%.

Constructing fidelity clusters

To characterize distinct patterns of fidelity we conducted a cluster analysis by using a non-hierarchical k-means conglomerates method. K-means were evaluated a priori with between two and seven clusters, with four groups finally being chosen as the best fit. Fidelity clusters were then tested for statistical differences using a one-factor ANOVA. As a result, four clusters (i.e. groups of classrooms) with different patterns of fidelity were identified, such as classrooms with high adherence but low quality and dosage, or classrooms with high adherence and quality but low dosage.

Investigating associations between patterns of FOI and school socioeconomic contexts

Schools were categorized according to the concept of 'territorial scenarios' developed by Steinberg and Tófalo (2018) for the City of Buenos Aires (CABA). The authors' segmented districts according to the following dimensions: work and income, habitat and housing conditions, health, educational achievements of the population, and district availability of goods and public services. As a result, the CABA districts were sorted into four different and non-overlapping territorial contexts. For this study, we categorized all schools from the two least advantaged contexts as 'unfavorable' (n=19) and those from the two more advantaged contexts as 'favorable' (n=13). We then analyzed the percentage of classrooms in each fidelity group for favorable and unfavorable contexts.

Results

Considering our research questions, in the following sections we examine the adherence, dosage and quality with which teachers implemented the ECM in their science lessons. Also, we explore and describe patterns of implementation amongst classrooms and then consider how these patterns differ across school socioeconomic contexts.

What was the FOI (considering adherence, dosage and quality) of a seventh-grade research-based science ECM?

When analyzing how the ECM was implemented, we found differences between the average level of each of the three dimensions of FOI considered, as well as high variability amongst classrooms in all three dimensions (see Figure 1).

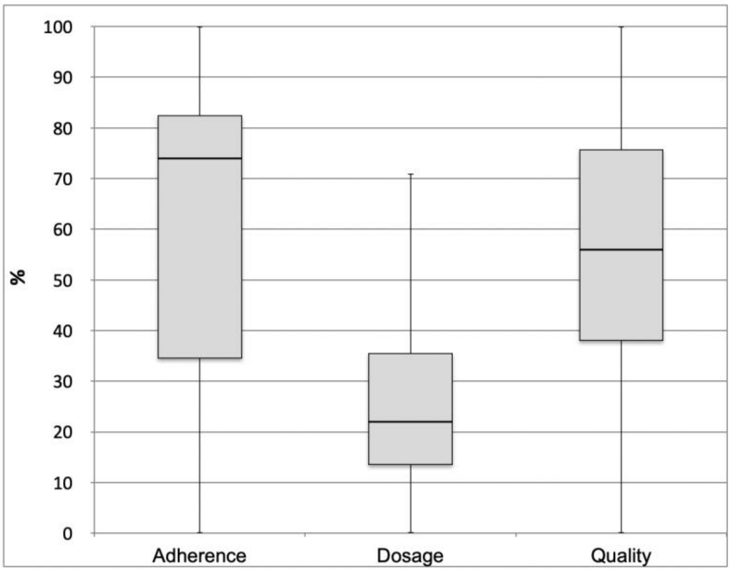

Figure 1 Box-plot of adherence, dosage and quality of ECM use across 32 classrooms (median and quartiles represented)

Adherence

Adherence is a measure of 'how much' of the ECM teachers implemented expressed as the proportion of activities that were taken from the ECM as opposed to other sources (such as their own lesson plans or other curricular materials). We found high adherence levels, with a median of 74% of activities taught taken from the ECM, as shown in Figure 1. However, adherence varied from 0 to 100%. In a quarter of the classrooms the ECM was implemented with an adherence under 33%.

Given that participation in the program was mandatory but not enforced, this high average level of adherence is a noteworthy finding in a context such as Argentina, where a culture of low compliance and high resistance to school interventions (even when led by the local Ministry of Education) is common (Gorostiaga, 2007).

Dosage

Dosage (i.e. the exposure to the intervention) was very low overall, with a median of 23%. This is equivalent to 8.8 hours being dedicated to science lessons, out of the proposed 38.5 hours over the 12 week period. Similarly to adherence, we saw large variability in the dosage, with a quarter of classrooms indicating a dosage under 14%, and no classrooms reaching a full dosage (implying that even when considering non-ECM activities, no classroom taught 38.5 hours of science).

The prevalence of such low teaching time is concerning, given that seventh-grade teachers in the CABA are expected to teach four hours of science per week (Secretaría de Educación, 2004). The intervention took place over 12 weeks, which means teachers should have been able to comfortably cover all topics and activities within the allotted time frame. These results support other studies that indicate that teachers are devoting less time to science teaching than that stipulated by the district guidelines (Furman et al., 2018; Valverde & Näslund-Hadley, 2010). Even considering the limitations of the methodology used (in that notebooks do not capture everything that is done throughout a lesson, therefore perhaps under-representing teaching time) this still indicates a large difference between the expected and enacted dosage. Considering that teaching time has been found to correlate with learning outputs (Kruger, 2016), this may at least partially explain the low levels of performance in science of Argentine students in local and international assessments (Gamboa & Walterberg, 2012; Vegas, Ganimian, & Bos, 2014).

Quality

Quality is a measure of how closely implementation reaches a theoretical ideal, in this case, if teachers implemented the more cognitively-demanding activities aligned with reform-based science teaching.

We found that the median quality level was 56%, also with high variability among teachers. This suggests that, on average, teachers negatively selected almost half the activities aimed at promoting higher-order thinking skills included in the ECM. This is consistent with findings from other fidelity studies that show that teachers adapt ECM in ways that resemble their regular practices, which often implies lowering the original cognitive load of the activities and the ECM overall (Davis et al., 2014). As in these studies, our results seem to provide evidence on the need to further support teachers to successfully enact reform-based science teaching practices oriented towards the development of higher-order thinking skills, for instance, through instructional coaching and/or in service teacher training sessions.

What different patterns of FOI were found when teachers implemented the ECM?

High degrees of variation were evident for adherence, dosage and quality across classrooms. Therefore, looking only at averages across our whole sample could hide more nuanced patterns of teachers' ECM usage.

We performed a k-means cluster analysis of the three dimensions of fidelity to identify groups of classrooms with similar patterns of overall fidelity. As a result, the following four groups emerged: non compliant, low, medium, and compliant (See Figure 2). Each group was constructed based on the three dimensions measured, with groups differing statistically from each other in at least two of the three dimensions ($p<0.01$). In other words, each group was clustered based on similarities in their adherence, dosage and quality levels, with each group having two of those elements significantly different to each of the other groups.

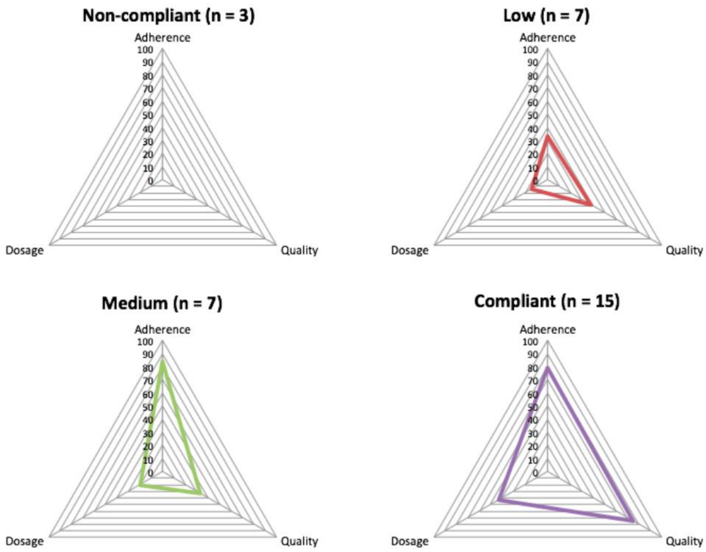

Figure 2 Radar diagrams of the four fidelity clusters identified, considering the average level of adherence, dosage and quality of each group

The first of the four groups was made up of the three classrooms in which teachers did not implement the ECM at all (i.e. 0% adherence, dosage and quality), thus named 'non-compliant'. Although beyond the scope of this study, it would be interesting to explore the reasons behind non-compliance to be able to understand whether it was due to resistance to external professional development interventions, a lack of confidence in the ECM, not teaching science in general, or finding the intervention un-implementable due to logistical or other challenges.

Within the remaining 29 classrooms in which teachers did use the ECM, we identified three clusters with distinct patterns of overall FOI. The group of overall 'Low' FOI (n=7) had low adherence (average 33%) and quality (38%), and very low dosage (14%). These were classrooms whose teachers implemented a few of the ECM activities or implemented their own activities, and practically none of the higher-order inquiry-based activities considered in the quality dimension, while using other resources to teach their science lessons. As the very low dosage shows, in these classrooms there was very little science taught overall. We hypothesize that these classrooms represent teachers who need considerably more incentives or pedagogical support to use the ECM, or might indicate the need to monitor and supervise implementation as part of ECM-based professional development interventions.

The group of 'Medium' FOI (n=7) showed high adherence (84%), but low dosage (20%) and low quality (33%). In these classrooms teachers used the ECM for most of their activities and taught slightly more hours than those with low fidelity, but still skipped most of the suggested higher-order activities. In other words, most of the lower-order activities from the ECM were implemented, perhaps as these were most similar to their regular teaching practices. The combination of low dosage and high adherence seen in the medium implementation group means that these teachers did not devote much time to science teaching, but what they did teach came from the ECM. This suggests that the ECM might have been a useful tool for teachers, but that it was not enough to increase the overall amount of time dedicated to science teaching. Had adherence been lower, this would have implied that teachers simply taught their own activities and did not find the ECM useful. Also, these teachers could benefit from further support during ECM implementation, given that they appeared to be interested in using the materials but unable to do so fully.

Lastly, the ‘Compliant’ group (n = 15) had high levels of adherence (79%), medium dosage (43%), and a high quality (75%). These classrooms were those where teachers used the ECM and included the higher-order activities, with considerably more teaching time devoted to science teaching. Having found that half the total number of participating teachers belong to this cluster is encouraging, indicating that ECM-based interventions have potential as a large-scale strategy for professional development and science teaching improvement. However, as shown by the persistently low level of dosage, more attention could be given to further support teachers in increasing the time devoted to science teaching.

How did these patterns of fidelity of implementation vary according to school socioeconomic contexts?

Given that there is some evidence that curriculum implementation is influenced by school and student characteristics (Bumen, 2014), we explored whether the found patterns of FOI varied across the schools' socioeconomic contexts.

Although all four FOI groups were present in both favorable and unfavorable contexts, we identified a trend suggesting higher fidelity in more favorable contexts (see Figure 3). Schools classified as belonging to unfavorable scenarios demonstrated higher variability and lower overall fidelity. Conversely, all schools in more favorable contexts implemented at least some of the ECM activities. All non-compliant teachers were from schools in unfavorable scenarios.

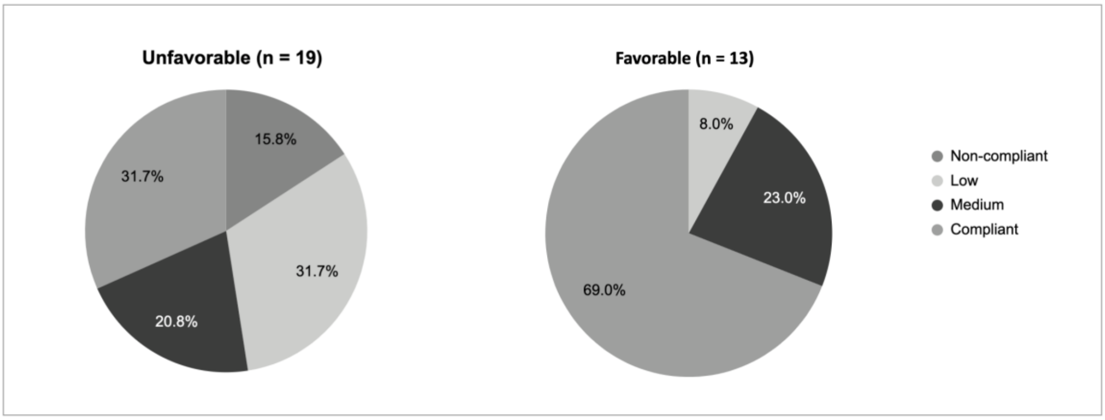

Figure 3 Fidelity across different school socioeconomic contexts (% of classrooms in each fidelity cluster)

These results coincide with studies showing that school socioeconomic contexts impact educational processes (Steinberg & Tófalo, 2018). Although more information would be needed to understand why and in which ways, these results also point to the need of adjusting and tailoring science teaching improvement and professional development interventions, such as the provision of ECM, considering the specific needs in each context.

Discussion

Despite the popularity of and considerable economic investment in using Educative Curriculum Materials (ECM) as a teacher development strategy across Latin America (Furman , 2020), we see a lack of large-scale empirical evidence of the use of these materials in diverse or representative classroom samples. This study responds to a call in the research literature stating the need to understand variations in implementation processes (Lin et al., 2010; Rogers et al., 2010; Shin et al., 2017), particularly in contexts where there is an urgent need to improve science teaching and learning. We adopted a FOI framework to understand if, how much, and how 28 seventh-grade teachers from a representative sample of schools in Buenos Aires, Argentina, implemented a research-based science ECM in their seventh-grade classrooms.

We first aimed to understand the FOI of the ECM, considering adherence, dosage and quality. We found that most teachers -except those with low adherence- taught the required topics by using the ECM as the main source of lesson plans. This is an interesting and encouraging finding, as other studies from the region indicated low teacher compliance with government or other types of school improvement programs (Gorostiaga, 2007). However, we also found very high variability in all dimensions of FOI across classrooms.

Therefore, we wondered if this variability hid patterns of differential use, which led to our following research questions: what patterns of fidelity were found when teachers implemented the ECM, and did these vary according to school socioeconomic contexts? Having a clearer answer to these questions would help understand if groups of teachers or schools are using the ECM in similar ways (regardless of overall averages). This, in turn, might clarify how best to design and implement tailored interventions aligned with teacher behavior to maximize their effectiveness (Rogers et al., 2010; Shin et al., 2017).

Our analysis revealed four main FOI patterns (non-compliant, low, medium, and compliant). Almost half the teachers were found to use the ECM in a compliant way, regardless of whether their schools belonged to favorable or unfavorable socioeconomic contexts. This implies that for many teachers, providing high-quality structured lesson plans in the form of ECM is a 'good enough' intervention that holds value as a large-scale intervention to support teachers in their science practices.

However, this was not the case for all teachers, which means that these others could further benefit from more targeted forms of support. For instance, since teachers in the group of medium fidelity used the ECM with high adherence but low quality -as they omit higher-order activities- they might benefit from interventions such as selective and specific coaching (Kraft, Blazar, & Hogan, 2016), which focuses on supporting teachers towards the implementation of more demanding activities.

On the other hand, the (very few) teachers who did not implement the ECM at all might need a different type of professional development support. Follow-up studies would be needed to understand more about why these teachers were reluctant to use ECM, and whether or not it is by chance that all of them were in unfavorable contexts. For example, if non-compliance is due to teachers not being technically able to implement the ECM they may need more intensive support. If, on the other hand, non-compliance is a calculated choice based on conscientious objection, more may be needed to convince these teachers of the benefits of ECM use, or allow them to use their own lesson plans if proven to be effective in terms of student learning. If non-compliance is simply a case of resistance to interventions, these teachers might benefit more from having their school leadership teams implementing an accountability framework with increased monitoring.

Improving school accountability frameworks and organization through more effective school leadership might also increase the dosage of an intervention, which in this study was strikingly low in all groups (on average, teachers only taught 8.8 hours of science within a 12-week timeframe). This is important as teaching time impacts learning directly (Kruger, 2016). In turn, it raises questions as to why we see such a low dosage, and indicates the need to strengthen institutional organization so that the required hours are spent on science teaching (as stipulated by the local curriculum guidelines). It also raises questions around what the untaught science hours are being used for - it would be an interesting avenue for a follow-up study to investigate this further (Pringle et al., 2017).

However, based on our results and previous studies, we hypothesize that differences in fidelity of implementation are probably more impacted by structural issues such as the school's socioeconomic context. This may be because in unfavorable contexts there might be low teacher expectations regarding what students can learn, or structural reasons such as lower resources, students with complex needs, or student absenteeism, as many indicators show (Haberman, 1991; Shin et al., 2017; Di Virgilio and Serrati, 2019). These results coincide with studies that note 'poorer' education and lower fidelity of implementation of educational programs in disadvantaged or low-performing schools, even when using the same curriculum materials (Buxton & Lee, 2007; Shin et al., 2017), and highlight an urgent need to reinforce teaching practices in these contexts. Again, this raises the question of how best to support teachers working in unfavorable contexts with low or non-compliance fidelity, perhaps because teachers feel they need to focus on other urgent aspects of student development and well-being.

One limitation of this study concerns the concept of fidelity. It could be argued that a FOI of 100% is not necessarily the best outcome, given that a teacher could keep the integrity of the ECM intact despite modifications (Fogo et al., 2019; McNeill, Marco-Bujosa, González-Howard & Loper, 2018). A skilled teacher can possibly be more effective when modifying or adapting curricular materials based on their knowledge, pedagogical experience, and understanding of their students' needs. In this case, our study allows for the possibility of teachers using the ECM flexibly. Our methodology did not identify teachers who might be adapting the ECM activities in ways that fundamentally benefit their students and match their needs. Nevertheless, we did not find classrooms who fit this description (i.e. high dosage, low adherence but high quality).

To conclude, the provision of effective resources to help science teachers encourage the development of skills and competencies in science by fomenting analytical and critical thinking in students across all contexts remains an important and urgent task. Therefore, finding accurate ways of identifying implementation patterns to then design interventions that respond to contextual needs is undoubtedly beneficial. As we move towards a world with scientific skills ever-more needed, supporting teachers with well-designed professional development interventions is fundamental.

Acknowledgements

We extend our thanks to María Victoria Anauati and Facundo Albornoz for their help. We also thank CIAESA for funding this study.

Ethics and declaration of interest statements

Informed consent was obtained from all individual participants involved in the study, in accordance with institutional ethical standards. The authors have no relevant financial or non-financial interests to disclose.

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