Within this context, Verschaffel, Reybrouck, Jans, et al. (2010) recently carried out a study in which third- and sixth-grade children (aged 8–13) were exposed to short sonic fragments, generated by the researchers with the aim to maximally isolate one salient sonic parameter (pitch, duration, or loudness). For each fragment, six pairs of contrastive notations were designed, constituting both a graphic representation that was more and less appropriate according to one of six representational criteria inspired by diSessa's (2002) framework:

1. Correctness: "A representation is considered to be correct when it accurately shows the articulation of certain sonic parameters over time" (Verschaffel, Reybrouck, Jans, et al., 2010, p. 482). Since we are dealing with symbolic systems that do not fulfil the requirements to be considered standard forms of notation, it remains unclear to what extent a given representation could be assessed as correct.
2. Completeness: "A representation is considered to be complete when it represents the whole of the music fragment, and not only a part" (Verschaffel, Reybrouck, Jans, et al., 2010, p. 482). Both correctness and completeness are quite similar criteria, with a subtle difference between them. The distinguishing aspect is the integrity of the representation, which is a necessary, but not a sufficient, condition to correctness.
3. Transparency: "When a representation contains an additional element that shows or suggests systematic variation that does not refer to any corresponding variation in the sound fragment that is to be represented, the representation is considered as misleading. When such misleading elements are absent, the representation is called transparent" (Verschaffel, Reybrouck, Jans, et al., 2010, p. 482).
4. Formality: "A representation is considered to be formal when it uses signs, symbols, rules, and/or conventions that belong to a formal notational system" (Verschaffel, Reybrouck, Jans, et al., 2010, p. 483). Despite the existence of alternative notational systems, we have restricted this study to standard musical notation, since it was the main musical code that the students of our sample were taught during their schooling.
5. Parsimony: "A representation is considered parsimonious when it contains no redundant information" (Verschaffel, Reybrouck, Jans, et al., 2010, p. 483). This is not to say that it is always easy to decide whether redundancy could be seen as beneficial, since "if a representation were intended for one purpose or another, features would be more or less fitting" (diSessa, 2002, p. 115).
6. Beauty: "This criterion refers to the presence or absence of a pleasant visual effect" (Verschaffel, Reybrouck, Jans, et al., 2010, p. 483). It belongs to *aesthetic* criteria, which "would typically be classified non-scientific" (diSessa, 2002, p. 116).

For each pair, the children had to choose the representation they considered to be the best. In addition, they were invited to explain their choice. The analysis of their representational choices and their underlying explanations revealed that the children were able to adequately use several *representational criteria* in their evaluation of the representations of sonic fragments, which was in line with diSessa's findings on students' criteria for representations in mathematics (diSessa, 2002). Stimulated by these findings, Verschaffel, Reybrouck, Jans, et al. (2010) argued for additional experimental studies and intervention-based studies in music, related to this field.

Besides this research on MRC as related to graphic representation of music, there is also another emergent body of research which is related to *ecological perception* in music (Gaver, 1993a, 1993b; Godøy, 1999; Martindale & Moore, 1989; McAdams, 1993; Reybrouck, 2001, 2009; Windsor, 2004). This approach conceives of music as a small subset of a broader sonic environment, with music users—a generic term to encompass both listeners and

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performers— being considered as organisms which cope with music as a sonic environment in an attempt to make sense of it (Reybrouck, 2001, 2005). The ecological approach thus broadens the scope of "music" to the realm of "sonic environment", surpassing any restriction to the kind of music and sound, and going beyond any cultural and historical constraints (Reybrouck, 2005). As such, this approach provided two major premises which inspired our design of the testing and teaching materials that were used in the present experiment. First, we conceived of the students as music users in an ecological sense. Second, we conceived of the sonic material as sonorous stimuli, rather than music fragments belonging to a (Western) cultural tradition.

Taking into account this empirical and theoretical background, we set up a teaching experiment, aimed at determining whether middle school students showed positive signs of MRC when they were involved in a twofold musical task: they were requested (a) to generate and play music in small groups, according to pictures that were provided to them, and (b) to draw self-generated representations, in accordance with some sonic stimuli that were presented to them. To the best of our knowledge, this is the first study in which an educational intervention was carried out in order to test its effectiveness to improve children's MRC related to music graphic representation. In addition, making music students aware of their strategies to represent the sounding environment surrounding them, and enhancing their critical sense to judge representations may have valuable educational implications. Music teachers, further, could also benefit from using students' spontaneous drawings instead of the standard notation so as to keep them engaged in music.

Hypotheses and questions

Our first hypothesis was that the experimental program would have a positive overall effect on students' MRC, to be measured by assessing the more appropriate answers on several items of a test. We predicted a significant increase in the number of more appropriate answers from pretest to posttest for the experimental group, who received an educational intervention. For the control group, who did not receive this intervention, no significant increase from pretest to posttest was expected. As a result, we also expected a significant difference in favour of the experimental group at the posttest.

We also hypothesized that the positive effect of the experimental program would be lasting. As such, we predicted that the expected significant difference in the number of more appropriate answers in favour of the experimental group would not disappear in a retention test.

Besides testing these two hypotheses on the basis of students' overall performances on the different tests, we also attempted to answer two additional research questions:

1) Was the experimental program equally effective for students with different levels of musical experience (i.e., for the musically high-experienced, medium-experienced, and low-experienced students in the experimental class)?; and
2) Was the experimental program equally effective for the six types of representational criteria involved in the program?

Method

Overall design

Three classes of students participated in the teaching experiment: one class was randomly assigned to the experimental condition (E), while the other two classes functioned as a control

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group (C). We decided to work with two control classes instead of one so as to counteract the experimental threat of attrition. In turn, we assumed that a larger C group would be more representative of a typical non-treatment learning environment. In the E group, an educational intervention on MRC was carried out during the hours allocated for the music course. The actual teaching was done by the class teacher, who regularly met the first author to coordinate the implementation of the experimental program. During the experiment, the students from the C group continued to follow the regular music curriculum, respecting the prescribed annual program. Both groups (E and C) received the same pretest and posttest, which measured students' MRC. One month after the posttest, they also completed a retention test.

Participants

The recruited sample of participants consisted of 78 middle school students (aged 11–14). Twenty-two students were removed from the sample as they did not participate in one or more of the tests. Finally, the E class consisted of 20 students and the C classes of 19 and 17 students respectively ($n = 56$). The three classes attended the same secondary school in a small Majorcan town, which was selected on the basis of its willingness to participate in the experiment. Although the school recruits its students from families of different socio-economic backgrounds, the vast majority of the families were middle-class. Between the two groups there were no significant differences with respect to students' gender (E: 17.9% boys/17.9% girls; C: 25% boys/39.3% girls; $p > .05$), age (E: 12.40±0.75; C: 12.13±0.54; $p > .05$), and musical experience (E: 2.76±1.33; C: 2.86±1.19; $p > .05$) as measured by means of a questionnaire.

Instruments

Musical Experience Questionnaire. A self-reported musical experience questionnaire (MEQ) was created from a model which was proposed by Pirie (1999). It was divided into two parts: part A asked for general background details of participants, while part B was concerned with information about their musical background, and consisted of five questions (see Appendix A). Regarding part B, Questions 1 and 2 focused on general skills as demonstrated by instrumental playing. A Likert scale was used to ask participants to rate how often they performed certain musical tasks. Question 3, on self-definition, was designed to measure self-awareness of musical ability. Question 4 asked for information on formal music training, while Question 5 aimed at determining how often participants listened to music. Each question was assigned an adjustment index so as to get a global mark (scale 1–10). The instrument yielded a good internal consistency (Cronbach $\alpha = .80$).

Pretest. Before the intervention, an evaluation instrument was collectively administered to the E and the two C classes. It consisted of a version of a previously validated test (Verschaffel, Reybrouck, Jans, et al., 2010, p. 502), in which 18 pairs of representations were provided on paper together with some free space to draw and write down comments. After having attended to the teacher's explanations and after having read the instructions, the students listened to three sonic fragments and carried out, for each item, either one of the two following actions: (a) to choose the best representation of each pair, or (b) to provide their own representation as an alternative for the two given pictures.

Every sonic fragment accentuated one salient sonic parameter, namely pitch, duration, and loudness. With respect to the pictures, three series of six pairs of representations were generated by the researchers. Every series emphasized one sonic parameter, and every pair of representations was related to a representational criterion, namely correctness, completeness,

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transparency, formality, parsimony, and beauty. For each pair of representations, there was a more appropriate and a less appropriate choice apart from the possibility for students to provide a self-generated drawing (see Appendix B for an extract).

Posttest. At the end of the experimental program, an analogous version of the pretest with new representations and sonic fragments was administered in all three classes as a posttest. The latter was administered in the same way as the pretest.

Retention test. One month after the posttest, an analogous version of the pretest and posttest with new representations and sonic fragments was administered in all three classes as a retention test, following the same procedure as the previous ones.

Data handling and analysis

For all items of the pretest, posttest, and retention test, four answer categories were distinguished: a) More appropriate answer (MA): the chosen picture corresponds with the most adequate representation of the sonic fragment, according to the selected representational criterion; b) Less appropriate answer (LA): the chosen picture does not fit with the most adequate representation of the sonic fragment, according to a selected representational criterion; c) Disallowed answer (DA): more than one representation is selected, or one representation is selected and an additional representation is drawn; and d) No answer (NA): no picture is selected, and no representation is drawn.

"MA" category was assigned value "1", while the rest of the categories were assigned value "0". Given that the students could decide to draw an alternative representation, their self-generated drawings were assessed according to the abovementioned values.

To evaluate the effects of the experimental program, non-parametric tests were performed with group (E vs. C) and time (pretest vs. posttest vs. retention test) as the independent variables, and with the students' MRC scores as the dependent variable, since our data were not normally distributed. The musical experience quotient was used as a covariant.

Description of the experimental program

Implementation of the educational intervention

The intervention consisted of three teaching–learning units (TLU) of 110 minutes each, spread over a period of three consecutive weeks.

First week. Sessions 1 and 2 (TLU 1) aimed at making the representational criteria familiar to the students. It was not so important to remember the names of the criteria, but rather to understand their meaning. Correctness, completeness, and transparency criteria were dealt with in session one; formality, parsimony, and beauty criteria in session two. At first, the music teacher provided brief notions on each criterion and then tried to motivate the students' participation by requesting their opinion. The procedure consisted of showing on the classroom projection screen six pairs of pictures—each pair related to a representational criterion—and playing a sonic fragment related to the pictures (see Figure 1 for an extract). Both the sonic and graphic material were different from those used in the pre-test, post-test, and retention test. Thereafter the students were requested to discuss which picture of each pair yielded the best fit.

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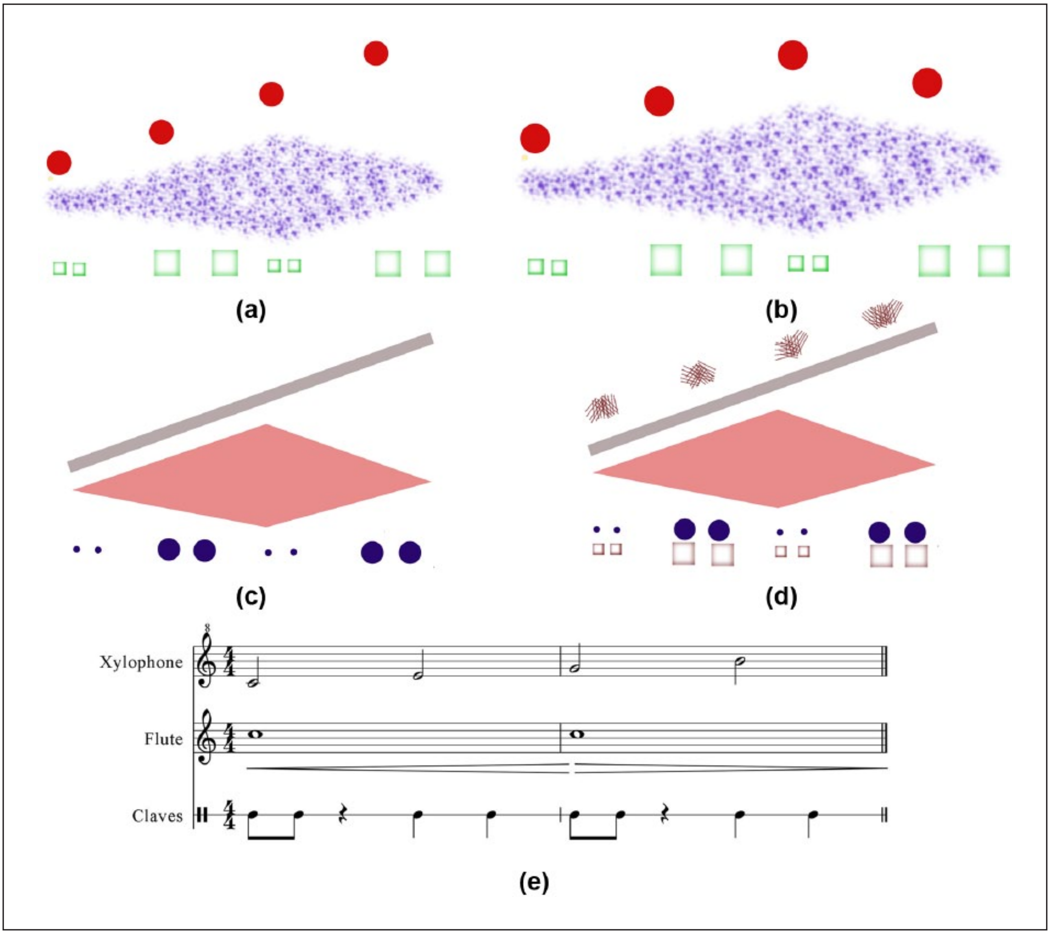

Figure 1. Material used in TLU 1. Examples of contrastive representations (left: more appropriate; right: less appropriate) related to correctness (a and b), and parsimony (c and d). Musical notation for the pictures is provided (e). The audio file is also available as supplemental online archive.

Second week. Sessions 3 and 4 (TLU 2) were aimed at applying into practice what had been taught at a theoretical level during the first week. Two pictures (Figure 2), each containing a reference to the three mentioned sonic parameters, were shown on the classroom projection screen—one per session—and students were requested to improvise (session 3) and play (session 4) music according to these pictures in small groups (2–3 students). Music classroom instruments were available, i.e. xylophones, glockenspiels, and hand percussion. Next, a discussion started about which group had generated the music fragment that accorded best to the picture, taking into account the representational criteria reminded in the session. TLU 2 tasks are the reverse side of TLU 1 activities, since this time the students were asked to create music, instead of having been given a sonic fragment beforehand.

Third week. Sessions 5 and 6 (TLU 3) consisted of a Jigsaw Classroom project (Kirk, 2001; Mesch, 1991), in which students were requested to make a self-generated drawing which fitted

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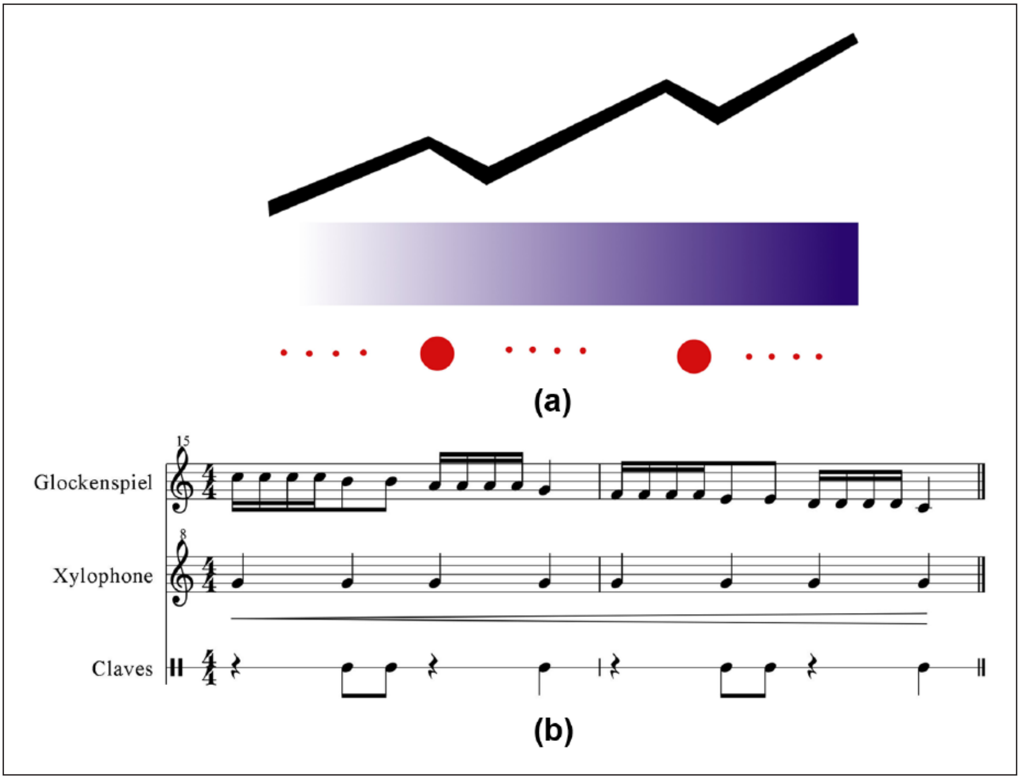

Figure 2. Material used in TLU 2. Graphic notation in Session 3 (a) and musical notation in Session 4 (b).

in a sonic fragment containing the three aforementioned sonic parameters. To this respect, the class was distributed into small groups (2–3 students), in which every student had a responsibility, namely: "expert in pitch", "expert in duration", and "expert in loudness." Two types of groupings were proposed: (a) small groups which consisted of three experts for each area, and (b) large groups (6–7 students) which consisted of all the experts for a certain area. At the beginning, every student was first allocated to a small group, then to a larger group, and finally they joined the original group again.

Results

Results for the two hypotheses

To test Hypothesis 1 about the positive effect of the experimental program, we analysed whether there was a Group (E vs. C) x Time (pre- vs. posttest) interaction effect. A Kruskal-Wallis rank sum test was performed, which revealed a significant difference between the E and C group in the posttest (E: 11.85±3.13; C: 8.83±1.99; $p < .001$). Additionally, a Wilcoxon test showed a significant decrease in the number of MAs from pretest to posttest for the C group (pretest: 11.05±2.71; posttest: 8.83±1.99; $p < .05$), while scores for the E group tended to improve, but not in a significant way (see Figure 3).

On the other hand, the positive results on the retention test confirmed Hypothesis 2 about the lasting effect of the experimental program. We analysed whether there was a Group (E vs.

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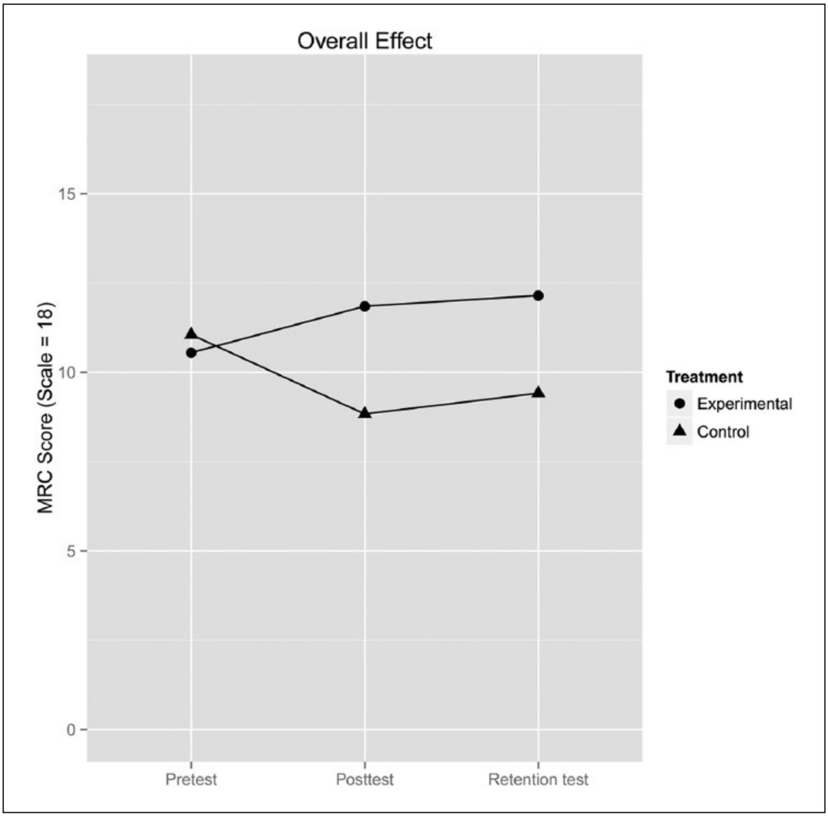

Figure 3. Group x Time interaction effect.

C) x Time (post vs. retention test) interaction effect. A Kruskal-Wallis rank sum test was performed, which revealed a significant difference between the E and C group in the retention test (E: 12.15±2.05; C: 9.41±2.75; $p < .001$). In this case, a Wilcoxon test showed no significance for each group from posttest to retention test, though the scores for both E and C groups slightly improved (see Figure 3).

Results for the two additional questions

To determine the influence of students' musical experience on the effectiveness of the program, we separately computed the sum of MAs of the pretest, the posttest, and the retention test for musically high-experienced, medium-experienced, or low-experienced students. To make this analysis possible, every student was assigned to each group, based on his or her score on the MEQ. Students with a score on the questionnaire between 3.33 and 6.66 were put in the medium-experienced group, and those with a score below 3.33 in the low-experienced group. No student got a score higher than 6.55, which implied that the high-experienced group was ruled out in this study. A Kruskal-Wallis rank sum test revealed no significant Group x Time x Musical experience interaction effect (see Figure 4). Additionally, a Wilcoxon test showed a significant decrease in the number of MAs from pretest to posttest for the C group low-experienced students (pretest: 11.32±2.61; posttest: 8.52±2.08; $p < .001$).

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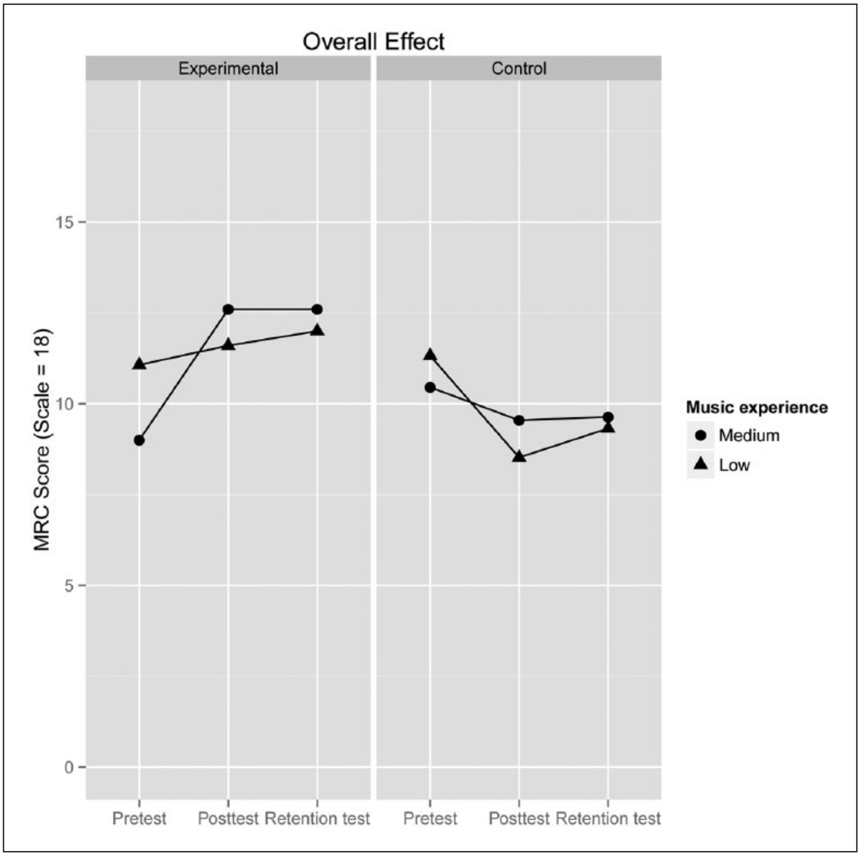

Figure 4. Group x Time x Musical experience interaction effect.

Similarly, we computed the number of MAs in the E class on the pretest, posttest, and retention test separately for each of the six representational criteria (see Table 1). The data showed that the intervention was effective for correctness, completeness, and transparency criteria, while the formality criterion remained rather stable. The most striking results were the scores for parsimony and beauty criteria, which followed an unpredictable pattern, with unexpected gains and losses.

Finally, even though we did not raise explicit research questions about the influence of gender and age on the results, we performed additional analyses including both variables and no significant result was found.

Discussion and conclusions

The aim of this study was to analyse the effect of an educational intervention on students' MRC in a music-listening and playing task. Some new features were introduced with respect to previous studies. First, we conducted an intervention-based study instead of a descriptive study, as commonly carried out in this field. Second, a musical experience questionnaire was used in order to analyse the effect of the intervention in relation to that covariant. Third, the

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Table 1. Frequency (F) and percentage of more appropriate answers (MAs) of the E class students (n = 20) on the pretest, posttest, and retention test corresponding to the six representational criteria.

Criteria	More appropriate answers					
	Pretest		Posttest		Retention test	
	F	Mas	F	Mas	F	Mas
Correctness	41	68.33%	45	75.00%	59	98.33%
Completeness	41	68.33%	50	83.33%	56	93.33%
Transparency	30	50.00%	40	66.66%	41	68.33%
Formality	27	45.00%	29	48.33%	32	53.33%
Parsimony	42	70.00%	29	48.33%	32	53.33%
Beauty	30	50.00%	44	73.33%	23	38.33%

abovementioned ecological approach determined both the type of intervention (with the students conceived as music users) and the type of sonic material (simple sonic stimuli instead of musical fragments) that were used.

The results that were obtained in an experimental class were compared with those in two control classes and provided partial support for our general hypothesis that the experimental program would have a positive overall effect on students' MRC. Despite an overall significant difference in favour of the E group both at the posttest and the retention test, as hypothesized, this overall gain was seriously reduced due to the negative results for two representational criteria, namely parsimony and beauty. Moreover, the overall gain was to a great extent due to a decrease in the score of the C group at posttest, while the gain in the E group was rather small. A further analysis revealed that this significant decrease was influenced to a great extent by the scores of the low-experienced students of the C group. These findings let us consider a possible change in the educational intervention in a future study, such as an improvement of the learning environment, by means of hypermedia resources. More specifically, parsimony and beauty comprehension should be enhanced, since students' subjective judgements apart from the content of the educational intervention itself are likely to have jeopardized their choice for the more appropriate representation.

From a theoretical viewpoint, the present study is in line with diSessa's (2002) findings about the increasing importance of the epistemic criteria (correctness, completeness, and transparency) and the decreasing importance of the aesthetic criterion (beauty) in the domain of sound and music, as already confirmed by Verschaffel, Reybrouck, Jans, et al. (2010) and Verschaffel, Reybrouck, Degraeuwe, et al. (2013).

With respect to the methodology, the intervention-based approach of the present study allowed us to investigate the impact of certain instructional techniques on students' MRC. It enabled us also to derive some conclusions about the impact of various task variables (i.e., learning environment, instructions given) and subject variables (i.e., age, musical experience). Broadly speaking, our intervention consisted of a two-fold task where the students were required to invent both "sounds in response to given visual shapes" and "visual shapes in response to given sounds" (Walker, 1981, p. 108). As far as measurement of MRC is concerned, we designed an instrument which combined a matching task (Verschaffel, Reybrouck, Jans, et al., 2010, p. 482) and a freehand drawing task from researchers' generated sonic stimuli. The latter links up our study to seminal literature on children's graphic representation of music (see

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Barrett, 1997, pp. 2–3 for an overview). However, our approach entails some limitations as well. First, as already pointed out by Verschaffel, Reybrouck, Jans, et al. (2010, p. 498), we do not have conclusive confirmation that the students actually attended to the salient parameters of the sonic fragments, or to the visual features of the graphic representations in the same way that we, as researchers, did. So, more process-oriented assessment methods will be needed to gain a better insight into students' choices. Second, the worse scores on the parsimony criterion after the intervention may indicate that the intervention itself did not work properly for this criterion so that perhaps a different educational setting is required, with alternative instructional techniques. In this respect, the proportion between the number of representational criteria and the time allocated to deal with each one should be considered in further research. Third, although our Music Experience Questionnaire yielded a good internal consistency, more testing would be needed in order to ensure both its validity and reliability. Further research should also address the need of considering alternative constructs, namely musical ability or musical training. Fourth, due to the quasi-experimental design and the educational setting in which the educational intervention took place, with odd variables possibly intervening, it is difficult to determine to what extent the different elements of the intervention contributed to the obtained effect. In this respect, a decline in motivation between pretest and posttest among the students from the C groups is likely to have led to a decline in their performance, since they had to do a similar test twice without any related intervention in between. Finally, this study was set in a concrete location with a particular historical and cultural background, which clearly limits its external validity. Moreover, being more a theory-oriented study rather than a practice-oriented study, our outcomes must be contextualized according to an anthropological view of music education, where certain goals, content, procedures, and assessment make sense.

Given the limited number of subjects (56 students) and the moderate nature of the obtained effects, educational implications are limited. First, it is still unclear whether students need a systematic instruction to show positive signs of MRC, as stated in Verschaffel, Reybrouck, Jans, et al. (2010, p. 499). However, our results show that especially low-experienced students could benefit from teaching aimed at developing their MRC. Second, as Reybrouck et al. (2009) and Verschaffel, Reybrouck, Janssens, et al. (2010) have already stated, it seems to be worthwhile to give more attention to children's informal representations, instead of imposing on them standard notation systems. This is particularly important to music teachers, who should be aware of their professional bias which often leads them to consider standard notation as more appropriate than students' spontaneous notations, as already noted by Bamberger (1982) and Barrett (2004, 2005). Finally, there is a need for more research that continues to show further evidence relating to children's MRC and how it develops in various education environments in the field of music.

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Author biographies

Vicent Gil obtained his Master's degree in Specific Didactics from the University of Valencia, Spain. The current article is based on his master's thesis, which was supervised by Jesús Tejada.

Mark Reybrouck is professor in Musicology at the University of Leuven, Belgium. His major research interests are musical sense-making, music psychology and music education.

Jesús Tejada is professor in Music Didactics at the University of Valencia, Spain. His main interest is music technology applied to music education.

Lieven Verschaffel is professor in Educational Sciences at the University of Leuven, Belgium. His major research area is instructional psychology, especially psychology of mathematics education.

Appendix A

Musical Experience Questionnaire (MEQ): Part B

1. Instruments you play individually at your own leisure:[1]

☐ String instruments	☐ Wind instruments	☐ Percussion instruments

2. Music groups in which you participate:[1]

☐ Wind band	☐ Choral	☐ Rock group	☐ Pop group	☐ Orchestra

3. Ability to. . .[2]

☐ read music on score	☐ play/sing music at sight-reading	☐ play/sing music without score, by ear	☐ improvise music, either playing or singing	☐ compose music and write down on a score

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4. Music lessons, out of the schooling:[3]

☐ Private lessons	☐ Music School	☐ Conservatory

5. You listen to. . . music[1]

☐ blues	☐ classic	☐ folk	☐ jazz	☐ pop	☐ rock	☐ techno

[1]Scale: 0 = “never”; 1 = “every month”; 2 = “every week”; 3 = “one time a day”; 4 = “more than one time a day”.
[2]Scale: 0 = “very low”; 1= “low”; 2 = “medium”; 3 = “high”; 4 = “very high”.
[3]Scale: 0 = “never”; 1 = “academic year 2009–10”; 2 = “academic year 2010–11”; 3 = “academic year 2011–12”.

Appendix B

Pretest (extracts)

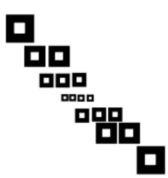
Three pairs of contrastive representations are shown, accompanied by the corresponding sonic fragments in standard music notation. Audio files are also available as supplemental online archives.

a) Sonic parameter: pitch; representational criteria: completeness.

☐ 	☐ 	☐ *

A melody with three salient peaks was played (see below), therefore the best fit was the second drawing.

b) Sonic parameter: duration; representational criteria: formality.

☐ 	☐ 	☐ *

The second drawing is more formal, as it represents duration according to standard notation (see below).

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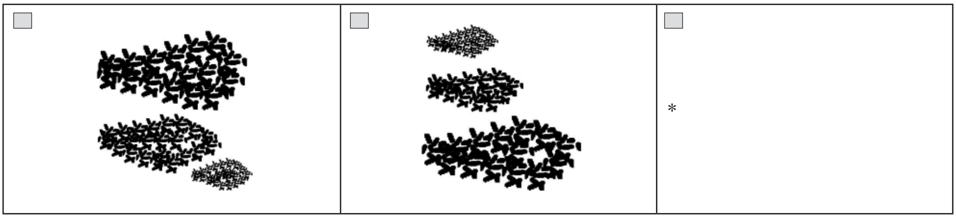
c) Sonic parameter: loudness; representational criteria: correctness.



A tone with three increasingly salient crescendos and diminuendos was played (see below), therefore the best fit was the second drawing.

* Blank space for students to self-generate an alternative representation.

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