





ARTICLE



<https://doi.org/10.1057/s41599-021-00934-3>

OPEN

Exploration of implementation practices of Montessori education in mainland China

Amber Chen ¹ 

This descriptive research work highlights the implementation practices of Montessori education in mainland China and the concerns over Montessori education's localization in mainland China. Localization can be understood as the adaptive process Montessori education undergoes in order to fit within Chinese culture. Two hundred and ten in-service Montessori teachers and administrators in China were surveyed to discover information concerning implementation practices in the following areas: mixed-aged classrooms, whether classrooms were co-teaching, student-to-teacher ratios, and morning and afternoon work cycles. The study found that the majority of classrooms were mixed-aged, reflecting high-fidelity Montessori practices. However, it also found that classrooms are co-teaching, have lower student-teacher ratios, and shortened work cycles, reflecting a departure from high-fidelity Montessori implementation. While localization should be considered to safeguard Montessori education's sustainability, Chinese Montessori educators should also reflect on these findings as high implementation fidelity has been linked to better student outcomes.

¹Qingdao University, Qingdao, China. ✉email: amberchen534@yahoo.com

Introduction

China has placed great emphasis on early childhood education (ECE) to provide the most beneficial education methods for its youngest citizens (Li et al., 2016; State Council of China, 2010; Sun and Rao, 2017). One method used, while not universal, is the Montessori education method. Montessori education became widespread in mainland China in the late 1990s and 2000s (Shi, 2012, 2015), yet little is known about classroom implementation practices. Evaluating implementation practices is relevant and meaningful as international research confirms Montessori preschool programs that are high in implementation fidelity result in better outcomes for children not only academically but also in areas of executive function, social development, motivation, and others (Diamond, 2013; Diamond and Lee, 2011; Ervin et al., 2010; Lillard, 2012; Lillard and Else-Quest, 2006; Lillard et al., 2017; Mallett and Schroeder, 2015; Rathunde and Csizszentmihaly, 2005). This study surveyed 210 in-service Montessori teachers in China to explore implementation practices of Montessori teachers in mainland China. Montessori implementation practices in China has not been researched before and while the exact number of Montessori preschools in China remains unknown, it has been suggested that China has around 10,000 Montessori schools (Tian and Xia, 2012), more than any other country in the world (Song, 2019; Whitescarver and Cossentino, 2008), making research on its implementation practices of great interest.

This research adopts an exploratory approach and seeks to answer the following questions:

1. To what extent do early childhood Montessori education in mainland China reflect high-fidelity Montessori practices in the areas of mixed-aged classrooms, teaching practices, student to teacher ratios, and work cycle times?
2. To what extent is fidelity across Chinese Montessori preschools linked to localization?

As there is limited published international research on Montessori ECE practices in mainland China (Chen and Guo, 2021), this research hopes to continue drawing attention to Montessori education in mainland China.

Background

Maria Montessori, the woman for whom the Montessori method is named, started the first preschool classroom in Italy in 1907. What started as one classroom in 1907 has turned into a systematic education method most popular for use with children at the preschool level. Montessori writes the reason her method became so well regarded in the early days was that through purposeful activity, which she called *work*, negative characteristics typically found in young children disappeared through concentration and what resulted were happy, cooperative, and balanced children (Montessori, 1967/1995). She called this process *normalization*, stating it the principal objective of her work (Montessori, 1967/1995).

Founded on human development, Montessori education has grown in popularity worldwide, including in China, as parents look for alternative education options for their young children (Chen and Guo, 2021; Choy, 2017). Specifically, in China, where education methods remain teacher-centered and didactic in nature (Choy, 2017), Montessori ECE is a desirable substitute sought out by parents as it satisfies the developmental needs of each child and promotes respect toward children (Duan, 2016; Liu and Lin, 2003; Zhang, 2013).

Montessori ECE was first introduced into mainland China in the early 1900s, but because of the economic and political climate,

it quickly faded from ECE practices (Chen and Guo, 2021; Shi, 2012, 2015). Initial concern over the use of the Montessori method in China in the early 1900s centered on the need to purchase and import a specific set of Montessori materials that were not economically feasible at the time. However, following China's move to a market economy in 1978, Montessori education eventually resurfaced in the late 1990s as China began promoting the privatization of ECE (Chen and Guo, 2021; Li et al., 2016; Zhu, 2015). At this time, Chinese Montessori organizations also began manufacturing Montessori materials (personal communication, Director of the Chinese Montessori Society, Yunbo Duan, October 7, 2020), helping to advance the spread of Montessori education.

While Montessori ECE continues to grow in popularity, in academic circles, it is both admired and critiqued (Deng et al., 2016; Huo, 2001; Liu and Lin, 2003; Tian, 2007; Tian, 2008; Tian et al., 2014; Wang, 2012; Yang, 2002, 2004; Yuan, 2014). Viewed as an imported, western education model by Chinese research, the topic of how to implement Montessori education while embracing Chinese culture and identity has generated significant discussion (Chen and Guo, 2021, Deng et al., 2016; Huo, 2001; Yang, 2002, 2004). Research addresses concern over implementing Montessori education, stating that adjustments are necessary in order for Montessori education to align within a Chinese context as well as fulfill educational requirements outlined by the Ministry of Education (MOE) (Deng et al., 2016; Huo, 2001; Liu and Lin, 2003; Tian, 2007; Tian, 2008; Tian et al., 2014; Wang, 2012; Yang, 2002, 2004). Specifically, the research states that Montessori education must *localize*, which is the process of contextualizing Montessori education to embrace and promote Chinese cultural values, identity, and educational requirements (Deng et al., 2016; Huo, 2001; Liu and Lin, 2003; Wang, 2012; Yang, 2002, 2004). While theoretical discussion on localization continues in the literature, precisely to what extent Montessori education has been adapted to satisfy these points has not been researched.

Localization is a valid concern to ensure the suitability of Montessori education yet at the same time, localization insinuates a change from the original model. This becomes an issue of concern as it is broadly agreed upon by Montessori research that Montessori education that adheres to practices as outlined by Montessori in her writings results in better outcomes for children (Diamond, 2013; Diamond and Lee, 2011; Ervin et al., 2010; Lillard, 2012; Lillard and Else-Quest, 2006; Lillard et al., 2017; Mallett and Schroeder, 2015; Rathunde and Csizszentmihaly, 2005). The term used to describe this adherence to fundamental Montessori practices is implementation fidelity (O'Donnell, 2008), and while there is not yet a reliable instrument for measuring the fidelity of a Montessori program (Murray et al., 2017), there are agreed-upon guidelines and standards based on Montessori's writings as to what constitutes a high-fidelity Montessori program (AMIUSA, 2020; Lillard, 2012; Lillard and Heise, 2016; Lillard and McHugh, 2019a, 2019b, NCMPS, 2016).

This study looked at four characteristics of Montessori education at the preschool level to evaluate implementation practices in China. The literature review will discuss the theory and research surrounding four primary Montessori practices alongside the existing literature on how such practices have been adapted in Chinese Montessori classrooms due to localization pressures.

High-fidelity Montessori practices

It is becoming recognized that Montessori programs of high fidelity have more significant benefits and outcomes (Diamond,

2013; Diamond and Lee, 2011; Ervin et al., 2010; Lillard, 2012; Lillard and Else-Quest, 2006; Lillard et al., 2017; Mallett and Schroeder, 2015; Rathunde and Csizszentmihaly, 2005). According to the National Center for Montessori in the Public Sector (NCMPS), exemplary Montessori practices that represent a high-fidelity Montessori program include mixed-aged classrooms based on Montessori's theory of human development, classrooms managed and run by a single, trained head teacher accompanied by a non-teaching classroom assistant, a classroom composed of "no fewer than 24 students supervised by two adults", and a three-hour uninterrupted morning work cycle and a two-hour afternoon work cycle for older children (NCMPS, 2016).

Mixed-aged classrooms

Based on Montessori's theory of developmental planes, Montessori classrooms are made up of mixed-ages. Mixed-aged classrooms at the preschool level are made up of children from 15–18 months to three years old and three to six years old.

Montessori stated that mixed-aged classrooms lead to social harmony not found in traditional classrooms where children are the same age. She wrote that in mixed-aged classrooms, children teach each other and learn and care for one another in ways that cultivate greater acceptance, care, and understanding towards differences resulting in feelings of "love and admiration" towards one another (Montessori 1967/1995, p. 226).

International research on the benefits of mixed-aged classrooms varies (Ansari et al., 2016; Justice et al., 2017; Wang and Su, 2009; Wisler et al., 2002), although peer learning is strongly supported (Lillard, 2005). Studies that report adverse outcomes from mixed-aged classrooms were those that engaged in whole-group teaching, quite different from Montessori education, which provides individual instruction. Research that supports multi-aged groupings at the preschool level highlight the beneficial opportunities younger children have to observe and imitate the actions of older peers (Bailey et al., 1993), which Montessori education provides in abundance.

The use of mixed-aged classrooms has been discussed in the Chinese literature about Montessori education, but information concerning the actual practice remains unknown. Huo (2001) and Liu and Lin (2003) state that parents have a hard time accepting mixed-aged classrooms, as they fear older children may fall behind academically and younger children may be bullied. As a result, Liu and Lin (2003) state that some Montessori preschools in China run single-aged classrooms to satisfy parents. However, this localized adaptation would be a departure from high-fidelity Montessori practices as Montessori states, "what matters is to mix the ages" (Montessori, 1967/1995, p. 226).

Teacher-assistant model

Another characteristic of high-fidelity Montessori education is that classrooms are run and managed by a single head teacher responsible for giving lessons to children and a non-teaching assistant. This practice is particularly different from traditional Chinese preschool classrooms of at least two academic teachers and one caregiving teacher for a total of three adults in the classroom (Yue and Yu, 2019). Montessori felt adults were often a hindrance to the child's development and wrote, "more often than not [teachers] give unnecessary help" (Montessori, 1967/1995, p. 229). This is not to say that a second teacher is not present in the classroom, but a second teacher's responsibilities center more on maintaining the classroom environment and assisting the headteacher, not one of direct instruction (NCMPS, 2016).

The role of the teacher in a Montessori classroom is very different from that of a traditional Chinese preschool classroom

teacher. Chinese research points out that this difference presents a challenge to Chinese ECE teachers (Shi, 2015; Tian, 2007; Tian, 2008; Tian et al., 2014) as ECE classrooms in China are traditionally teacher-centered and heavy on didactic instruction (Choy, 2017; Gu, 2014). Hu et al. (2017) point out that even though Chinese preschool teachers are aware of the benefits of child-centered educational practices, they tend not to implement them based on "traditional cultural beliefs and practices" (Tobin et al., 2009). It has yet to be made known if Montessori classrooms in China are co-teaching, but with a tendency to be teacher-centered and co-teaching traditionally (MOE, 2013), it may be that they are. However, this information has not yet been documented. Chinese localization research also states that an unfavorable characteristic of Montessori education is the lack of interaction between the teacher and the child (Hou, 2001), which may also lead to classrooms implementing co-teaching practices.

Student-teacher ratios

High-fidelity Montessori programs are traditionally larger in size with higher student-to-teacher ratios (Montessori, 1989). The reason for this relates to the child's social development and independence as Montessori said: "When the classes are fairly big, differences of character show themselves more clearly, and wider experience can be gained. With small classes, this is less easy. The higher levels of perfection all come through social life" (Montessori, 1967/1995, p. 225). Quite different from mainstream assumptions that lower student-to-teacher ratios are beneficial, Montessori proposed the opposite, and while some parents or educators may see such ratios as advantageous, some research suggests otherwise.

Perlman et al. (2017) state that research is inconclusive about whether low student-to-teacher ratios lead to more significant student outcomes, but that ratios result from local education department guidelines. In a Montessori classroom, it is possible to comply with local regulations for student to teacher ratios by having sufficient teachers present in the classroom, but, as stated, these teachers would not take on a direct teaching role. In addition, Lillard (2005) points out, Montessori "consistently refers to the teacher in the singular" at the preschool level, stating that this model encourages "more opportunity for peer teaching and less possibility of adult control" (p. 203).

As already mentioned, opportunities for peer teaching are a benefit to mixed-ages and of having higher student-to-teacher ratios. Research shows that children learn by observing and imitating others (Tomasello et al., 1993; Bandura et al., 1963; Ryalls et al., 2000), which the Montessori classroom provides through its classroom structure. Ryalls et al. (2000) discovered in their study that children are more likely to mimic complex actions of a slightly older peer than an adult, giving the idea that larger classroom sizes would provide more opportunity for imitation amongst children that could benefit children's learning. Montessori saw the benefits of larger classroom sizes, noting that her best results came in classrooms of 40 children but that 25 children was acceptable (Montessori, 1989). As outlined by the NCMPS, exemplary standards for classroom ratios at the preschool level is a ratio of 12:1 (NCMPS, 2016).

Chinese localization research does not explicitly address classroom ratios but does speak of the difficulty teachers experience implementing a mixed-aged, child-centered pedagogy (Tian et al., 2014; Yang, 2002, 2004). Chen Heqin, the founder of Chinese ECE (Wang, 2012), commented on Montessori education, stating that Montessori education places a greater demand on teachers and, due to the low educational attainment of ECE teachers in China, Chen Heqin recommended limiting classroom

size to seven or eight children to ensure a successful program (Tian, 2007). Teacher capacity is a concern not only in the Montessori research in China but in ECE research in general as ECE teacher aptitude is problematic in China's ECE field (Li et al., 2016; State Council of China, 2010; Sun and Rao, 2017; Zhou, 2011; Zhu, 2015).

Work cycles

Montessori schools institute work cycles, which are blocks of time in the morning and afternoon, giving children adequate time for concentration without interruption. It is agreed upon by Montessori experts and Montessori organizations that work cycle times for children three to six years old be three hours in the morning and at least two additional hours in the afternoon for older children (AMIUSA, 2020; Lillard, 2012; Lillard and Heise, 2016; Lillard and McHugh, 2019a; NCMPS, 2016). Children receive lessons from the teacher during these work cycles, repeat previously given lessons, and help and teach one another (Montessori, 1967/1995).

Extended work cycles are highly valued in Montessori education because Montessori education's goal is achievable through freely chosen, independent activity: *normalization*. *Normalization* is the term Montessori used to describe when the child, through concentration on physical activity, "returns to his normal, natural state" that results in "the disappearance of many childish traits" (Montessori, 1966/1972, p. 154, 155). Montessori saw normalization as "the most important single result of our whole work" (Montessori, 1967/1995, pg. 204) as it was only when a child had become normalized could he be an active, functioning member of his society.

While there is no empirical research on work cycles in the Chinese literature, Chinese localization concerns over the structure of the Montessori classroom are twofold. One problem is in connection with the amount of time children work independently throughout the day. Some literature states that because China is a socialist country "characterized by a collectivistic orientation" (Choy, 2017, p. 32), Montessori classrooms should hold more group lessons to cultivate a collective and socialist identity (Deng et al., 2016; Yang, 2004). Deng et al. (2016) write that for Montessori education to localize in mainland China group lessons should be given to increase children's socialization.

The second concern over classroom structure is in response to the Ministry of Education's (MOE) educational requirements for ages three to six. While there is no set education curriculum for preschools in China, there are national education guidelines, adequately entitled, *Guidelines for Learning and Development for Ages 3–6 (Guidelines)*, which include compulsory subject areas of health, language, social studies, science, and art (MOE, 2018). In an attempt to fulfill the *Guidelines'* requirements, Montessori preschools often omit afternoon work cycles and instead conduct whole-class lessons in the afternoons covering the five content areas outlined in the *Guidelines* (Liu and Lin, 2003). Liu and Lin (2003) point out that teachers can easily create lessons according to *Guidelines* following Montessori principles and teach children individually or in small groups during the morning or afternoon work cycles instead of relying on group lessons to promote higher fidelity Montessori education.

Research objectives

Based on these descriptions of high-fidelity Montessori practices and localization concerns, the author set out to determine how Montessori preschools within mainland China implement Montessori education and precisely determine what adaptations are being made and whether they reflect the Chinese research concerning localization.

The research design

Methods. The author developed a questionnaire to discover details concerning Montessori implementation practices while taking into account the literature on Montessori implementation fidelity and guidelines (Lillard and McHugh, 2019a, 2019b; NCMPS, 2016; Whitescarver and Cossentino, 2008), Chinese Montessori localization concerns (Deng et al., 2016; Huo, 2001; Liu, 2010; Liu and Lin, 2003; Tian, 2007; Tian, 2008; Tian et al., 2014; Wang, 2012; Yang, 2002, 2004) as well as Dr. Montessori's writings (Montessori, 1966/1972, 1967/1972, 1967/1995, 1989, 1994/2007, 2000/2008, 2004, 2012, 2013). A translated version of the questionnaire can be found in Supplementary Appendix 1. Questions centered specifically on implementation practices of mixed-ages, whether classrooms were co-teaching, student-to-teacher ratios, and work cycle lengths. The goal was to discover how Montessori preschools organize themselves and utilize the school day and discover whether Montessori preschools revert to seemingly traditional ECE practices. This study chose not to focus on the presence or use of Montessori materials, another fundamental component of Montessori education (see Lillard, 2012; Lillard and Heise, 2016; NCMPS, 2016) as it is not uncommon for schools to have Montessori materials in China and as Wang (2010) writes, Montessori preschools in China often equate Montessori materials with the Montessori method "but do not follow Montessori educational concepts" (*translated*). This research wanted to discover to what extent Montessori teachers and preschools implemented the non-material components of Montessori education that would be dependent upon understanding Montessori philosophy and not on the physical materials in the environment.

Questions were presented in multiple-choice, yes/no, and write-in format to allow for teachers to elaborate on specific answers if necessary.

Participants. Chinese Montessori teachers who had received Montessori training within mainland China and were currently working at Montessori preschools were invited to participate in the study via the social media platform WeChat. Similar to Facebook, WeChat has over 1.2 billion users and is an essential component of daily life in China for everything from personal communication to business transactions (China Commercial Industry Research Institution, 2020). An advertisement and QR code was sent out to Montessori Wechat groups and teachers who were interested could scan the QR code to join the research group. Teachers were informed they would be asked a series of questions regarding how they implement Montessori education, and their answers would be used to analyze implementation practices of Montessori education in Mainland China. Teachers who agreed to join the survey were sent a link electronically via WeChat message, and once completed, it could not be opened again.

Procedure. First, statistical information was gathered concerning teachers' backgrounds and implementation practices regarding mixed-ages, teaching practices, classroom ratios, and work cycle times. Second, Pearson's Correlations were used to look for relationships between morning work cycle lengths, classroom size (i.e., the average number of children in a classroom), and the number of teachers in a classroom to evaluate whether larger classrooms had more teachers, as would be expected and whether longer work cycle lengths could be associated with larger classrooms. Third, a point-biserial correlation was used to look for an association between co-teaching and classroom size to discover whether teachers instituted co-teaching as classroom size increased. Lastly, chi-squared tests for association were used to discover relationships between whether classrooms were co-

teaching and whether classes gave whole-group lessons, had traditional morning circle times, and whether or not there was an afternoon work cycle, as these activities give insight into how the day is spent and whether children are learning independently or as a whole group. All responses were analyzed using SPSS 22.

Results

A total of 210 valid responses were received, of which 147 reported to be teachers in a Montessori classroom (29 teachers working with 18 months to three-year-old children and 118 working with three to six-year-old children), and 63 reported to be school administrators (Table 1). All respondents had received either Montessori head teacher or administrator training that included learning about Montessori theory.

Of the 210 responses, 197 (93.8%) were female, similarly reflecting research that Montessori teachers are predominantly female (Cossentino, 2009). In addition, a good percentage of teachers had bachelor’s degrees or higher (53.8%), which is above the national average (22.7%) of all preschool teachers in China holding a bachelor’s degree or higher (Table 2) (MOE, 2019).

Participants’ locations represent the breadth of China, from Xinjiang in the west to Shandong in the east, Inner Mongolia in the north, to Hainan in the south. Of responses, 9.5% were from first-tier cities such as Beijing and Shanghai, 53.3% were from second-tier cities such as Wuhan and Changsha, and 37.2% were from smaller cities, towns, and counties, such as Weifang and Kunshan. This data accurately exemplifies the extent to which Montessori education has spread in mainland China and provides a good look into implementation practices throughout China.

Regarding mixed-ages, participants were asked whether the school they worked at had mixed-aged classrooms of 15–18 months to three years old and three to six years old. A high percentage, 96.7%, stated their school implemented mixed-aged classrooms.

To determine whether classrooms were co-teaching, participants were asked how many teachers were allowed to give lessons in the classroom, as in high-fidelity Montessori classrooms, only one teacher gives lessons. Of total responses, 87.1% stated that more than one teacher was allowed to give children lessons, showing a high percentage of co-teaching classrooms (Table 3).

Regarding classroom ratios, participants were asked about classroom sizes and how many teachers were in each classroom. For these analyses, teachers working in classrooms with children three years and under were excluded, as it is common practice for teachers working with younger children to have a lower student-teacher ratio.

A total of 180 valid responses were analyzed, looking at classroom size. Classroom size varied, but the most frequently reported classroom sizes were 20 students (18.8%) and 25 students (29.3%). Since Montessori found an acceptable classroom size of at least 25 students (Montessori, 1989), classroom sizes were grouped into two categories: having 25 and above students and those with 24 or fewer. From the findings, there was an even percentage split (50/50) of schools with 25 and above students per classroom and 24 or fewer. Of these groupings, 77.8% of

classrooms with 25 and above students had three or more teachers in the classroom, and 75.6% of classrooms with 24 or fewer students did as well (Table 4).

In looking further at classroom size groupings, in response to how many teachers were allowed to give lessons, 85.6% of classrooms with 24 or fewer students reported more than one teacher was allowed to give lessons in the classroom, and 90% of classrooms with 25 and above students said the same (Table 5).

For analysis of teacher ratios, only responses from teachers working in classrooms for ages three to six were analyzed. A total of 118 valid responses were assessed for classroom ratios. Ratios varied by classroom size, with most classrooms under 25 students having three teachers per classroom. Most classes over 25 students had four teachers per classroom. Classroom ratios ranged from 15 students with four teachers to 50 students with four teachers, with a mode ratio of 25 students with three teachers (about 8:1 ratio).

Questions also sought information concerning morning work cycle lengths and whether there was an afternoon work cycle. For analysis of work cycles, teachers working in classrooms with children three years and under were excluded, as it is common practice for classrooms with younger-aged children to implement short work cycles. Three respondents stated there was no morning work cycle, although children did come to school in the morning. Of the remaining respondents, 66.9% of responses stated a one to a two-hour work cycle in the morning, while the remaining 31.5% claimed a two-and-a-half or three-hour work cycle (Table 6). Reporting on afternoon work cycles, 74.8% of responses stated having no afternoon work cycle (Table 7).

Participants were asked whether they started their morning with a whole-class circle time and whether they gave whole-class lessons in the morning work period, two activities that do not support a high-fidelity Montessori practice. A large percentage of participants, 86%, stated they held a morning circle time similar to non-Montessori preschool, and 56% said they gave whole-class lessons in the morning.

After statistical analysis, Pearson’s product-moment correlations were computed to assess the relationship between morning work cycle lengths and the number of teachers in the classroom, work cycle lengths and classroom size, and classroom size and number of teachers. Two hundred and ten responses were identified. There was a weak, positive correlation between work cycle lengths and the number of students in the classroom, $r = 0.196$, $p = 0.004$, showing classrooms with higher percentages of students had longer work cycle lengths. There was also a weak, positive correlation between classroom size and the number of teachers, $r = 0.225$, $p = 0.001$, showing classrooms with more students had more teachers. There was no significant correlation between work cycle lengths and the number of teachers (Table 8).

Table 1 Job positions of respondents (n = 210).

| Position | Frequency | Percentage |
|---------------------------|-----------|------------|
| 0–3 age classroom teacher | 29 | 13.8% |
| 3–6 age classroom teacher | 118 | 56.2% |
| Administrator/Principal | 63 | 30% |
| Total | 210 | 100% |

Table 2 Education level of study participants and in China generally (MOE, 2019).

| Degree | Sample frequency (%) | MOE frequency (%) |
|--------------------------------|----------------------|-------------------|
| Graduate Degree | 5 (2.4%) | 4856 (0.2%) |
| Bachelors Degree | 108 (51.4%) | 581,592 (22.5%) |
| Associates Degree | 88 (41.9%) | 1,503,628 (58.2%) |
| High School/ Vocational School | 8 (3.8%) | 448,850 (17.4%) |
| Below High School | - | 42,437 (1.7%) |
| Missing | 1 (.5%) | - |
| Total | 210 (100%) | 2,581,363 (100%) |

Table 3 Co-teaching in a montessori classroom.

| Response | Frequency | Percentage |
|--------------------------------------|-----------|------------|
| More than one teacher giving lessons | 183 | 87.1% |
| Only one teacher giving lessons | 27 | 12.9% |
| Total | 210 | 100% |

Table 4 Classroom population to number of teachers (n = 181, missing = 1).

| Number of students | Number of teachers | | | Total |
|-----------------------|--------------------|------------|------------|-----------|
| | 2 | 3 | 4 | |
| 24 students and fewer | 12 (13.3%) | 68 (75.6%) | 10 (11.1%) | 90 (100%) |
| 25 students and above | 2 (2.2%) | 70 (77.8%) | 18 (20.0%) | 90 (100%) |

Table 5 Co-teaching situation by classroom size (n = 210).

| Number of children | Practice co-teaching |
|--------------------|----------------------|
| 24 and fewer | 85.6% |
| 25 and above | 90% |

Table 6 Length of morning work cycle (n = 181, exclude 0–3-year-old classroom teachers).

| Time Length | Frequency | Percentage |
|-------------|-----------|------------|
| None/0 h | 3 | 1.6% |
| 1–2 h | 121 | 66.9% |
| 2.5–3 h | 57 | 31.5% |
| Total | 181 | 100% |

Table 7 Afternoon work cycle (n = 210).

| Response | Frequency | Percentage |
|--------------------------|-----------|------------|
| Afternoon work period | 53 | 25.2% |
| No afternoon work period | 157 | 74.8% |
| Total | 210 | 100% |

A point-biserial correlation was computed to establish whether there is a relationship between co-teaching and classroom size. Two hundred and ten responses were included. There was no correlation between co-teaching and classroom size, $r = -0.094$, $p = 0.176$.

A chi-square test for association was conducted between co-teaching practices and whether teachers gave whole-class lessons, co-teaching practices, whether classrooms held morning circle times and co-teaching practices, and whether there was an afternoon work cycle. All expected cell frequencies were greater than five. There was no statistical significance between co-teaching practices and whole-class lessons, $\chi^2(1) = 0.317$,

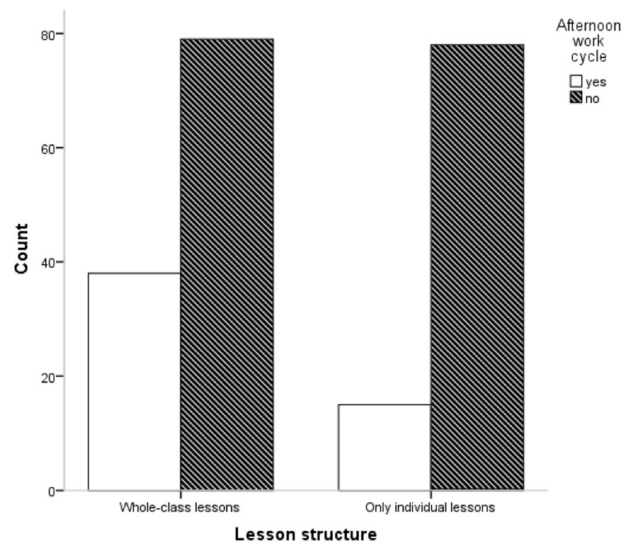


Fig. 1 This shows a chi-squared association between whole-class lessons and whether classrooms had afternoon work cycles. There was a weak significant association between classrooms that gave whole-class lessons and those that had afternoon work cycles $\phi = 0.187$, $p = 0.007$.

Table 8 Pearson's correlation for study variables.

| | # of students | # of teachers |
|---------------|---------------|---------------|
| # of teachers | 0.225** | |
| Morning WC | 0.196** | -0.019 |

Note: # of teachers = number of teachers in the classroom, # of students = number of students in the classroom, Morning WC = morning work cycle lengths.
** $p < 0.01$ level.

$p = 0.574$, co-teaching practices, and morning circle times, $\chi^2(1) = 0.255$, $p = 0.774$ or co-teaching practices and whether there was an afternoon work cycle, $\chi^2(1) = 0.317$, $p = 0.636$.

A chi-squared test for association was conducted between whole-class lessons and morning circle times and whole-class lessons and whether classrooms had afternoon work cycles. All expected cell frequencies were greater than five. There was no statistical significance between whole-class lessons and having morning circle time, $\chi^2(1) = 0.080$, $p = 0.777$. There was statistical significance between whole-class lessons and afternoon work cycles $\chi^2(1) = 7.341$, $p = 0.007$, showing a minimal association between classrooms that gave whole-class lessons also implemented an afternoon work cycle $\phi = 0.187$, $p = 0.007$ (Fig. 1).

Discussion

This study is the first to look at the implementation of Montessori education in mainland China and assess whether practices reflect high-fidelity Montessori practices in the areas of mixed-aged classrooms, teaching practices, student to teacher ratios, and work cycles. It found high fidelity in using mixed-aged classrooms (96.7%), but other areas assessed reflect a departure from what is considered high-fidelity Montessori implementation. There is also evidence that classrooms with more students have longer work cycle lengths and more teachers, and there is a slight relationship between whole-class teaching and afternoon work cycles. Further elaboration of these findings is as follows:

Mixed-aged classrooms. Huo (2001) and Liu and Lin (2003) suggested that mixed-aged classrooms were a localization concern in mainland China; however, mixed-aged classrooms appear to be widely accepted in this research. A possible reason for the widespread adoption of mixed-aged classrooms may be the high percentages of single-child families in China and parents' desire to provide a diverse social environment for their only child. Before 2016, the one-child policy was in place, creating 90 million single-child families (Sun and Rao, 2017; Zhu, 2015). As a result, preschool education is used to compensate for missing siblings and as a means to provide socialization opportunities (Sun and Rao, 2017). In addition, multi-aged classrooms may be appealing to families because they reflect siblings' age ranges similar to a home (Montessori, 1967/1995). The MOE recognizes mixed-age classrooms as an acceptable option for preschool education (MOE, 2013), and as can be seen in this study, the practice of mixed-age classrooms is implemented at a high rate.

Co-teaching practices and student to teacher ratios. This study noted that classrooms with more students have more teachers, which can be expected as local and national guidelines for classroom ratios dictate these requirements to ensure children's safety and appropriate care (MOE, 2013). While Montessori classrooms can comply with such standards, based on philosophical understanding, the concern with ratios surrounds whether lower student-to-teacher ratios can ensure a child-centered practice or whether classrooms default to teacher-centered practices.

Most Montessori classrooms in this study reported being co-teaching, regardless of classroom size. While more teachers giving lessons may appear on the surface like a good thing, Montessori classrooms support personal independence and social interdependency instead of constantly seeking out an adult's assistance. Montessori saw a child-centered education approach as one where children were not only the focal point of the education system but, more importantly, the active subjects in the environment (Montessori, 1967/1995). That most classrooms practice co-teaching shows that the Montessori classrooms in this study still gravitate towards a teacher-centered, or at least, teacher-dependent model. Whether this is due to teacher ability or traditional education culture is hard to tell. However, these findings also confirm what previous research has suggested, that ECE teachers in mainland China, though familiar with the benefits of child-centered learning, tend not to implement child-centered teaching (Hu et al., 2017). On an interesting note, co-teaching practices and classroom size were not significantly correlated. Had they been, it would have appeared that a possible reason teachers practiced co-teaching was because of larger classroom sizes. However, in this study, it appears Montessori classrooms generally implement co-teaching practices, reflecting a universal localized alteration of Montessori education.

One of the main concerns surrounding co-teaching in a Montessori classroom is the imposition it may have on the child's need for independence. Montessori writes:

To be able to do a thing without any help from others: this is independence...Although our natural inclinations are all toward helping him in his endeavors, this philosophy teaches us never to give more help than is absolutely necessary...[once] independence has been reached, the adult who keeps on helping becomes an obstacle (Montessori, 1967/1995, p. 155).

Montessori believed too many adults in the classroom would impose on the child's drive toward independence as adults have a tendency to interfere in the children's matters unnecessarily.

Thus, combining co-teaching with lower student-to-teacher ratios would negatively impact the child's quest for independence.

Work cycle times. Most teachers in this study implemented shortened work cycle times, gave whole-group lessons, held traditional morning circle times, and did not have afternoon work cycles, reflecting a pronounced departure from high-fidelity Montessori education. While it would seem that holding whole-class lessons and circle times would shorten the morning work cycle, significant correlations were not found.

Whole-class teaching showed a weak, positive correlation to afternoon work cycles, meaning classrooms that give whole-class lessons are more likely to have an afternoon work cycle. This particular finding highlights the question as to whether afternoon work cycles in these cases were authentic, independent work cycles or whether they also included whole-class teaching, as whole-class teaching in the afternoon would not constitute a genuine afternoon work cycle.

The tendency for Montessori teachers in this study to keep children together as a group throughout the day demonstrates a divergence from high-fidelity Montessori practices. While Deng et al. (2016) assume group teaching and group activities are the essential methods by which preschools can foster a collective identity, Montessori addresses this issue in her writings and proved otherwise.

Consideration for the group and understanding one's role as a member of the group is what Montessori describes as the highest awareness in social development as children learn about themselves in relation to the group, and for the harmony of the group, put other's needs and the group's needs above their own. This concept she termed *social cohesion* reflects values similar to those held by collectivist cultures and socialist societies, as the focus is not only on the individual but also on the group and the role one plays within the group (Choy, 2017; Montessori, 1967/1995). Montessori saw that normalized children think about themselves in relation to the group, which happens through daily experiences interacting with each other, taking care of each other and the environment, solving social problems together, learning to wait, and learning from each other (Montessori, 1967/1995). In actuality, the tendency to default to whole-class teaching and group activities does not enhance social relationships as children spend more time sitting next to each other instead of interacting with each other (Lillard and McHugh, 2019a). Based on Montessori's theory of social cohesion, group identity, and social unity are dependent upon experiences within the group, not just physically doing the same thing simultaneously. Not only is social development impeded by group instruction, but research also shows that mixed-aged classrooms that implement whole-class instruction are problematic because instruction cannot be individualized in whole-class teaching (Ansari et al., 2016). The majority of the classrooms in this study appear to be implementing mixed-aged, whole-class instruction, which is problematic, as instruction cannot be tailored to meet the needs of children of different ages.

Cutting into the morning work cycle time and eliminating afternoon work cycles is a critical issue as the primary goal of Montessori education, normalization, depends on children having ample time in the classroom environment. Without an adequate work cycle, children do not have enough time to engage in learning with the Montessori materials, and repeated interruptions lead to "the child [losing] the courage, the constancy, and the determination necessary for achievement [and failing] to acquire a habit of applying himself to purposeful ends" (Montessori, 1961/2007, p. 54, as quoted in Lillard and McHugh, 2019a).

From these findings, it can be seen that the practices of Montessori teachers in this study do not reflect high-fidelity Montessori practices as most classrooms are co-teaching, have lower student-to-teacher ratios, reduce work cycle times, and remove the afternoon work cycle altogether. It also appears that these alterations reflect localization concerns in the literature about Montessori implementation in mainland China.

Limitations and direction for future studies

While this study contributes to the neglected research on Montessori implementation practices in mainland China, there are significant limitations. First, while the data represented Montessori teachers from China geographically, the sample size of 210 participants cannot be assumed to represent all Montessori teachers in China. A larger sample size would be helpful in future studies.

A second limitation to the study is that in this study, the Montessori materials were not evaluated in looking at implementation practices of Montessori education. While the goals of this research focused on teachers' practices and organization of the classroom, it would be helpful to include the use of Montessori material to gauge implementation practices. Classroom observations and teacher interviews would be useful to discover whether classrooms have full sets of Montessori materials, or whether materials are supplemented in some way. Teacher interviews could also potentially shed light on teachers' philosophical understanding of the Montessori theory to see if discrepancies of understanding are connected to implementation practices.

Being one of the first empirical studies on Montessori education in China, more information is needed about outcomes of student who have attended Montessori preschool. As previously stated, research shows the benefit of high-fidelity Montessori education on students' outcomes. Therefore, it would be of great value to conduct a study looking at student outcomes to address whether Montessori education in its current localized form is in fact a beneficial educational choice for children in China.

Conclusion

This research looked at Montessori ECE implementation practices of teachers in mainland China to determine whether they reflected high-fidelity Montessori practices and whether divergence resulted from localization concerns as found in the literature. While it appears from this study that mixed-aged classrooms reflect high-fidelity practices, Montessori classrooms appear to adopt co-teaching practices, lower student-to-teacher ratios, and shorten work cycles in the morning, and in most cases, eliminate afternoon work cycles. Research supports a high-fidelity Montessori program, meaning one that sticks closely to Montessori's original intent. However, in this research, Montessori classrooms in China often alter fundamental practices to make Montessori education more suitable to a Chinese educational and cultural context (Chen and Guo, 2021).

Of particular concern is the discovery of high rates of co-teaching and low student-to-teacher ratios, which assumes a disruption to the child's efforts toward independence, social cohesion, and the ultimate goal of Montessori education, normalization. As one of the main goals of Montessori education, independence comes from learning through one's experience how to be free from the help of others (Montessori, 1967/1995). Montessori believed that the presence of too many adults in the classroom and small classroom sizes would negatively impact this pursuit, insisting on larger classroom sizes with a single head teacher to ensure success. Similarly, long work cycles are needed, both morning and afternoon, to ensure children enough time to

interact with one another, learn from one another, and build community within the classroom. In this very natural way, values and goals of a collective society are achievable, contrary to research that suggests keeping children together as a group.

Interestingly, despite these implementation issues, Montessori education continues to spread in mainland China, yet what is spreading needs to be reevaluated as to the quality and content of the program. It would do well for Montessori educators in China to reflect on their practice to implement high-fidelity Montessori education more effectively. It would also be of great benefit to establish a Montessori alliance in China, such as the Montessori Leadership Collaboration in North America, to provide direction and support to the Montessori movement in China and help establish higher standards of Montessori practice.

Sometimes, to fit perceived or actual cultural, social, or local regulation concerns, Montessori educators change fundamental elements of the method to become better suited within the culture. Localization of Montessori education is not a new concept, nor should it be ignored. Nevertheless, it is important to continually question adaptations to the method, as changing fundamental elements, while seemingly crucial to ensuring the method's receptiveness, may adversely influence the outcomes.

Data availability

The datasets generated during and/or analyzed during the current study are not publicly available due to confidentiality but are available from the corresponding author on reasonable request.

Received: 10 March 2021; Accepted: 12 October 2021;

Published online: 28 October 2021

References

- Ansari A, Purtell K, Gershoff E (2016) Classroom age composition and the school readiness of 3-and-4-year-olds in the Head Start program. *Psychol Sci* 27:53–63
- Association Montessori Internationale USA (2020) Montessori classrooms. <https://amiusa.org/families/montessori-classrooms/>. Accessed 14 Apr 2019
- Bailey DB, Burchinal MR, McWilliam RA (1993) Age of peers and early childhood development. *Child Dev* 64:848–62
- Bandura A, Ross D, Ross SA (1963) Imitation of film-mediated aggressive models. *J Abnorm Psychol* 66(1):3–11
- Chen A, Guo SL (2021) The spread of Montessori education in mainland China. *J Montess Res Educ* 1–8. <https://doi.org/10.16993/jmre.17>
- China Commercial Industry Research Institute (2020) Acceleration of the commercialization of WeChat! In the second quarter of 2020, the monthly active users of WeChat increased to 1.206 billion. *Signal Commun Soc*. <https://www.askci.com/news/chanye/20200813/1106321182774.shtml>
- Choy G (2017) Chinese culture in early educational environments. In: Rao N, Zhou J, Sun J (eds.) *Early childhood education in Chinese societies vol 1*. Springer Science + Business Media B.V, The Netherlands, pp. 31–52
- Cossentino J (2009) Culture, craft, & coherence: the unexpected vitality of Montessori teacher training. *J Teach Educ*, <https://doi.org/10.1177/0022487109344593>
- Deng W, Luo L, Du H (2016) On the localization of montessori education in kindergarten. *Stud Early Childh Educ* 7:64–6
- Diamond A (2013) Executive function. *Ann Rev Psychol* 64:135–168. <https://doi.org/10.1146/annurev-psych-113011-143750>
- Diamond A, Lee K (2011) Interventions shown to aid executive function development in children 4 to 12 years old. *Science* 333:959–964
- Duan YB (2016) *Montessori approach to children*. Scientific and Technical Documentation Press, Beijing
- Ervin B, Wash PD, Mecca ME (2010) A 3-year study of self-regulation in Montessori and non-Montessori classrooms. *Montessori Life* 22(2):22–31
- Gu MY (2014) *Cultural Foundations of Chinese Education vol 1*. Brill's Series on Chinese Education, Boston. (J.F. Wang, Z.J. Yao, J. Teng & Y. Zhun trans.). The Netherlands: Koninklijke Brill NV
- Hu YB, Fan X, Yang Y, Neitzel J (2017) Chinese preschool teachers' knowledge and practice of teacher-child interactions: the mediating role of teachers' beliefs about children. *Teaching and Teacher Education*. <https://doi.org/10.1016/j.tate.2016.12.014>

- Huo LY (2001) How China should reference Montessori. *Studies in Preschool Education*, <https://doi.org/10.13861/j.cnki.sece.2001.01.048>
- Justice LM, Logan JA, Purtell K, Bleses D, Hogden A (2017) Does mixing age groups in early childhood education setting support children's language development? *Appl Dev Sci*, 1–13. <https://doi.org/10.1080/10888691.2017.1386100>
- Li HY, Yang W, Chen JJ (2016) From 'Cinderella' to 'beloved princess': The evolution of early childhood education policy in China. *Int J Child Care Educ Policy* 10(2):1–17
- Lillard A (2005) *Montessori: the science behind the genius*. Oxford University Press, Oxford
- Lillard A (2012) Preschool children's development in classic versus supplemented Montessori, and conventional programs. *J School Psychol* 50:379–401
- Lillard A, Else-Quest N (2006) Evaluating Montessori. *Science*. <https://doi.org/10.1126/science.1132362>
- Lillard A, Heise M (2016) Removing supplemental materials from Montessori classrooms changed child outcomes. *J Montessori Res* 2(1):16–26
- Lillard A, Helse MJ, Richery EM, Tong X, Hart A, Bray PM (2017) Montessori preschool elevates and equalizes child outcomes: a longitudinal study. *Front Psychol*. <https://doi.org/10.3389/fpsyg.2017.01783>
- Lillard A, McHugh V (2019a) Authentic montessori: The Dottoressa's view at the end of her life Part I: the environment. *J Montessori Res* 5(1):1–18
- Lillard A, McHugh V (2019b) Authentic montessori: The Dottoressa's view at the end of her life Part II: the teacher and the child. *J Montessori Res* 5(1):19–34
- Liu W, Lin HX (2003) A preliminary study of the Montessori model in China. *J Educ Sci Hunan Normal Univ* 2(6):37–42
- Liu XD (2010) Problems of Chinese learning and western learning and of the ancient and the modern within children's education. *J Nanjing Normal Univ (Soc Sci)* 11(6):73–78
- Mallett JD, Schroeder JL (2015) Academic achievement outcomes: a comparison of Montessori and non-Montessori public elementary school students. *J Elem Educ* 23(1):39–53
- Ministry of Education (2013) Kindergarten Staff Requirements. http://www.moe.gov.cn/srcsite/A10/s7151/201301/t20130115_147148.html Accessed 04 Apr 2017
- Ministry of Education (2018) Kindergarten Guidelines Outline, 2001. <https://www.shuyang.gov.cn> Accessed 04 Apr 2019
- Ministry of Education (2019) Breakdown of kindergarten heads, full-time teachers by academic qualifications, and professional rank. <https://en.moe.gov.cn/documents> Accessed 06 June 2020
- Montessori M (1961/2007) *What you should know about your child* (A. G. Prakasam, Trans.). Amsterdam, the Netherlands: Montessori-Pierson
- Montessori M (1966) *The secret of childhood*. (M. Joseph Costelloe, S.J., trans.). Ballantine Books, New York, NY, 1972
- Montessori M (1967) *The discovery of the child*. (M.J. Costelloe, S.J. trans.). Ballantine Books, New York, NY, 1972
- Montessori M (1967) *The absorbent mind*. (C.A. Claremont trans.). Henry Holt and Company, New York, NY, 1995
- Montessori M (1989) *The child, society, and the world: Unpublished speeches and writings vol.7*. Clio, Oxford, England
- Montessori M (1994) *Creative development in the child vol 2*. Kalakshetra Press, Madras, India, 2007R. Ramachandra, trans.)
- Montessori M (2000) *The California lectures of Maria Montessori, 1915: collected speeches and writings*. Montessori-Pierson Publishing Company, The Netherlands, 2008
- Montessori M (2004) *The Montessori method*. Ed. Gerald Lee Gutek. Rowman & Littlefield Publishers, Inc, New York, NY
- Montessori M (2012) *The London lectures*. Montessori-Pierson Publishing, Amsterdam, the Netherlands
- Montessori M (2013) *The 1913 rome lectures*. Montessori-Pierson Publishing, Amsterdam, the Netherlands
- Murray A, Brown K, Culcasure B (2017) What does research say about Montessori theory and practice? www.amshq.org/conference-handout-2017. Accessed 06 June 2020
- National Center for Montessori in the Private Sector (2016). *Essential Elements of Montessori Practice in the Public Sector*. <https://www.public-montessori.org/wp-content/uploads/2016/12/NCMPSEssential-Elements-4.6.pdf>. Accessed 14 Apr 2018
- O'Donnell C (2008) Defining, conceptualizing and measuring fidelity of implementation and its relationship to outcomes in K-12 curriculum intervention research. *Rev Educ Res*. <https://doi.org/10.31102/0034654307313793>
- Perlman, M, Fletcher, B, Falenchuk, O, Brunsek, A, McMullen, E, Shah, PS (2017) Child-staff ratios in early childhood education and care settings and child outcomes: a systematic review and meta-analysis. *PLoS ONE*. <https://doi.org/10.1371/journal.pone.0170256>
- Rathunde K, Csikszentmihalyi M (2005) Middle school students' motivation and quality of experience: a comparison of Montessori and traditional school environments. *Am J Educ* 111(3):341–371
- Ryalls BO, Gul RE, Ryalls KR (2000) Infant imitation of peer and adult models: Evidence for peer model advantage. *Merrill-Palmer Quart* 46(1):188–202
- Shi S (2012) The characteristic analysis of the Montessori method introduced in China initially. 26(2):79–82
- Shi S (2015) Montessori education idea and method in modern China. *Educ Sci* 32(2):92–6
- Song ZL (2019/07/27) A hundred years of Montessori: The location and prospects of Montessori education in China. The 2019 14th International Symposium on Montessori Education and the 10th Qingdao Forum for Chinese Children's Education. Qingdao, China
- State Council of China (2010) National education reform and development of long-term planning programs (2010-2020). Xin Hua Du, Beijing. http://www.gov.cn/jrzq/2010-07/29/content_1667143.htm
- Sun J, Rao N (2017) Growing up in Chinese families and societies. In: Rao N, Zhou J, Sun J (eds.) *Early Childhood Education in Chinese Societies vol 1*. Springer Science + Business Media B.V, The Netherlands, pp. 11–29
- Tian JZ (2007) Montessori's educational thought in modern China—on the 100th anniversary of Montessori's idea of children's education. *J Hebei Normal Univ (Educational Science Edition)* 9(4):52–5
- Tian JZ (2008) On the consistency and characteristics of chen heqin teaching method and montessori teaching method. *Teach Educ Res* 20(1):54–7
- Tian JZ, Wan XJ, Deng YH (2014) Montessori teaching method and its spread in China. *Curr Teach Mater Method* 34(6):91–6
- Tian T, Xia YY (2012) Reflections on montessori's educational method fever in China. *Pu Yang Vocational Technical College Record* (02)
- Tobin J, Hsueh Y, Karasawa M (2009) *Preschool in three cultures revisited: China, Japan, and the United States*. University of Chicago Press, Chicago, IL
- Tomasello M, Kruger AC, Ratner HH (1993) Cultural learning. *Behav Brain Sci* 16:495–552
- Wang F (2010) Scientific use of montessori education thought. *J Fuyang Teachers College (Social Science)* 6(6):137–140
- Wang Y (2012) Enlightenment of Chen Heqin's localized education thought on Montessori's. *Stud Preschool Educ* 12(216):41–5
- Wang Y, Su Y (2009) False belief understanding: children catch it from classmates of different ages. *Int J Behav Dev* 33:331–337. <https://doi.org/10.1177/0165025409104525>
- Whitescarver K, Cossentino J (2008) Montessori and the mainstream: a century of reform on the margins. *Teach College Record* 110(12):2571–2600
- Wisler A, Caverly SL, Wilson-Quayle A, Carlton MP, Howell C, Long GN (2002) The social and behavioral ecology of mixed-age and same-age preschool classrooms. A natural experiment. *J Appl Dev Psychol* 23:305–330
- Yang LJ (2002) On the modernization and sinicization of Montessori's education program. *Stud Preschool Educ*, <https://doi.org/10.13861/j.cnki.sece.2002.05.015>
- Yang LJ(2004) Montessori's education method needs scientific interpretation and localization. *People Educ* 11:23–5
- Yuan M (2014) Analysis of adapting Montessori teaching method in ethnic minority areas. *J Guangxi Normal Univ, Philos Soc Sci Edn*. <https://doi.org/10.16088/j.issn.1001-6597.2014.05.022>
- Yue D, Yu DQ (2019) Preschool Caregiving team population educational traits analysis and policy suggestions. *Stud Preschool Educ*, <https://doi.org/10.16194/j.cnki.31-1059/g4.2019.07.016>
- Zhang SY (2013) The interpretation of Montessori's educational philosophy and its enlightenment to China's early childhood education. *J Chifeng Univ (National Science Edition)* 29(7):260–261. <https://doi.org/10.13398/j.cnki.issn1673-260x.2013.14041>
- Zhou X (2011) Early childhood education policy development in China. *Int J Child Care Educ Policy* 5(1):29–39
- Zhu JX (2015) Early childhood education and relative policies in China. *Int J Childcare Educ Policy* 3(1):51–60

Acknowledgements

The author did not receive support from any organization for the work submitted.

Competing interests

The author declares no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at <https://doi.org/10.1057/s41599-021-00934-3>.

Correspondence and requests for materials should be addressed to Amber Chen.

Reprints and permission information is available at <http://www.nature.com/reprints>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit <http://creativecommons.org/licenses/by/4.0/>.

© The Author(s) 2021