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BREATHING IT IN:

A REVIEW OF INDOOR AIRBORNE MICROPLASTIC RESEARCH

SUPPLEMENTAL MATERIALS

Prepared by:

Kristine Roy

Thea Caplan

Zachary Adams

WPI

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Breathing It In: Mitigating Indoor Airborne Microplastics

Project Proposal

by

Zachary Adams

Thea Caplan

Kristine Roy

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Report Submitted to:

Prof. Barbara Rothen-Rutishauser, Prof. Alke Fink, Dr. Patricia Taladriz, and Dr. Ruiwen He

Adolphe Merkle Institute

Prof. Laura Roberts and Prof. Christopher Brown

Worcester Polytechnic Institute

Authorship Statement

	Primary Author	Primary Editor
Authorship Statement	Kristine Roy	Thea Caplan
AI Statement	Kristine Roy	
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Introduction

Airborne microplastics have become a cause of increasing concern in recent years, due to their now-ubiquity in our world. Much of the current research on microplastics has been directed at their mitigation in natural environments, due to their known negative effects on ecosystems and animal life. However, the nature and effects of airborne microplastics, particularly indoor airborne microplastics (IAMP), have been minimally researched.

Human beings spend over 90% of their life indoors. As such, particles present in indoor air pose a much more significant risk of inhalation than those in other environments due to exposure alone (Kacprzak & Tijing, 2022). Despite the known risks of exposure to microplastics in living organisms, IAMP have not been heavily studied.

This project, conducted through the BioNanomaterials Group at the Adolphe Merkle Institute (BNG), aims to identify sources of airborne microplastics in indoor environments, as well as potential strategies for mitigating their impact. This will be accomplished by conducting a review of existing literature on the subject and interviewing professionals in relevant fields.

The impact of nanoparticles, particularly nanoplastics, on environmental issues, human health and other societal issues is the focus of the BNG. The organization employs techniques including cell culture and microscopy, synthesizing nanoparticles on-site in order to develop a better understanding of their effects in human health and environmental applications. This project has been established to help gain a better understanding of the particular characteristics of IAMP, due to the identified lack of major existing research in the area.

In this proposal, we will provide a background on current information regarding microplastics, both in general and in indoor airborne environments. We will then describe our methods for collecting more information about IAMP through a deeper literature review and semi-structured interviews. Analysis will be performed on the collected data to produce a report of sources and mitigation strategies and two tables evaluating both study methods and results respectively. This report will be used as the basis for a future grant proposal.

Background

Airborne Microplastics in Indoor Environments

Microplastics are plastic particles defined as having an outer diameter between 1µm and 5mm (Kacprzak & Tijing, 2022). Due to their size, microplastics are easily transportable and can be found in almost any environment.

There are currently two recognized classifications of microplastics. Primary microplastics are plastic particles introduced to an environment while already under 5mm in size, including microbeads, used in toothpastes and cosmetic products, and plastic pellets used for the manufacturing of plastic products. Secondary microplastics are introduced to an environment as larger products, such as water bottles or plastic bags, which then break down due to environmental effects, releasing microplastics into the environment (Choi et al., 2022). Microplastics may consist of a variety of materials, including polyester, polyvinyl chloride, micro-rubbers and polyethylene (O'Brien et al., 2023). As these materials become increasingly common, the issue of microplastics and their growing presence in the environment is an increasing cause of concern.

Sources of Microplastics

Microplastics can originate from a multitude of sources, from outdoor activity and environmental abrasion of trash in landfills to everyday actions within homes. Understanding the many sources of microplastics is essential to discovering mitigation strategies, especially within indoor environments where there is limited airflow.

Sources of Outdoor Airborne Microplastics

Microplastics are introduced to outdoor environments from several sources, commonly including particles released from sea spray, wind abrasion abrading microplastics from landfills, and tire wear resuspending microplastics deposited on roads (O'Brien et al., 2023). A study conducted on microplastic deposition on surfaces inside of schools found that outdoor microplastic distribution is affected by a variety of factors, including land topography, population density, and wind direction (Nematollahi et al., 2022). This lack of uniformity, in addition to making accurate sample collection in outdoor environments more difficult, can affect how airborne microplastics are transferred between indoor and outdoor environments. Some examples of this transmission include outdoor airborne microplastics being deposited on clothes and shoes and carried into residences and offices.

Sources of Indoor Airborne Microplastics

Airborne microplastics may originate from a number of sources within indoor environments. The most common is indoor textiles, particularly those containing synthetic materials such as polyester and rayon, examples ranging from clothes to mattresses. As the fabric is placed under stress, including when clothes are worn or carpets are walked on, abrasion allows microscopic fibers to disengage from their source material and become suspended in the air. One study collected and analyzed airborne microplastic particles within a dormitory, and found that most of the airborne microplastic fibers collected matched those produced by textiles. In particular, the most common fibers present in these environments came from low-quality synthetic textiles, notably low-quality clothing. Conversely, higher quality textiles were noted to produce far fewer microplastics (Zhang et al., 2020).

Of all known indoor sources, synthetic clothing is the largest producer of microplastics. Clothing is subject to the constant movements and frictions of everyday life, each abrasion pulls microplastics from the textile and introduces it into the environment. Some clothes undergo abrasion testing, where the ability of the fabric to hold up against abrasions is examined (Salthammer, 2022). However, this study focuses on the integrity of the material's surface, not the release of microplastics. Despite this, clothes made of higher quality fabrics perform better in abrasion testing, and are likely to produce a lesser number of microplastics (Zhang et al., 2020). Other textiles, such as flooring and furniture, may be tested as well. These textiles show a similar correlation between performance in abrasion testing, and a decreased likelihood of producing microplastics. Though they are not textiles, shoes may also produce a number of microplastics as their plastic soles scuff are worn down. If one were to brush against an interior wall while walking, their clothes and shoes would not be the only sources of microplastics. The wall paint and floor finish would also likely produce microplastics, as a result of the friction created (Przekop, Michalczuk, Penconek, & Moskal, 2023).

Factors beyond everyday movements add to the concentration of microplastics within the indoor environment as well. Microplastics may be produced if a plastic is subjected to high levels of heat. 3D printing is a probable source of microplastics within the indoor environments (Przekop et al., 2023). Other activities may contribute to increasing concentrations of microplastics indoors, especially those which involve artificial turf. Turf is often found in both indoor and outdoor arenas for sports activities, and may be categorized as either artificial grass or rubber mat. Artificial grass consists of organic polymers, and rubber mats are produced using recycled materials. There are high levels of stress exerted on these flooring materials, and as a result, high concentrations of airborne particles may be produced (Salthammer, 2022). As these particles often exist in such high concentrations in their source environments, they may be spread by airflow or human carriers to other indoor environments.

A study conducted in 2022 by Chen et al., also found that microplastic fibers can accumulate in air conditioner filters. Results, in addition, showed that long before the end of the filters' useful lifespan, enough microplastic particles built up in the filter that they could be picked up by the air exiting from the unit. This was shown to, after that point, lead to a significantly increased concentration of microplastic particles present in the air surrounding the unit, which was noted as a concern due to potential health effects (Chen et al., 2022).

Studies have found that other household items such as toys, bowls, utensils, electrical cables, and electronics become a source of microplastics as they wear down over time (Ageel, Harrad, & Abdallah, 2022). Small plastic beads are added to a number of household products, such as cosmetics, personal care products, detergents, and cleaning agents (Salthammer, 2022). These beads are not only a primary source of microplastics, as they may persist within the indoor environment in which they are used. These beads may end up in water systems as well, as they are often small enough to avoid being removed by water filtration systems. Salthammer (2022) identifies multiple pathways to indoor microplastics exposure (Figure 1).

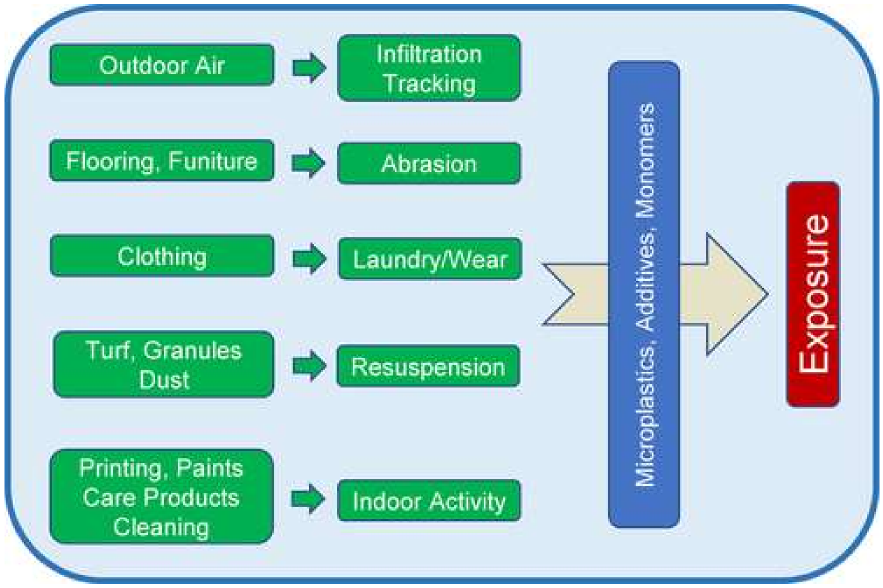

Figure 1: This diagram displays possible pathways to microplastic exposure indoors (Salthammer, 2022)

Medical Effects of Indoor Airborne Microplastics

As the concentration of microplastics in the environment increases, human exposure will only increase. The health effects of microplastic exposure are still heavily debated, but it is generally agreed upon by researchers that these effects are likely detrimental (Wright & Kelly, 2017). The prevalence of microplastics in all environments makes studies of their effects on human health difficult as there are no natural control groups. Adverse health effects tied to high microplastic exposure include obstruction, inflammation, and accumulation in organs (Ageel et al., 2022). These effects may lead to conditions such as chronic bronchitis, lung disorders, and autoimmune diseases (Przekop et al., 2023). As production of materials prone to producing microplastics continues without the technology to remove them from the environment, the predicted health effects will only become more prevalent.

The primary method of ingesting IAMP is inhalation. When microplastic particles are inhaled, most are trapped by the natural filtration mechanisms in human lungs. In some cases, the fibers may bypass these safety measures, and remain within the lung (Wright & Kelly, 2017). This buildup of microplastics may lead to serious health issues. When microplastics enter an organ, such as the lung, at a faster rate than they are removed, there is a risk of particle and chemical toxicity, or microbial toxins. This risk persists even if particles are low in concentration, as long as the deposition rate exceeds the clearance rate (Enyoh, Verla W., Verla N., Ibe, & Collins, 2019). This means that any health concerns associated with microplastics would likely grow in severity as the concentration of microplastics builds in the body.

This buildup of microplastics in the body leads to additional health risks. Chemical additives used in plastic production processes can leach from the microplastics inside the body (Lehner, Weder, Petri-Fink, & Rothen-Rutishauser, 2019). These include several additives with known to have health effects, such as reproductive toxins like DEHP and BPA, carcinogens such as vinyl chloride and butadiene, and mutagenicins which can cause mutations within the body, including benzene and phenol (Wright & Kelly, 2017). Microplastics can decompose into nanoplastics, which are small enough to pass through the walls of pulmonary alveoli, as well as blood-brain, gastrointestinal and placental barriers. Foreign bodies not impeded by these barriers pose significant risks to human health (Lehner et al., 2019). The material properties which make plastics so desirable for manufacturing purposes, such as their resistance to being broken down, make them a unique challenge to human health after being introduced to the body.

Not all researchers are convinced of the risks of microplastic ingestion to human health. Some findings have even suggested that the concentration of airborne microplastics is too low to have any adverse effects on human health (Lehner et al., 2019). Another study directly compared the respiratory health effects of superabsorbent polymers and paper dust, finding that workers exposed to a combination of the two, or exposed to only the paper dust experienced major negative health effects, whereas the effects for the polymer were far less significant (Holm, Dahlman-Höglund, & Torén, 2011). It has been argued that these results suggest that inhaled microplastics pose no particularly significant risk as compared to other particles. Following this conclusion, exposure to microplastics would be considered of no particular significance, especially when compared to exposure of other foreign airborne particles.

Shortcomings of Existing Research

The first studies on IAMP only appeared in 2016 (Enyoh et al., 2019). Unlike the thoroughly studied field of microplastics in aquatic environments, there is not a wealth of research on indoor microplastics, meaning that drawing reputable conclusions from the limited number of sources is difficult. The difficulty of tying specific health effects to a certain cause, especially one as ubiquitous as microplastics, means that most academic writing on the health effects of microplastics is speculative.

It is extremely difficult to compare the results of current studies due to the lack of a SOP (standard operating procedure) in the research. A SOP explains in detail how to perform a laboratory process both safely and effectively. This ensures both the safety of laboratory technicians, and consistent experimentation across different laboratories. Another obstacle in creating a SOP is the lack of a “standard” microplastic particle. As microplastics are generated from a wide variety of sources, they are extremely heterogeneous. They may vary in size, shape, density, and chemical composition (Lehner et al., 2019), meaning that the methods used to collect and analyze certain microplastics are typically tailored to their specific qualities. This variation in methods often leads to varying results, as demonstrated by one study which standardized the results collected by 27 studies. This study found that results found by separate studies were incongruent (Wright, Gouin, Koelmans, & Scheuermann, 2021). This is very likely a result of the lack of a SOP, emphasizing the difficulty of conducting research in a field without standardized testing methods.

Possible Mitigation Strategies

As microplastics are ubiquitous, there has yet to be a clear method for mitigating the effects, much less removing microplastics from either indoor or outdoor environments. However, as current understanding of the dangers of microplastics to the environment and to human health increases, there have been initiatives to reduce both the current concentrations and quantity produced overall of microplastics.

Filtering Options

In order to reduce the quantity of IAMP already within the indoor environments we frequent, the most prominent mitigation strategy is proper indoor ventilation. Some current ventilation systems are capable of lowering concentrations of microplastics, but have high maintenance costs.

One study conducted in urban Seoul, South Korea tested the effects of indoor ventilation on microplastics by modifying the ventilation times within residential homes. Classifying long ventilation times as 12-42 hours and short from 1-5 hours, the study determined that increased ventilation time also decreased the quantity of indoor microplastics, as seen in Figure 2 (Choi et al., 2022). Using this correlation, it is essential that proper filters and ventilation systems be implemented into indoor environments to lower indoor airborne microplastic concentrations.

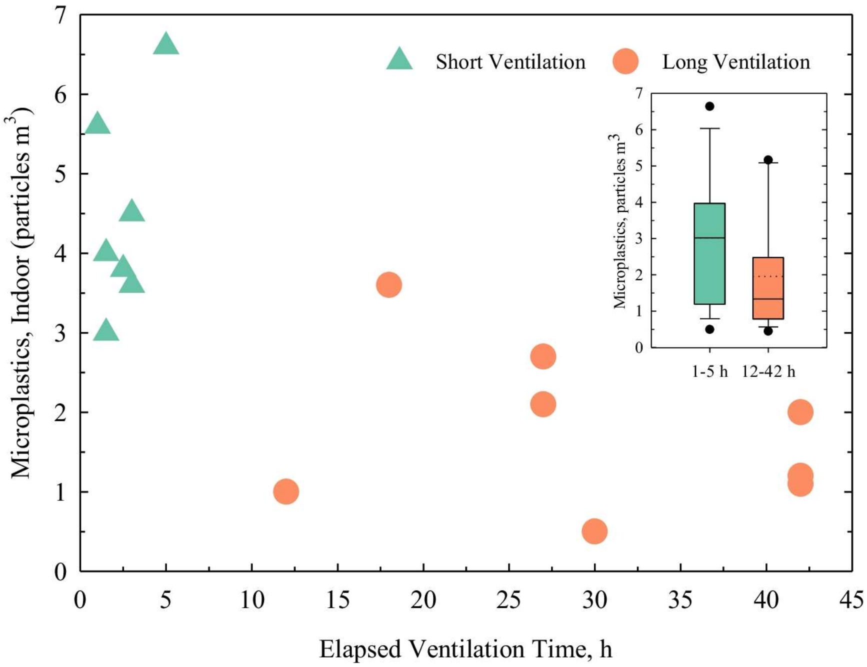

Figure 2: A graph showing the number of microplastic particles within an indoor environment after variable ventilation time (Choi et al., 2022)

However, current ventilation options are not ideal for most indoor environments. In mechanical air filter systems, filter efficiency is defined as the fraction of particles removed from air passing through a filter. A filter's efficiency is categorized by its Minimum Efficiency Reporting Value (MERV), ranging from 1 to 16, with 16 being the highest efficiency. High efficiency particulate (HEPA) filters have an efficiency higher than MERV 16 filters and are considered at least 99.97% efficient at filtering 0.3µm particles. Putting lower efficiency filters in sequence can often be more efficient than using a higher efficiency filter. Overall, filter efficiency is affected by the quality of the filter installation, the size of the particles, and the specific concentrations in the environment the filter is intended for.

Unfortunately introducing higher quality filters into most indoor environments is unrealistic. Higher filter efficiency leads to increased pressure drops within the system, which not all systems can support ("Filtration / Disinfection", n.d). The quality of the filters also increases the l cost for installation, usage, and maintenance, leading most building owners to have to compromise between filtration quality and the financial burden (Kacprzak & Tijing, 2022). As such, filtration is not a realistic solution for removing all airborne microplastics from indoor environments, and must be paired with techniques for decreasing the concentrations of microplastics produced.

Legislation

Many governmental and commercial guidelines aiming to reduce overall microplastic production have already begun to take effect in multiple countries, including Australia and the United Kingdom. Much of this legislation results from research into microplastic presence in outdoor aquatic environments. As such, it does not cover all aspects of indoor airborne environments, but it does provide an example of what anti-microplastic legislation currently looks like, and contributes to decreasing the production of microplastics.

One of the main targets of current legislation is a common source of airborne microplastics: microbeads. Microbeads are primary microplastics intentionally designed to have a diameter between 5 µm and 1 mm. Their composition includes many synthetic polymers such as polyethylene, polylactic acid, and polypropylene. Uses of microbeads include cleaning supplies and cosmetics including face and body wash, deodorants, lotions, and nail polish. One study estimated that in just one day, eight trillion microbeads are released into aquatic environments in the United States alone (Rochman et al., 2015). In 2014, the Netherlands became the first country to ban microplastics from cosmetic products. By 2019, Australia, Canada, Italy, Korea, New Zealand, Sweden, the United Kingdom, and the United States had all produced legislation banning microbeads (Watkins et al., 2019). These rulings have led to increased use of alternative options such as pumice, oatmeal, and walnut husks (Rochman et al., 2015).

Another possible mitigation can be implemented through increased regulation on the production of clothes to increase the durability of the fibers. This could be done through increasing the standards for abrasion testing on fabrics. As previously mentioned, current abrasion requirements focus on the surface of the fabric being tested, or how well the fabric itself holds under abrasive conditions, but do not include how many microplastic particles are released. As such, adjusting the abrasion testing requirements to also include the amount of microplastics produced could allow for the production of higher quality clothes that produce less microplastics (Kacprzak & Tijing, 2022).

Public Awareness

While public awareness of airborne microplastics is still limited, marine plastic debris has gained much attention. By increasing public awareness of the effects of microplastics in not only aquatic environments, but indoor environments and humans as well, more progress could be made in mitigating the effects of microplastics through individual action.

Current public awareness about microplastics focuses on the effects microplastics have on aquatic environments, and less about how microplastics are created. Using a survey with a free association technique, one Norwegian study looked into current public perceptions on microplastics (N = 2720). After breaking down results into categories of solutions, consequences, evaluations, spread, sources, and other, it was determined that the most commonly noted category was spread, or where microplastics were found. Most respondents focused on aquatic environments and aquatic animals, with air being one of the least common responses. The least common category noted was possible sources, with only 24.1% of participants including sources in their answer. Of the sources listed, the most common ones were clothing and litter, with a few mentions of artificial turf, personal care products, paint, and car tires. The study noted that while the participants noted many negative effects of microplastics, there was little identification of how microplastics arrived within aquatic and other environments and a negative perspective questioning the feasibility of microplastic mitigations. With these discoveries the study concluded that the public understanding of microplastics was mainly focused on the possible negative effects, and awareness campaigns should focus on specific instances of microplastic sources and suggest individual actions to mitigate microplastics (Felipe-Rodriguez, Böhm, & Doran, 2022).

Other studies ran focus groups to evaluate current knowledge of microplastics and openness to following mitigation recommendations. Within a group of 20 participants from Australia, most knowledge about plastics was found limited to plastic bags and microbeads. A group of 42 in the United Kingdom showed slightly more knowledge about plastic pollution based on media representation. In general, both groups' current knowledge was lacking, limited to media portrayals of plastic litter rather than the link between every-day activities and microplastic production. Once properly informed of what microplastics are, the possible dangers became more open to taking on individual mitigating strategies (Kacprzak & Tijing, 2022). These studies demonstrated that with proper education and increased public awareness, populations would be more willing to introduce mitigating measures into their own lives to reduce microplastics.

Individuals can reduce their contribution to microplastic production by educating themselves on the impact of the products they purchase. This is particularly significant in countries without bans on microbeads, where opting for cosmetics that employ biodegradable or natural exfoliants can reduce an individual's contribution to microplastic generation. In addition, purchasing higher-quality or natural textiles reduces the risk of clothing deterioration contributing to microplastic production, and avoiding use of single-use plastic products reduces the amount of microplastic sources introduced to the environment. As more individuals follow these practices, the concentrations of microplastics within indoor environments will decrease.

Conclusion

By proactively reducing and filtering the microplastics that already exist within our environment, the effects of microplastics can be diminished, improving the health of all affected. As plastics are continuously manufactured on a massive scale, microplastics will endure as a health risk to humans and to the environment at large. Studies have only begun to be conducted in this field in relatively recent years, and there is a distinct lack of standardized methodology in testing. The combination of the relatively few papers on this topic and results which cannot be compared create some obstacles when examining the conclusions drawn by researchers. As such, a SOP must be developed for proper data analysis. The extent of the health effects that microplastics pose to humans are not fully understood, but preliminary studies have shown that they may be linked to serious issues. Mitigation strategies must be improved to reduce the extensive harm that microplastics have the potential to cause. If the sources of IAMP and relevant mitigation strategies are identified and studied, there is a possibility that their harmful effects may be reduced.

In order to develop a more complete understanding of the current research status of IAMP sources and mitigation strategies, it is necessary to evaluate the research practices which have been used. This will allow for a fuller understanding of presented results, as well as ensure any results which are considered within this study are a result of credible research.

Methods

The goal of this project is to assist the BioNanomaterials Group at the Adolphe Merkle Institute in identifying sources and mitigations and evaluating research for IAMP by collecting and analyzing currently published research.

IAMP have only recently begun to be studied in depth, meaning that much of the current research is unstandardized and often lacking in depth. We will identify sources of IAMP and recommend strategies for mitigation by conducting a literature review and semi-structured interviews on sources, mitigation strategies, methodologies, and research conclusions. A report of sources and mitigation strategies and an evaluation of methodologies and conclusions will be produced. We will discuss the objectives of our research and methods for collecting and analyzing data in detail below.

Objectives

To ensure the project goal is achieved, we divided the essential stages of the project into four distinct objectives. By doing so, we can produce a framework for our process. The objectives are as follows:

I. Compile existing literature on the sources of microplastics in indoor airborne environments
II. Identify currently implemented mitigation strategies
III. Asses current methodologies and research conclusions
IV. Produce a report of sources and mitigation strategies for indoor airborne microplastics

Each of our objectives will be accomplished with a combination of three methods: literature review, semi-structured interviews, and data analysis. The first objective will consist of an intensive literature review. Current research on IAMP will be compiled in order to gain a full understanding of both the sources and properties of IAMP, and the current state of research in the field. Semi-structured interviews will be conducted with relevant professionals, in the hope of gaining a more complete perspective on the topic through information not present in existing published work.

The second objective is to identify current implemented mitigation strategies with respect to IAMP. Specifically, this research will consider each strategy's frequency, tools used, cost-effectiveness, and success rate. Similar to the first objective, literature reviews and semi-structured interviews will be essential for understanding current real-world mitigation strategies and the feasibility of possible new solutions. This research will be used in conjunction with the research found in the first objective to later evaluate new mitigation strategies.

As previously mentioned, the absence of a SOP in research on IAMP leads to limitations when comparing results. Our third objective will address the discrepancy by analyzing current IAMP research studies and for each evaluate the methods implemented and the quality of the results. Research studies covering similar topics to IAMP with pre-existing SOP will be analyzed as well to identify any missing methods in IAMP research procedures. This analysis will allow for the identification of proper methods for future SOP development and will clarify the causes of discrepancies and uncertainty in the results of studies to better enable comparisons between future studies.

For the final objective, all compiled data will be analyzed and organized into a final report. This report will compare the data found throughout our research. Tables will be created, which will organize all data gathered from the previous three objectives into comprehensive tables. These tables will be used to identify gaps in research methods, examine the effectiveness of currently implemented mitigation strategies, and to propose alternative solutions where they may be necessary.

Strategies

Within each objective, we will use literature reviews and semi-structured interviews to evaluate our findings. In the following sections, we will describe each strategy which will be used to address the project objectives.

Literature Reviews

Literature reviews are essential for understanding the current state of research. As such, we will conduct an in-depth literature review of sources, methods, and mitigations to determine why certain sources produce microplastics, which methods should be implemented, whether there is any possibility of standardization, and what mitigations are possible to implement in indoor environments. Before commencing the literature review, we will define a shared key for coding analysis, but will adjust as necessary codes are found. Each team member will use annotation and coding to classify common themes with respect to each objective, and overall results will be compiled into categories for analysis.

Within our literature review on sources of IAMP, we will focus on both the physical sources of microplastics, as well as actions that may result in the production of secondary microplastics. For known sources such as clothes and artificial turf, we will look deeper into the industrial production methods and the abrasive conditions that produce microplastics.

We will also review mitigation strategies already exist for improving air quality through the removal of microscopic airborne particles. These mainly occur through different types of filtration, but most of these strategies have not been properly tested in regard to their effectiveness in removing microplastics from the air. Through our literature review, we will aim to identify microplastic mitigation strategies which already exist, as well as more general air filtration methods which may be implemented as novel microplastic mitigation strategies. We will also look into legislation to reduce primary microplastics such as microbeads, and the process to which said legislation was passed.

Finally, our literature review will also consist of performing coding analysis on studies specific to IAMP and other microplastic studies with clearly defined SOP. We will design our codes to categorize methods and procedures within both types of studies, identifying commonalities and gaps within IAMP research procedures. These codes will be essential for completing our fourth objective in evaluating the quality of methods and conclusions of IAMP studies.

Semi-Structured Interviews

Semi-structured interviews will be conducted to gain insight into IAMP, and to discover information that may not be present within academic articles. Semi-structured interviews will be used because they have a pre-established backbone and line of inquiry, but still allow for some flexibility as the interview proceeds. Key stakeholders will be interviewed, including researchers, government officials, and air filtration specialists. These interviews (Appendix B-D) will focus on their knowledge of the sources of microplastics, mitigation strategies, and current studies. The flexibility of semi-structured interviews will allow us to alter the path of the interview, which will be useful when interviewing professionals who are more knowledgeable than the interviewers. By consulting professionals in a wide range of fields, we aim to gather a holistic view of current understandings of and impacts of IAMP. Once we have exhausted the interviewees recommended to us by our project sponsors, we will use a combination of snowball and purposive sampling to find new interviewees (Gill, 2020). When snowball sampling, the current interviewee will be asked if they have any recommendations for others they think should be interviewed in the future. When purposive sampling, we will select candidates based on their qualifications for interviews.

Analysis

Once the results of our literature review have been compiled, they must be examined to draw conclusions regarding sources of microplastics, currently implemented and possible mitigation strategies and their effectiveness, and methods used within current research.

Sources and Mitigation Analysis

Once the data from each of the papers examined within our literature review has been compiled, we will analyze which sources of IAMP are most commonly identified, as well as what data is included to prove any hypotheses drawn regarding the impact of each source. Currently implemented mitigation strategies will be examined as well, including how frequently they are mentioned within research papers, and any presented data regarding the effectiveness of the strategy. Given the information collected regarding current research topics in sources and mitigation strategies, we may recommend additional areas of focus.

Research Evaluation

Based on the results of the literature reviews and semi-structured interviews, we will produce two tables: one which will organize and evaluate methods used in existing IAMP studies based on the quality of the studies' procedures and their implementation, and another which will gather the results presented in each of the papers and attempt to standardize them for the most accurate possible comparison.

The codes identified from our literature review for procedures used in IAMP studies and studies with defined SOP will be used as the categories for evaluating IAMP studies' quality. Further clarification gained from interviews with researchers will enable us to weigh different methods by importance and feasibility. With proper methods defined, we will evaluate a number of studies (~50) by method for including relevant proper techniques and clarity in describing said techniques. Studies will be scored on a number scale that will be determined with proper understanding of the ideal SOP methods gained from the literature reviews and interviews. As shown in Table 1, a previous study produced an evaluation table of current microplastics studies and their methods using a 0-2 scale (Wright et al., 2021). We may adopt this scale and layout or develop our own depending on our findings.

Table 1

A portion of an overview of individual and accumulated scores for evaluation criteria from studies reporting microplastic concentrations in air, atmospheric deposition, snow, dust and moss (Modified after Wright et al., 2021, p.6)

Source	Sample type	Evaluation Criteria[a]											TAS
		1	2	3	4	5	6	7	8	9	10	11	
Wright et al. (2020) [42]	Deposition	2	2	2	2	1	1	1	2	2	1	2	18
Gaston et al. (2020) [43]	Air (outdoor and indoor)	2	2	0	2	0	2	0	2	1	2	2	15
Wang et al. (2020) [44]	Air (outdoor)	2	2	1	2	1	1	0	2	1	2	1	15
Klein and Fischer (2019) [22]	Deposition	2	2	1	2	1	2	0	1	2	1	1	15
Bergmann et al. (2019) [3]	Snow	1	0	1	2	2	1	0	2	2	2	2	15
Vianello et al. (2019) [45]	Ambient Air (indoor)	2	2	0	1	2	1	0	2	2	1	1	14
Wright et al. (2020) [42]	Deposition	2	2	2	2	1	1	1	2	2	1	2	18
…	…	…	…	…	…	…	…	…	…	…	…	…	…

[a]Evaluation Criteria: 1. Sampling methods; 2. Sample duration; 3. Sample processing and storage; 4. Laboratory preparation; 5. Clean air conditions; 6. Negative controls; 7. Positive controls; 8. Sample treatment; 9. Filter substrate; 10. Polymer identification; 11. Particle properties

Once all studies have been evaluated and the data organized, an analysis of the results will be conducted focusing on trends such as high and low scoring categories and methods identified within studies with SOPs but missing within IAMP studies. Challenges and future plans noted within studies will also be compared for consensus on where future structure and research must be focused. It will be important to recognize what aspects of current IAMP research has focused on the most in order to analyze how the flow of focus on IAMP has changed over time and compare to suggested future plans.

With the method quality of the selected IAMP studies evaluated, we can use their scores to evaluate the credibility of each respective study's findings in a second table. This will allow us to better understand the significance of their results, and help mitigate the impact of the high uncertainties noted in much of the currently conducted research. Most research studies draw conclusions directly from the data they collect, therefore any studies with issues in their procedures likely have inaccuracies within their conclusions. By creating a table to evaluate each study's methods and conclusions, we will be able to disregard any erroneous findings and ensure the most accurate information possible.

Potential Obstacles

There are several potential obstacles which we anticipate will arise when working to achieve our project goal, many of which stem from the recent nature of research on IAMP, as a majority of the field's research has only been conducted in the last twenty years. This means that there is not yet a wealth of information to draw from, and there is a lack of definitive conclusions which have been reached and agreed upon by a significant number of researchers. The lack of a research base also makes it difficult to verify certain studies, making it difficult to determine which results are credible.

As previously stated, the lack of an established SOP within current research means that it is impossible to directly compare the results of each study. This obstacle may only be overcome by taking into account each study's methods, their reliability, and the control variables that they did and did not include. It is unlikely that a SOP will be developed within the near future. Microplastics, including IAMP, are extremely variable in composition and characteristics. Different types of microplastics likely require different strategies for collection and testing. This makes creating a standardized methodology quite difficult, if not impossible, for the time being.

Project Deliverables

There are several project deliverables we plan to submit to the BioNanomaterials Group following the conclusion of our work with them. These deliverables will form a substantial basis of background research which could be used in a paper or grant proposal.

We will produce a comprehensive literature review that will compile existing information on sources and composition of indoor airborne microplastics in a variety of environments. We will also produce two tables, for which the format will be further developed during the project in collaboration with the BioNanomaterials Group. The first table will provide an evaluation of the procedures employed by previous studies on IAMP, which will aid in future development of an SOP for research specific to IAMP. The second table will evaluate the results obtained by the same studies, which in conjunction with the first table, will allow for a more complete understanding of where current research in the field stands.

Conclusion

This proposal has outlined the process by which we plan to assist the BioNanomaterials Group at the Adolphe Merkle Institute in their research regarding IAMP. From the understanding developed through our background literature review, we have highlighted key gaps within current research. This includes sources, mitigation options, as well as research procedures and quality. These gaps will be addressed through an in-depth literature review and semi-structured interviews. We will compile our research and analysis to produce a report containing a comprehensive review of sources of IAMP, possible mitigation strategies to be implemented, tables analyzing methods utilized in IAMP research, and conclusions drawn about possible SOP implementations. This report is to be used as a basis for further research and development in the quickly-growing field of IAMP, including a possible grant proposal that will fund further work by the Adolphe Merkle Institute.

Ethical Considerations and the Institutional Review Board

Informed Consent Agreement for Named Inclusion in Research Study

Investigator:
Contact Information:
Title of Research Study: Indoor Airborne Microplastics IQP
Sponsor: Adolphe Merkle Institute

Introduction: You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding the inclusion of your personal information and participation.

Purpose of the study: This project will assist the BioNanomaterials Group at the Adolphe Merkle Institute to identify sources and known mitigation strategies for airborne microplastics in indoor environments, in addition to identifying and evaluating methodologies employed in existing research on the subject. This research study aims to gain a deeper understanding of these aspects through interviews of professionals in relevant fields.

Procedures to be followed: We will interview our participants with questions relevant to the research we are conducting and the participant's expertise. A participant may choose to skip any questions or end their participation at any time. Interviews will last between 30 to 60 minutes, depending on the availability of the participants and the content covered within the interview.

Risks to study participants: There are no expected risks or discomforts to the participants.

Benefits to research participants and others: The information obtained from the study will be published online in a report within the WPI archives and may be used by the Adolphe Merkle Institute to promote future research regarding indoor airborne microplastics. Participant quotes and names may be used within the report.

Record keeping and confidentiality: Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or its designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify your personal information. Any inclusion of personal information or quotations within the report will require explicit consent for the specified information to be included from the participant.

Compensation or treatment in the event of injury: This study has minimal to no risk of injury or harm. You do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact:

WPI Student Researcher
Zachary Adams
Tel. +33 6 52 76 99 57
Email: xxx@wpi.edu

WPI Student Researcher
Thea Caplan
Tel. +1 (978)-852-3888
Email: tcaplan@wpi.edu

WPI Student Researcher
Kristine Roy
Tel. +1 (203)-464-5057
Email: koroy@wpi.edu

IRB Manager
Ruth McKeogh
Tel. +1 (508)-831-6699
Email: irb@wpi.edu

Human Protection Administrator
Gabriel Johnson
Tel. +1 (508)-831-4989
Email: gjohnson@wpi.edu

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

____________________________ Date: ____________________
Study Participant Signature

____
Study Participant Name (Please print)

_____________________________________ Date: ____________________
Signature of Person who explained this study

References

Ageel, H. K., Harrad, S., & Abdallah, M. A.-E. (2022). Occurrence, human exposure, and risk of microplastics in the indoor environment. *Environmental Science: Processes & Impacts*, *24*(1), 17–31. https://doi.org/10.1039/d1em00301a

Chen, Y., Li, X., Zhang, X., Zhang, Y., Gao, W., Wang, R., & He, D. (2022). Air conditioner filters become sinks and sources of indoor microplastics fibers. *Environmental Pollution*, *292*, 118465. https://doi.org/10.1016/j.envpol.2021.118465

Choi, H., Lee, I., Kim, H., Park, J., Cho, S., Oh, S., Lee, M., & Kim, H. (2022a). Comparison of microplastic characteristics in the indoor and outdoor air of urban areas of South Korea. *Water, Air, & Soil Pollution, 233*(5). https://doi.org/10.1007/s11270-022-05650-5

Enyoh, C. E., Verla, A. W., Verla, E. N., Ibe, F. C., & Collins, E. A. (2019). Airborne microplastics: a review study on method for analysis, occurrence, movement and risks. *Environmental Monitoring and Assessment, 191*(11), 1-17. https://doi.org/10.1007/s10661-019-7842-0

Felipe-Rodriguez, M., Böhm, G., & Doran, R. (2022). What does the public think about microplastics? insights from an empirical analysis of mental models elicited through Free Associations. *Frontiers in Psychology*, *13*. https://doi.org/10.3389/fpsyg.2022.920454

Filtration / Disinfection. ASHRAE. (n.d.). https://www.ashrae.org/technical-resources/filtration-disinfection

Gill, S. L. (2020). Qualitative Sampling Methods. *Journal of Human Lactation*, *36*(4), 579–581. https://doi.org/10. 1177/ 0890 3344 20949218

Holm, M., Dahlman-Höglund, A., & Torén, K. (2011). Respiratory health effects and exposure to

superabsorbent polymer and paper dust - an epidemiological study. *BMC Public Health, 11*(1), 557–557. https://doi.org/10.1186/1471-2458-11-557

Kacprzak, S., & Tijing, L. D. (2022). Microplastics in indoor environment: Sources, mitigation and fate. *Journal of Environmental Chemical Engineering*, *10*(2), 107359. https://doi.org/10.1016/j.jece.2022.107359

Lehner, R., Weder, C., Petri-Fink, A., & Rothen-Rutishauser, B. (2019). Emergence of nanoplastic in the environment and possible impact on human health. *Environmental Science & Technology, 53*(4), 1748–1765. https://doi.org/10.1021/acs.est.8b05512

Nematollahi, M. J., Zarei, F., Keshavarzi, B., Zarei, M., Moore, F., Busquets, R., & Kelly, F. J. (2022). Microplastic occurrence in settled indoor dust in schools. *Science of the Total Environment*, 807, 150984. https://doi.org/10.1016/j.scitotenv.2021.150984

O'Brien, S., Rauert, C., Ribeiro, F., Okoffo, E. D., Burrows, S. D., O'Brien, J. W., Wang, X., Wright, S. L., & Thomas, K. V. (2023). There's something in the air: A review of sources, prevalence and behaviour of microplastics in the atmosphere. Science of The Total Environment, 874, 162193. https://doi.org/10.1016/j.scitotenv.2023.162193

Przekop, R., Michalczuk, U., Penconek, A., & Moskal, A. (2023). Effect of microplastic particles on the rheological properties of human saliva and mucus. *International Journal of Environmental Research and Public Health*, *20*(22), 7037–7049. https://doi.org/10.3390/ijerph20227037

Rochman, C. M., Kross, S. M., Armstrong, J. B., Bogan, M. T., Darling, E. S., Green, S. J., Smyth, A. R., & Veríssimo, D. (2015). Scientific evidence supports a ban on microbeads. *Environmental Science & Technology*, *49*(18), 10759–10761. https://doi.org/10.1021/acs.est.5b03909

Salthammer, T. (2022). Microplastics and their additives in the indoor environment. *Angewandte Chemie*, *134*(32). https://doi.org/10.1002/ange.202205713

Université de Fribourg. (n.d.). Adolphe Merkle Institute. BioNanomaterials Group at the Adolphe Merkle Institute. https://www.ami.swiss/bionanomaterials/en/

Wright, S. L., & Kelly, F. J. (2017). Plastic and human health: A micro issue? Environmental Science & Technology, 51(12), 6634–6647. https://doi.org/10.1021/acs.est.7b00423

Wright, S. L., Gouin, T., Koelmans, A. A., & Scheuermann, L. (2021). Development of screening criteria for microplastic particles in air and atmospheric deposition: Critical Review and applicability towards assessing human exposure. *Microplastics and Nanoplastics*, *1*(1). https://doi.org/10.1186/s43591-021-00006-y

Zhang, Q., Xu, E. G., Li, J., Chen, Q., Ma, L., Zeng, E. Y., & Shi, H. (2020). A review of microplastics in table salt, drinking water, and air: Direct human exposure. *Environmental Science & Technology*, *54*(7), 3740–3751. https://doi.org/10.1021/acs.est.9b04535

Appendix A - Timeline

All literature review sections and interviews will be conducted concurrently and full analysis will be completed once a majority of information has been gathered. Due to the nature of our project, we will concurrently achieve our objectives through iterating between strategies and adjusting as additional information is compiled.

Task	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**
Literature review	X	X	X	X	X	X	
Tables			X	X	X	X	
Semi-Structured Interviews		X	X	X			
Analysis			X	X	X	X	X

Appendix B - Interview Questions for Industrial Personnel

Informed Consent Script

Our names are Zach, Thea, and Krissy, and we are students from Worcester Polytechnic Institute conducting research about indoor airborne microplastics. Participation in our research is voluntary and you can choose to stop your participation at any time. You can choose to not answer any question, and all information shared such as name, responses, or any other identifiable information will be kept anonymous and confidential. Names and quotes will only be included with your explicit prior consent. Our research will be produced as a report and published online within the WPI archives. Do you consent to us recording audio for transcription purposes and taking notes for the duration of this interview?

Interview Questions Script

We will start with an overview of our project and current status of our research, then lead into questions.

1. What are the primary considerations you take into account when designing a filter?
2. What are the company's current goals when it comes to filter design? Is there a focus on small particles, airflow, or some mixture of both?
3. Do you have any experience designing filters which trap microplastics?
    a. Do microplastics present any unique challenges when designing a filter compared to other airborne particulates?
4. Has there been any investigation into evacuation of accumulated particles from filters?

Appendix C - Interview Questions for Policy Experts

Informed Consent Script

Our names are Zach, Thea, and Krissy, and we are students from Worcester Polytechnic Institute conducting research about indoor airborne microplastics. Participation in our research is voluntary and you can choose to stop your participation at any time. You can choose to not answer any question, and all information shared such as name, responses, or any other identifiable information will be kept anonymous and confidential. Names and quotes will only be included with your explicit prior consent. Our research will be produced as a report and published online within the WPI archives. Do you consent to us recording audio for transcription purposes and taking notes for the duration of this interview?

Interview Questions Script

We will start with an overview of our project and current status of our research, then lead into questions.

1. What are the current legislations and regulations on the production of microplastics?
2. Have there been any pushes for increasing awareness within the public about microplastics sources, rather than environmental effects?
3. Are there any issues with feasibility when implementing legislation regarding microplastics?
4. The focus of our project is indoor microplastics. What power does legislation have over public, or government funded indoor environments?
    a. How does this power change when considering privately owned indoor environments, such as homes?
5. Besides microbeads, has there been any legislation to reduce other intentionally produced microplastics?

Appendix D - Interview Questions for Researchers

Informed Consent Script

Our names are Zach, Thea, and Krissy, and we are students from Worcester Polytechnic Institute conducting research about indoor airborne microplastics. Participation in our research is voluntary and you can choose to stop your participation at any time. You can choose to not answer any question, and all information shared such as name, responses, or any other identifiable information will be kept anonymous and confidential. Names and quotes will only be included with your explicit prior consent. Our research will be produced as a report and published online within the WPI archives. Do you consent to us recording audio for transcription purposes and taking notes for the duration of this interview?

Interview Questions Script

We will start with an overview of our project and current status of our research, then lead into questions.

1. Are there any specific challenges that you have discovered when working with microplastics in a laboratory setting?
2. Is it possible to conduct testing in a space that is completely free from microplastics? If yes, how is this accomplished? If no, why not?
3. How did you develop the procedure for your study?
4. Do you have any knowledge of procedures performed within other laboratories? If yes, how do these procedures compare?
5. What would you say is the largest obstacle when conducting research on microplastics?