An investigation to determine how young children use and respond to the LEGO MINDSTORMS for Schools system, and to evaluate the potential learning benefits.
Executive Summary
The aim of this project was to explore how very young children use and respond to the LEGO® MINDSTORMS® for Schools for Schools system, to evaluate the educational benefit to be gained, and to determine the feasibility of using the system in a nursery school environment.

Small groups of nursery children were observed using the system in weekly sessions over a seven month period. The children worked in a quiet environment with one teacher and the researcher to design, make and program controllable buggies to their own specification.

This project demonstrates that children were very enthusiastic about the system and motivated to take part in the activities. They were able to use the LEGO components and the Robolab software to build and program functioning vehicles with a variety of functions.

The LEGO system capitalises on children's natural enjoyment of designing and making activities and enabled children to apply and develop learning in all six areas of the foundation stage curriculum. The most significant benefits were developments in the children’s concentration, manual manipulation and hand-eye co-ordination, language and communication, and co-operation. Nursery leaders noted the most significant benefits were for boys who otherwise found it difficult to engage themselves in everyday nursery activities.

Background
This project was initiated as part of work by the Design and Making Centre to promote and support the development of design and technology awareness and capability with the nation’s young generation. An integral part of this work is to enhance the provision of exciting design and making activities, which inspire children to take an active part in their made environment.

The project came about after a visit to the Reggio Emilia schools in Northern Italy, where the focus for learning is child centred; the teaching program responds to the child’s innate desires to learn, with the appropriate stimulus and support provided in the nursery environment. With appropriate support, children have shown remarkable fluency in designing, making and programming their own original LEGO buggies. In this situation the LEGO MINDSTORMS for Schools system has proved to be a valuable tool which motivates children to drive their own learning. This project aims to recreate the opportunities observed in the Reggio schools for children in the English nursery system.

The research was conducted by the Design and Making Centre in collaboration with Truro nursery school. The study took place from November 2004 to May 2005 with small groups of 3 and 4 year old boys and girls for one afternoon a week.

Objective
The objective of this project was to explore how very young children use and respond to the LEGO MINDSTORMS for Schools for Schools system, and to an assessment of the value of the system in the nursery environment.

There were a number of areas the project team wished to address:
- Young children’s ability to use the system
- Their attitudes towards the system
- The areas of learning, as defined by the foundation stage curriculum, which are provided through the system
- The extent of children’s understanding of the system

The project also aimed to determine the feasibility of managing the system’s resources in a nursery school environment.
Resources
The project was resourced with a LEGO® MINDSTORMS® for Schools set aimed at primary schools (code 9786), containing one RCX microcontroller unit, two gear motors, touch and light sensors, and a range of LEGO bricks and components per kit. Children programmed their creations using Robolab software, version 2.5.2. The instruction books were not made available.

Children worked with a pre-assembled basic buggy unit comprising the RCX unit, two independently driven rear wheels and supported at the front by a small smooth dome. Initially, the buggy followed a simple program where it drove forwards for a few seconds and stopped.

All subsequent programming was made by the children, with appropriate support given to achieve their desired output. The children were restricted to Inventor Level 1, which enabled forwards and reverse movement, rotation, light and sound outputs, ‘wait for time’ commands and the use of touch sensors.

The children had free access to the full range of LEGO bricks and accessories in the kits and were encouraged to make changes to the basic buggy design, or to build their own buggy from scratch.

Staff involvement and training
The project was conducted with two adults; a researcher from the Design and Making Centre and an early years teacher from Truro nursery school. This arrangement was designed to provide mutual support, expertise and monitoring whilst working with children.

The nursery teachers involved were given informal training, with explanations of specific details as the project progressed.

Study design and methodology

Work groups
The study was conducted with two children in each group, with one group at a time using the LEGO resources. The groups were chosen by experienced nursery leaders and normally consisted of friendship pairs. Groups of children were invited to use the resources and were free to leave as and when they had satisfied their curiosity and experimentation.

The children were encouraged to work together while designing and making, to share resources, discuss events, and overcome problems.

Activities
The activities were focused on child centred exploration and play, with progression reactive to the children’s personal agenda. For this reason there was a slightly different progression path for each child.

The normal progression through activities is described below:

1. Introduce basic buggy
2. Introduce program as a ‘story’
3. Run the buggy
   - Recognise that the buggy stops after the same distance every time
4. Return to the computer and read the story
   - Create links between the icons and real world objects
   - Recognise the value of the ‘wait for time’ icon and count to that number
   - Run the buggy
   - Count while the buggy runs, recognise that the buggy stops at the given count value
5. Discuss changes which could be made (normally related to the ‘wait for’ value)
6. Return to the computer and make changes to the program
   - Children use the mouse to make changes to the program
   - Read the story to check working
   - Children send the program to the RCX
7. Run the buggy

The sequence from stage 6 to stage 8 was repeated through the sessions. At the beginning of subsequent sessions the children returned to the original program or a more advanced program that they would recognise from a previous session.

As the children became more familiar with the program, other elements of control were introduced. Again the order was largely dictated by the wants and needs of each individual but the progression can be summarised:

- Inputs: ‘wait for time’ (counting), ‘wait for touch sensor’ (press)
- Outputs: motors (forward movement only, forward then backward movement, rotate only, combination of forward, backward and rotational movement), sound

At some stage during the first few sessions the children were introduced to the LEGO® bricks and components which they used to make changes or to accessorise the basic buggy design. Children were encouraged to make changes themselves, or request help to attain the feature they wish to incorporate.

The full range of LEGO Technic components in the kit was made available to the children to use for adapting and accessorising the basic buggy.

The groups were not given time limits and activities were not timetabled as a scheme of work. The children were free to spend as much or as little time as they wanted exploring the system; they were given freedom in choosing to swap between using the software, using the construction bricks or experimenting with their creations.

**Evaluation**

Evaluation was made through continual observation of the children as they worked with the system. These observations were made by experienced staff who worked at the nursery and as part of the project, and other staff who had not previously worked as part of the project. Observations have been supported by a comprehensive photographic record of the children as they worked.

**Observations**

All of the children who took part in the activities were paired with a friend. From the start of the project, these children were able to work well together through good communication. They were able gave each other simple instructions, such as “Push the green button” or to arrange the start of a game “You sit there. I’ll send the little car to you”.

The children were quick to understand that the LEGO buggy was made of small components and required

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A child has adapted the basic program to see what happens when the arrows on the motor icons face in different directions.

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a special brick which could remember instructions to switch
motors on and off, and could repeat them on demand. The
children were intrigued by the link between the buggy and
the computer, and they were confident to try and adapt the
buggy and the program.

All of the children quickly developed the knowledge, skill and
understanding to adapt a simple program using the Robolab
software. At first the children were only concerned with
changing the value of the timer icon; they would decide if
they wanted the buggy to travel a longer or shorter distance,
and replace the old timer icon with one of an appropriate
time value. When testing their program, the children would
often sit facing each other and send the buggy to each other,
adjusting their distance so that the buggy stopped just in front
of them. When they changed the journey time, they would
often discuss how far apart they should be, then adjust their
positions accordingly.

The children were keen to watch and commentate on the
buggy as it moved around the room, looking for similarities in
the way it moved each time. Many of the children had their
own ideas about how to change the buggies’ behaviour
and adapted the basic buggy design to test these theories. A popular test was to change the wheels to
determine the effects of wheel size on the speed of the buggy. The children would discuss the outcomes of
this test and theorise on why the buggy behaved in any unexpected ways.

As the children became more familiar with the system they would plan more complex movements, such
as turning or moving backwards. They often needed adult assistance with these movements as very few
understood how steering was achieved with two motors (i.e. one motor must be switched to ‘forward’ and
the other to ‘backwards’).

Towards the end of the project the children were able to use ‘wait for push’ in their program and a touch
sensor to stop their buggy. Some children experimented with placing the touch sensor at the front of the
buggy so that it would stop on impact, while others preferred
to use it as a remote control.

Children were most interested in exploring and investigating
the LEGO® bricks, rather than the programming element
of the system. Many children became engrossed with
investigating the various ways that the components could
be connected together, with little concern for making a
recognisable object. These investigations would often start
with a child selecting a component, asking “what’s this
for?” and then investigating ways to use and integrate the
component.

As the children became more confident, their constructions
became more recognisable as functioning vehicles, with
trailers and scoops a popular feature. At the time of the
project the nursery school overlooked a construction site, and
the vehicles on this site became the focus of many projects.
The children had made many observations and were keen to
recreate their functions in their LEGO creations. The children
enjoyed using the computer to program these vehicles
although this was usually a means to switch on motors, rather
than to control them for a sequence of events.
Over the course of the project, a significant improvement was observed in children’s ability to manipulate and connect the LEGO® components. The LEGO Technic system includes very small parts that require a number of different motor skills to be properly connected. For example, wheels need an ‘x’ shape axle component to connect them to other parts, which involves rotating the wheel or axle to mate the two parts. Some children would push the parts together, then rotate until they slotted together, while others orientated first, then pushed the two parts together. Nursery staff were very impressed with the children’s dexterity in manipulating and combining these components when constructing their buggies.

When programming the buggies, children had to use the computer mouse to select and place icons. The children were skilled at this activity and few had significant problems with the task. Nursery staff were very impressed with the children’s demonstration of fine hand-eye co-ordination, especially considering the small size of the icons. However, few children were able to connect the icons using the pink ‘solder’ wire.

The LEGO system provided a good opportunity for collaborative tasks where children could plan how they would use the LEGO bricks, adapt a game where the buggy was sent back and forth, or negotiate how to adapt the buggy and share bricks. In one case where two boys could not agree how to accessorise their buggy, they talked about the problem and decided between themselves to take half of the buggy each and decorate their half as they wished.

The children were introduced to vocabulary appropriate to the components they were using, for example motor, axle, chassis, wheel, wire. The children were able to use common words, such as wheel, with ease. Nursery staff noted that children used these words with confidence in other activities.

As the children became more confident with the system, the complexity of communication and accurate use of technical vocabulary increased. Children were happy to share their own expertise to help their less experienced partners through practical demonstrations and verbal instructions.

The children’s natural enthusiasm in designing and making resulted in remarkably long sessions. At first, all of the children were able to maintain their attention and concentrate for at least 15 minutes at a time. Most of the children remained focused on construction, programming or testing their creations for at least 20 minutes. By the end of the project, it was normal for the children to remain focused on their design and making activities for over one hour per session. It was not uncommon for children, including those with otherwise short attention spans, to work well beyond this time. Their interest, motivation and excitement with the possibilities available to them remained for the duration of these sessions.

Results
Children’s ability to use the system
This study has shown that nursery-aged children are able to use the LEGO system to design, make and program their own controllable LEGO buggies. Children are able to manipulate and combine the LEGO components with a little help from adults. Once properly instructed, most children are able to make changes to a prewritten program, and some go on to write their own program to control their buggy.
There were a number of factors which prevent children from maximising the use of the software. All of the children found the icons small, difficult to see, and very difficult to connect in sequence with the ‘solder’ wire. The children did become confused with some of the functions, for example the difference between the six different motor output icons (A, B and C, forwards and backwards); none of the children understood why a light connected to motor output A would switch on when the motor was on. The representation of each function as a recognisable icon was a clear benefit, since the children did not have to rely on their reading ability to recognise and use the functions.

The children produced complex working models, using the full range of parts available in the kit. Most of the children had no previous experience of construction using the LEGO® Technic parts and they had to learn the function of each part and how they related to each other; wheels, for example, need to be combined with a small connecting component or an axle so that they can be attached to a LEGO spar. The children also had to develop fine manipulation skills to orientate and connect the parts. Children who enjoyed construction activities found this an exciting challenge. However, those who would not normally play with construction toys found the LEGO components intriguing but fiddly, and could become frustrated without adult assistance.

### Attitudes towards the system

In the first instances, all of the children were very interested in the LEGO bricks and using the computer to write a computer program. All of the children were excited that the LEGO buggy would repeat the same movements and were motivated to learn about the program ‘story’, and how they could change the icons to write a new program.

In the initial sessions all of the children remained focused on construction, programming or testing their creations for at least 20 minutes. As the project progressed some children lost interest in the LEGO system and were not motivated to take part in the weekly activity sessions. Most of the children who chose to continue with the sessions were boys. One member of staff reported that boys who had previously had very short attention spans had shown improvements in their general level of concentration during other school activities.

At the start of the project, the children split their time evenly between constructing, programming and testing. As the project progressed boys tended to focus more on construction and testing, with little time spent on programming. Children who demonstrated greater understanding of the software and the relationship between the software and hardware spent more time programming than those who had a poorer understanding.

One unexpected observation was the remarkable difference in attitudes of boys and girls to the system. In general, boys were much more inclined towards using the system than girls. Boys were much more enthusiastic about taking part in activities, and remained focused for considerably longer periods of time. Girls required additional motivation to stimulate and justify construction, for example retelling a story through the bricks and programming tool. These girls had negative comments, for example the colour of the bricks, and preferred to use and additional components, such as sequins or ribbon to decorate their constructions.

### Understanding of the system

Most of the children developed good understanding of how the components could be combined in construction. They understood that some parts needed to be combined with others in certain ways, for example wheels and axles. All of the children experimented with combining cogs to make a gear train.
The children had a mixed understanding of the relationship between the programming and physical output of the system. Many children understood that the computer program affected the behaviour of the buggy, were able to recognise the function of each symbol and ‘read’ the program, and all of the children understood that they could change the output movement of the buggy by changing the program. However, other than reading the period of time that the buggy would move forwards for, most children had difficulty with describing how the buggy would move from a given program.

**Learning opportunities**

The LEGO® system capitalises on children’s natural enjoyment of the designing and making activities to introduce, apply and develop learning in all six areas of the foundation stage curriculum. The following areas of development were observed frequently and considered to be a direct result from working with the system:

**Personal, social and emotional development:**
- The children maintained their attention, concentrated, and sat quietly when appropriate
- They developed an increasing awareness of their own needs, views and feelings and were sensitive to the needs, views and feelings of others
- They were able to work as part of a small group, taking turns and sharing fairly

**Communication, language and literacy**
- The children interacted with others, negotiated plans and activities and took turns in conversations
- They extended their vocabulary, exploring the meanings and sounds of new words
- They used talk to organise, sequence and clarify their thinking, ideas, feelings and events

**Mathematical development**
- The children used number name in relation to their work
- They recognised numerals 1 to 9
- They used language such as ‘more’ and ‘less’ to compare numbers and space
- They used everyday words to describe position

**Knowledge and understanding of the world**
- The children investigated the LEGO and Robolab software by using all their senses as appropriate
- They looked closely at similarities, differences, patterns and change
- They asked questions about why things happen and how things work
- They built and constructed with a wide range of components, selecting appropriate resources, and adapting their work where necessary
- They learnt about and selected the tools and techniques they needed to join components they used
- They used programmable toys to support their learning

**Physical development**
- The children used small materials with control
- They handled objects and construction materials carefully and safely

**Creative development**
- The children explored colour, texture, shape, form and space in three dimensions
- They expressed and communicated their ideas, thoughts and feelings through designing and making
Practical considerations
While there were no significant management issues during this project, activities took place under unusual conditions. Unlike other nursery resources, the LEGO® was a controlled activity and only available to the children at specific times. The children worked in very small groups (2 or 3) under the constant supervision of at least one adult in a restricted room with no distractions from other nursery activities or from other children. The LEGO and computer would be set up by the researcher and a pair of children would be invited by their teacher to use the system. Once finished, the children were encouraged to pack away the LEGO using the layout diagram to help them locate each part in its correct place. This system meant that no components were lost and damage was restricted to normal wear and tear.

Conclusions
Children were excited by the opportunities provided by the system and were motivated to challenge their knowledge, skills and understanding through design and making activities made available to them. They were able to use both the LEGO components and the Robolab software, which provided valuable learning opportunities and achieved many of the national curriculum foundation stage goals. The particular benefits were developments in the children’s concentration, manual manipulation and hand-eye co-ordination, language and communication, and co-operation.

In general, girls were less inclined to use the system and therefore did not gain the same magnitude of benefits as boys. Imaginative presentation by the nursery teacher encouraged them to become more involved and helped to maintain their concentration. However, without frequent motivation many girls became disinterested, were quickly frustrated and less able to overcome difficulties particularly when constructing.

The children spent most of their time using the LEGO components to create abstract sculptures, animals and machines. After some instruction and practice the children demonstrated confidence and dexterity in choosing, manipulating and combining even the smallest components. This enabled them to make programmable machines with an array of functions.

Children were able to use the Robolab software, recognise function icons in Inventor Level 1 and could adapt a basic program to their own specification. Some children learnt and understood that a switch could be used to stop the motors. Beyond this, most children did not understand how the program worked and were not able to write an original program (some children were able to replicate a program they had previously seen). There were a number of issues with the layout of the software package that limited its suitability for young children. Robolab version 2.5.2 can be used by young children, but it is not ideal.

The resources were used under controlled conditions, which meant that there were no significant management issues. The system may be best used under similarly controlled conditions, with children’s access restricted to special times when a trained teacher can assist in a calm, quiet environment. As well as supporting and developing children’s learning, the teacher should act as a resource manager, helping to minimise loss and damage.

The system requires a considerable financial outlay, which some schools may find off putting. An alternative, although not as beneficial to the children’s learning would be to include small construction kits, such as LEGO, that can be driven by motors. While this is a more financially appealing option it would not address some key areas of learning, nor have the magical appeal of the LEGO® MINDSTORMS® for Schools system.

Two boys find alternative contexts for using the system, in this case designing and making a windmill
Recommendations for further investigation and development

The outcomes of this project indicate a number of areas worthy of further investigation and development.

- Investigate ways to make the LEGO® MINDSTORMS® for Schools system equally appealing to girls and boys
- Investigate how young children use and benefit from the system using a true Reggio approach, where making and programming is preceded with a focused design process.
- Develop and run in-service training courses for nursery, key stage one and key stage two teachers and teaching assistants
- Investigate the feasibility of managing the system in an everyday nursery environment